Unusually High Mean Sea Level in September 1971 Along the South Coast of Japan

—2. Unusual High or Low Sea Level in Tokyo Bay—
—Statistical Analysis—

by

Kiyoshi Kurashige

Meteorological Research Institute, Tokyo

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Abstract

A few typical cases of unusual high or low mean sea level are selected from the tidal data for Tokyo Bay by the following ways:

- (1) Unusual days are selected at each station under the condition that the magnitude of daily mean tidal residual be more than twice its standard deviation.
- (2) We take up those cases in which more than three consecutive unusual days occur simultaneously in the whole area of Tokyo Bay.

Both meteorological and oceanographic factors are considered in connection with the occurrence of unusual high or low sea level, which takes place once a year or so. At such times the weather condition is rather gentle in general, and the oceanic condition seems to be responsible for the unusual rise or fall. Warmer sea surface temperature is likely to be associated with the rising of the sea level and colder temperature with the falling. In the inner part of the bay, the land and sea breezes are related to these variations, so that the former (southerly wind) serves to raise up warmer water, and the latter (northerly wind) to drive out colder water.

1. Introduction

The author's part in the joint research was the statistical study of selected cases of unusual sea level in Tokyo Bay by comparing unusual circumstances with the normal. Concerning the unusual rise in 1971, a qualitative speculation was given by YOSHIDA et al. (1972), but its true nature is not yet well understood. We thus select similar cases from tidal data in Tokyo Bay, using two kinds of conditions by taking the scale of the above-mentioned case into account—a very large scale both in time and space.

In order to eliminate shallow water effects in the bay, the amount of sea level variation is measured by the standard deviation of tidal residuals at each station. The basic data are differences of daily mean residuals from their 31-day running

means. We only deal with selected daily mean residuals whose absolute values are larger than 1.5 times the standard deviation. We relate both the rise and fall of sea level with meteorological and oceanographical factors, the latter may be responsible for these phenomena.

2. The daily mean of sea level and atmospheric pressure

Data are as follows: hourly readings of the sea level for the period 1968 to 1970 at three tidal stations along the Tokyo Bay shores, the meteorological data for Tokyo, Yokohama and Tateyama. The location of these stations is shown in Fig. 1.

Fig. 1. Location of tidal stations (Harumi, Daini-kaiho, Mera), Meteorological observatories (Tokyo, Yokohama, Tateyama) and observation point of sea surface temperature (Habu, Ooshima).

The hourly residuals are calculated by subtracting predicted hourly tides from observed ones. The prediction was made by using MIYAZAKI's method (MIYAZAKI, 1967). In this calculation, the three years mean value of fifty-four tidal constituents whose periods are shorter than about one day is used to contain variations of longer periods. Daily mean residuals (H) contain seasonal or longer period variations, but they are outside the scope of present analysis. In order to eliminate them, the difference from the 31-day running mean (ΔH) is computed. The absolute height from the bench mark, Tokyo Peil, is eliminated in ΔH .

The atmospheric pressure is observed eight times a day at each meteorological station, and the daily mean pressure (P) is estimated from these values. P is also subjected to the same filtering scheme as is used in the estimation of ΔH .

Table 1. Statistics on daily mean tidal residuals (H), daily mean pressure (P) and daily sea surface temperature (T), and their deviation from 31-day running means (ΔH , ΔP , ΔT).

		Daily mean tidal residuals (cm)		Daily mean atmospheric pressure (mb)		Pressure adjusted sea level (cm)		Sea surface temp. (C°)
		Mera	Daini-k.	Harumi	Mera	Daini-k.	Harumi	Ooshima
Daily mean	mean	- 0.12	0.22	- 0.22	1013.77	1013.57	1013.92	
	S.D.	10.22	10.47	11.32	6.29	6.44	6.48	
	max.	35.8	35.0	45.8	1032.5	1030.9	1031.6	
	min.	-29.2	-27.0	-29.4	981.7	979.5	980.1	
Deviation from the 31-day running mean	mean	- 0.00	- 0.01	- 0.01	0.04	0.05	0.04	- 0.00
	S.D.	6.22	6.17	6.81	5.38	5.44	5.44	0.84
	max.	30.6	32.0	34.6	14.3	14.3	14.4	3.3
	min.	-20.5	-20.9	-20.7	-32.9	-34.7	-34.8	- 3.8
	skewness	0.48	0.54	0.84	- 0.66	- 0.71	- 0.72	0.15
	kurtosis	4.25	4.45	5.18	4.68	5.04	8.2	3.50
1.5 $\times$ S.D.		9.3	9.3	10.2	8.1	8.1	8.2	

Fundamental statistics in the original H and P , and the deviation of them ΔH and ΔP are shown in Table 1. As the tidal stations are located anywhere from the southern tip to the northern end of the bay, ΔH shows larger dispersion and slipping off than the normal distribution. This is probably due to the shallow water effect in the inner part of the bay. Since regional difference is smaller with respect to the frequency distribution of ΔP than that of ΔH , the horizontal extent of meteorological disturbances will be very large, and nearly similar influences will be exercised on the local sea water around the bay.

As the distribution of ΔH is obviously different at three stations, the amount of deviation must be compared by some standard proper to the locality of ΔH . The unit system of the standard deviation (S.D.), which is estimated from ΔH of every station, would make the problems much more clear-cut than the ordinary length unit does. A comparison of the unusual sea level at several places on Tokyo Bay, and also places along the Japanese coast can be effectively studied by this unit system.

The standardized condition

$$|\Delta H/\sigma_H| \geq 1.5 \quad (1)$$

is firstly used for the sampling of unusual ones from the whole of three-year data of ΔH ; where σ_H means S.D. of ΔH . The positive and the negative deviation satisfying equation (1) are hereafter abbreviated by (+) and (−), respectively. The total numbers of (+) and (−) are shown in Table 2 for every station. The examples of the really unusual sea level to be discussed in this paper will be included in these samples.

Table 2. Frequency table for rising (+) and falling (−) of ΔH .

	(+) <div>Mera Daini-k. Harumi Σ</div>				(−) <div>Mera Daini-k. Harumi Σ</div>			
	Mera	Daini-k.	Harumi	Σ	Mera	Daini-k.	Harumi	Σ
$3.0 > \Delta H/\sigma_H \geq 1.5$	66	68	68	202	50	55	37	142
$ \Delta H/\sigma_H \geq 3.0$	7	9	12	28	1	1	1	3
Σ	73	77	80	230	51	56	38	145

The set (+) may included extremely large values, although Tokyo Bay was not struck by severe storm surges or tsunamis in the period of analysis. In order to make a cursory estimation of those very large disturbances, the group (+) is divided into two classes by the magnitude of deviation. The one includes those larger than three times σ_H , and the other those from 1.5 to 3 times σ_H (see Tab. 2).

Rising of sea level takes place more frequently than falling, and this is predominant in the case of the larger variation. Among the three stations, (+) takes place more frequently and (−) most infrequently at Harumi; maximum occurrence of the larger class of (+) is also observed at the same station. Since the occurrence of the larger class in the set of (+) is a rare phenomenon at Harumi where the activity of sea level change is most pronounced, all cases of (+) are analyzed by the same statistical method.

Extremely large falling of sea level occurs on the same day for all stations, while

rising does not always occur on the same day. The number of days thus obtained of extremely large rising becomes fourteen.

3. Period of duration, regional distribution and relation between them

The persistence of the phenomena of unusual rising, which were observed last year, suggests that the period of duration may be used as an effective parameter to extract the samples of real high or low sea levels from (+) and (-). Hereafter the period of duration is expressed by "D"; for example, $D=2$ represents that deviations in two successive days satisfy the condition (1). In order to analyze the relation between the magnitude of sea level change and the period of duration, (+) and (-) in Table 2 are classified into sub-groups according to the rank of D 's at each station. The frequencies, arithmetic mean and S.D. of each sub-group given in Table 3.

The average rising of sea level is most predominant in the group $D=3$, about 2.4 times σ_H (fifteen to sixteen cm) at every station; while the minimum value takes place at Harumi for $D=2$ and at other stations for $D=3$; in any case the average falling is about twice σ_H (minus twelve to minus fourteen cm). The following conclusions on the regional variation can be drawn from Table 3. The frequencies increase from the exposed coast to the head of the bay in the case of (+) with $D=1$; in other words, rising of one-day period occurs frequently in the inner part of the bay. Variations of $D=4$ and $D=5$ are rare in Tokyo Bay. From the above considerations, sea level change of $D=1$ is not likely to be considered a sample of unusual high or low sea level.

It was also remarked in September, 1971, that the unusual high sea level was generated almost at the same time all along the long coast of south-west Japan. Hence the simultaneous variation at three stations may be used as another factor in making a decision on the unusual variations. The sets (+) and (-) in Table 2 are classified into seven sub-groups according to their local change, and the frequencies of each group are shown in Table 4.

Both the frequencies (n_1) of the simultaneous rising and falling pattern become maximum in the seven patterns, and most ratios of those numbers to the total of (+) and (-) exceed fifty percent. This indicates that a rising or falling of sea level at one station is fairly closely related to the variation at the others. The magnitude of mean variations also becomes 2.3 to 2.4 times σ_H (rising, fourteen to sixteen cm) or minus two times σ_H (falling, minus twelve to minus fourteen cm); these values are comparable to the magnitude in the group of $D=3$ in Table 3.

Meanwhile, phenomena of smaller extent can be verified from the other six patterns in Table 4. They show the existence of several small-scale disturbances in Tokyo Bay, and also the difference between rising and falling. More precise analysis will be given in another paper.

As an example of the space-time relationship, the rising of $D=2$ at Harumi is verified. The total number of this group is twenty-four: five of them are associated with a simultaneous rising of $D=1$ at all stations, and six with a simultaneous rising of $D=2$ at all stations. In short, eleven dates overlap and the percentage ratio

for this duplication is 45.8%. Percentages of duplication are shown in Table 5 for all cases in Table 3.

In the case of rising, this value becomes smallest for the group $D=2$ among the three groups of D ; on the contrary case it becomes smallest for the group $D=1$. These results indicate the existence of a preferable space-time scale for the rising or falling of the bay water as a whole. Moreover, it can be concluded that the generating mechanism and the maintenance of $D=1$ and $D=3$ for rising are different, while that of $D=2$ and of $D=3$ for falling are the same.

In view of the circumstances mentioned above, the principal features of the unusual high or low sea level may be summarized as follows. The deviation of ΔH exceeding two times σ_H persists at least three days on time scale and takes place simultaneously at all stations, and the time variation and its space are fairly correlated with each other.

Hereafter samples for analysis are restricted to 48 cases of simultaneous rising and 24 cases of falling, and these are expressed by the symbols $\oplus$ and $\ominus$, respectively. Extremely high sea levels mentioned in the last section amount to fourteen days, but three of them are dropped out due to this restriction.

In order to estimate the dependence of sea level change on the period of duration, the group means of standardized deviation ($\Delta H/\sigma_H$) in every D are shown in Table 6.

Table 5. Relation of frequencies for every D between the rising (falling) of one station (in Table 3.) and the associated simultaneous rising (falling) of three stations for its variation. Percentage value shows the ratio of duplicated date.

		Simultaneous change classified into the rank of D'S												
		$(+)$						$(-)$						
		n	1	2	3	Σ	%	n	1	2	3	Σ	%	
period of duration (D) at a given station (day)	1	Mera	30	25	—	—	25	83.33	16	7	—	—	7	43.75
		Daini-k.	38	25	—	—	25	65.79	15	6	—	—	6	40.00
		Harumi	42	26	—	—	26	61.90	14	7	—	—	7	50.00
	2	Mera	26	4	8	—	12	46.15	18	1	10	—	11	61.11
		Daini-k.	22	6	6	—	12	54.55	28	3	12	—	15	53.57
		Harumi	24	5	6	—	11	45.83	18	2	14	—	16	88.89
	3	Mera	9	1	—	6	7	77.78	12	—	4	3	7	58.33
		Daini-k.	12	—	2	6	8	66.67	9	—	4	3	7	77.78
		Harumi	9	—	2	6	8	88.89	6	—	2	3	5	83.83
	4	Mera	8	1	—	3	4	50.00	—					
		Daini-k.	—						—					
		Harumi	—						—					
	5	Mera	—						5	1	2	—	8	60.00
		Daini-k.	5	—	—	3	3	60.00	—					
		Harumi	5	—	—	3	3	60.00	—					

Table 6. Averaged deviation of simultaneous rising (falling) for each D.

period of duration	simultaneous rising $\oplus$						simultaneous falling $\ominus$					
	Mera		Daini-k.		Harumi		Mera		Daini-k.		Harumi	
	<i>n</i>	<i>m</i> σ	<i>m</i> σ	<i>m</i> σ	<i>m</i> σ	<i>n</i>	<i>m</i> σ	<i>m</i> σ	<i>m</i> σ	<i>m</i> σ	<i>m</i> σ	<i>m</i> σ
1	31	2.22 0.77	2.38 0.78	2.49 0.97	9	−1.74 0.28	−1.78 0.72	−1.78 0.25				
2	8	2.20 0.35	2.20 0.27	2.01 0.26	16	−2.11 0.48	−2.11 0.50	−2.04 0.43				
3	9	2.68 0.85	2.50 0.98	2.38 1.06	3	−2.27 0.21	−2.13 0.49	−2.03 0.49				

The mean changes of sea level become larger than the values given in Table 3 except at Harumi; and the absolute values for the group of $D=3$ become maximum at the open coast and minimum at the head of the bay. These results are convincing evidence that the unusual high or low sea levels are originated in variations of long periods in the open ocean.

4. Effect of local atmospheric pressure

It is well known that the sea levels respond to atmospheric pressure changes almost as one-to-one mirror image. In order to see whether this relation holds in unusual situations, the normal regression lines $\Delta H = b \cdot \Delta P + a$ are estimated by use of the whole of three years' data. Constant a is negligibly small but the barometric factor b is as follows: Harumi -0.887 , Daini-kaiho -0.818 , Mera -0.746 (unit:

Fig. 2. Relation between the mean standardized deviation of pressure ($\overline{\Delta P/\sigma_P}$) and that of tidal residual ($\overline{\Delta H/\sigma_H}$). The normal value is shown by estimated regression lines and the unusual one is given by the scatter diagrams classified by the period of duration (D).

cm/mb). These values suggest the existence of some other parameters affecting sea level change, on the ground that their magnitude differs from the minus one, that is hydrostatic relation.

The estimated regression lines are shown in Fig. 2, where units are given by σ_H and σ_P , respectively. A dispersion on this line is indicated by the interval of the standard error of estimate, σ_{HP} . These values are as follows: Harumi and Mera 4.8 cm/mb and Daini-kaiho 4.3 cm/mb, which are shown in Fig. 2. The relation between $\overline{\Delta H}$ in Table 6 and the mean pressure deviations $\overline{\Delta P}$ which correspond to each group of $\overline{\Delta H}$ are also shown in the same Figure. Noticeable discrepancies from the mirror-image are shown in the cases of $D=2$ and $D=3$. The group $D=1$ shows the larger deviation of pressure and the smaller discrepancy comparable to σ_{HP} ; but in the other groups the sense is reverse. Since the former scarcely shows the character of the unusual sea levels, it may be concluded that pressure is less closely related to them.

To eliminate the effect of pressure, it will be best to make comparison between different stations by use of sea levels adjusted as to pressure. This pressure-adjusted sea level ($\Delta H(P)$) is estimated from the whole of three year' data under the hypothesis of hydrostatic relation, and some results of statistical treatment are given in Table 1. Since the frequency distribution of $\Delta H(P)$ approaches to a normal distribution rather than ΔH , the use of S.D. unit will be more adequate.

In order to estimate the dependence of $\Delta H(P)$ on duration and location the group means of standardized $\Delta H(P)/\sigma(P)$ in every $\oplus$ and $\ominus$ are shown in Fig. 3, where the values are plotted proportionally against distance for the real spacing

Fig. 3. Mean standardized pressure-adjusted sea level ($\overline{\Delta H(P)}/\sigma(P)$) dependent on both D and location of station.

of the stations. If the duration becomes longer, the amount of mean deviation becomes longer, the amount of mean deviation becomes large and difference in locality becomes small. In view of these circumstances, the three curves can be divided into two classes. The first is the group $D=1$; a smaller value of deviation but a large inclination against the main axis of the bay. The second, $D=2$ and $D=3$, shows a larger value but flat variation in the horizontal direction.

This shows that the independence of pressure and the large but flat deviation of the adjusted ones in the group $D=2$ and $D=3$ may characterize the unusual sea level. The rising is followed by a larger deviation than falling but the falling is accompanied by flatter variations than rising. This suggests the difference of atmospheric conditions between rising and falling. Sea level change in the former class ($D=1$) will be mainly caused by change in pressure. The large number of occurrences of rising (thirty-one days) and the small one for falling (nine days) can be explained by the negative skewness of ΔP , Table 1.

5. Effect of local wind

Changes in wind accompany changes in pressure, and when wind blows strongly its effect is likely to be large and opposite in sign to the pressure effect. A method for detecting the effect of local wind is to make a comparison of the normal wind field (which is given by the normal wind rose) with the unusual case. Analyses are done only by use of the daily maximum wind speed and its direction.

It is well known that northerly land breeze and southerly sea breeze are prevalent in the vicinity of Tokyo Bay. Fig. 4 shows the normal wind rose of

Fig. 4. Normal wind rose at Yokohama, thin line for percentage frequency of wind directions and dotted line for normal wind speed.

Yokohama; the frequency of each wind direction is indicated by the percentage ratio and the normal mean speed is estimated for every direction. Three lobes are shown in it: namely the larger two lobes directed to *SW* and *N*, and the smaller one to *E*. The directions of prevailing winds (*DPW*) in Tokyo are (*S*, *NNW*) and those in Tateyama are the same as in Yokohama. Since the frequencies of prevailing winds are considerably large, the wind fields can be expressed by two representative directions, northerly and southerly. They are totalized in frequencies from the samples of which wind direction point to the range from ($DPW-45^\circ$) to ($DPW+45^\circ$). A few samples which are out of the range are called residual.

The typical features of wind direction at the occurrence of unusual sea levels can be evaluated by comparing, in regard to each of the three groups, the percentage ratios between the normal and the unusual ones which are classified into $\oplus$ and $\ominus$. Each group listed in Table 6 is rearranged into two classes of duration, $D=1$ and the additive set of $D=2$ and $D=3$ ($D=2+3$); then the comparison is shown graphically in Fig. 5.

In general, the *DPW* in the occurrence of unusual sea level fairly agrees with that in the normal wind field, because the frequency of unusual residual decreases until it is considerably less than that of the normal. The exception is the case $D=1$ in $\ominus$, where the frequency of easterly winds increases most in residual. The rising (falling) is followed mainly by southerly (northerly), and the reverse case, rising (falling) followed by northerly (southerly), is rare.

Southerly wind increases with $\oplus$ decreases with $\ominus$ but so as to be less than

Fig. 5. Percentage comparison of wind directions at the occurrence of unusual sea levels and normal wind directions. Comparisons are made according to the prevailing wind directions around Tokyo Bay, southerly and northerly.

normal; this is more predominant in $D=1$ than $D=2+3$ for both cases of rising and falling. In other words, when rising of a short period occurs, the set-up effect by southerly wind is predominant but longer-period variations are less closely related to the direction of wind. Northerly wind acts reversely to southerly does except for the case $D=2+3$ of $\ominus$; or falling of a longer period is fairly closely related to northerly wind.

The normal mean speed of S or SW ($\bar{V}_S$) is about nine m/sec at every station, while that of NNW or N ($\bar{V}_N$) is from six to eight m/sec; this will show that the sea breeze is somewhat stronger than the land breeze. In order to estimate the effect of wind speed on sea level change, the mean wind speeds on southerly (V_S) and northerly (V_N) on the unusual days are estimated from the arithmetic mean of the component speed on the prevailing directions. Fig. 6 shows the relation between the standardized wind speed $V_S/\bar{V}_S$ or $V_N/\bar{V}_N$ and the averaged sub-groups of $\Delta H(P)$ corresponding to V_S or V_N in $\sigma(P)$ unit.

In the case of rising, the larger positive deviations of sea level are followed by weaker winds as the duration becomes longer; while the larger negative ones are also followed by weaker winds. This means that negative correlationships are present between the amount of sea level change and the wind speed. This is distinctly shown in the case of rising with southerly wind and falling with northerly. Wind speed exerts little effect on sea level change in the case of group $D=3$, though southerly wind is stronger than northerly in that group.

Since the group $D=3$ for the rising, and $D=2$ and $D=3$ for the falling will

Fig. 6. Relation between the standardized wind speed southerly ($V_S/\bar{V}_S$) or northerly ($V_N/\bar{V}_N$) and that of $\Delta H(P)/\sigma_P$.

be regarded as the really unusual sea level, it will be concluded that its change is not accompanied by strong winds or large pressure deviations. These results make clear that the phenomena of the unusual sea level are not originated in severe meteorological disturbances producing the storm surge.

The numbers of extremely large rising and falling days mentioned in the last section are eleven and one, respectively. As a result of studies of meteorological conditions in these special cases, ten days of rising were followed by a severe unusual day. These samples are excluded from the next analysis. This fact shows that the magnitude of unusual sea levels can rarely exceed the amount of three times σ_H in Tokyo Bay. A few cases of rising in the group $D=1$ were accompanied by weak wind and a small deviation of pressure, but this will be treated more fully in our future study.

6. Effect of sea surface temperature

It is well known that the pressure-adjusted sea level and the dynamic depth has a fairly positive correlation. Only scanty data are available for the estimation of that depth around Tokyo Bay. A relation between the adjusted ones and sea surface temperature (ΔT) at Habu, Ooshima is analyzed (Fig. 1). The symbol Δ means that the daily sea surface temperature T is subjected to the same filtering scheme as was used in the series of sea level and pressure, and some statistics on ΔT are shown in Table 1.

The analysis is based on the relation which is given by the time-lagged cor-

Fig. 7. Time-lagged correlation coefficient between the deviation of sea surface temperature (ΔT , in $^{\circ}\text{C}$) at Habu, Ooshima and the pressure-adjusted sea level ($\Delta H(P)$, in cm).

relation coefficients ($\rho(\tau)$). Fig. 7 shows those coefficients between $\Delta H(P)$ in cm unit and ΔT in $^{\circ}\text{C}$ for every station by use of three years' data. The most pronounced feature is the existence of lag within them, and the curves show an asymmetry with respect to the axis of the values of maxima. In the case of Daini-kaiho and Mera, $\Delta H(P)$ of a given day has a maximum correlation with ΔT of two days before; the values of those coefficients are 0.33 and 0.29 respectively. A sharp cut shape in the range of $\tau \geq 1$ shows that no further sea temperature can effect the sea level, while the rounded-out shape in the range of $\tau \leq 0$ can be largely responsible for its variation. The curve for Harumi is somewhat different from the others. It has a skewed "top hat" shape of about one fourth the peak value during three days.

These peak values are so large as to make the change of $\Delta H(P)$ correspond to the variation of ΔT . Moreover, the shapes of $\rho(\tau)$ determine the way how each observation in time series ΔT contributes to the estimation of the relation between them.

The average sea surface temperature of three days $\overline{\Delta T}$ which correspond to the period of larger values of $\rho(\tau)$ are related to $\Delta H(P)$; these values are estimated from the time lag of $\tau = -2, -1, 0$ for Harumi and $\tau = -3, -2, -1$ for Daini-kaiho and Mera, so as to make the data of $\tau = 0$ coincide with that in each $\oplus$ and $\ominus$. These procedures will be fairly justified by the results given in section 3; the unusual sea levels are originated in oceanic variations of long periods. Fig. 8 shows the relation between the group mean of standardized $\overline{\Delta T}/\sigma_T$ and that of $\Delta H(P)/\sigma(P)$ in every D .

The larger positive (negative) difference of adjusted sea levels are accompanied by the higher (lower) sea temperature, as the period of duration becomes longer; in other words, a positive relationships holds between them. It is proved that

Fig. 8. Relation between group mean of 3 days mean $\overline{\Delta T}/\sigma_T$ and $\Delta H(P)/\sigma(P)$ in D for southerly and northerly.

the large deviation of pressure-adjusted sea level is accompanied by the "unusual" warm or cold temperature ranging about one to two times σ_T and small differences between the rising in warmer water and falling in the colder are verified. Determination of the correlation coefficients for the two quantities within the group of $D=3$ is difficult due to scantiness of data.

In connection with the wind, the sea level change of the inner part of the bay shows some relations between wind and sea level. That is, rising is followed by warmer temperature in northerly wind than in southerly, while falling is followed by colder temperature in southerly wind than in northerly. It will be concluded that northerly wind obstructs rising, and southerly falling, in the inner part of Tokyo Bay, even though the speed of wind at the time of unusual sea level is weaker than the normal mean field.

7. Selected cases in Tokyo Bay

Since the special data of ten days followed by severe meteorological conditions are excluded in section 6, the foregoing relation between the several quantities should be slightly modified. The recalculations of these relations by use of the renewed data are summarized in Table 7. The meteorological and oceanic conditions at the time of unusual sea level are determined under the consideration of S.D. for each quantity in Table 7, and results are shown in Table 8. It is difficult, for lack of data, to estimate a kind of multiple correlation existing between them.

The typical unusual sea levels detected by use of the criteria (Table 8) are the next three cases on the group $D=3$: the two cases of rising at the end of August, 1970 and the end of November, 1970 and the one case of falling at the end of December, 1968. Fig. 9 shows the daily variation of sea level (ΔH) and pressure-adjusted sea level ($\Delta H(P)$) at Daini-kaiho, and water temperature (ΔT) at Habu, Ooshima. Two cases of unusual high sea level along the Japanese coasts in 1968 were reported by ISOZAKI (1972), but their magnitude at Tokyo Bay obtained by the present author turned out to be as small as his estimation. It is remarkable that the pressure-adjusted sea level in light weather conditions is fairly correlated to sea surface temperature. One reason for the temperature change is proposed also by ISOZAKI in connection with the flow pattern of the Kuroshio.

As is evident from Fig. 9, variation of unusual sea level is not such a discrete phenomenon as is statistically analyzed in this paper but a sequential one in nature. It is to be noted that oscillations with periods of about half a month are associated with the change of unusual sea level; these variations will be discussed by the author in near future in the light of spectrum analysis.

8. Conclusion

A few selected typical cases of unusual sea level in Tokyo Bay have been studied here. The criterion for the selection was that the unusual high or low daily mean sea level should persist for three consecutive days, covering the whole area of the bay. The unusualness is defined by its magnitude being more than twice the standard deviation (S.D.) of the frequency distribution, which is estimated by the deviation

Table 7. Summary of the pressure-adjusted sea level ($\Delta H(p)$), pressure deviation (ΔP), standardized wind speed for southerly ($V_s/\bar{V}_s$) and for northerly ($V_N/\bar{V}_N$) and deviation of sea surface temperature (ΔT) at unusual sea level change at every D.

Period of duration (day)	ascension $\oplus$					descension $\ominus$														
	southerly			northerly		southerly			northerly											
	n	$\Delta H(P)$	ΔP	$V_s/\bar{V}_s$	ΔT	n	$\Delta H(P)$	ΔP	$V_N/\bar{V}_N$	ΔT	n	$\Delta H(P)$	ΔP	$V_N/\bar{V}_N$	ΔT					
1	15	1.02*	-1.85	1.04	0.18	9	0.42	-1.84	1.16	0.08	2	-0.95	1.45	0.75	-1.15	3	-0.67	1.90	1.12	-0.19
		1.05*	0.88	0.38	0.84		0.72	0.75	0.46	0.61		1.06	0.75	0.07	0.64		0.93	0.54	0.12	0.20
	5	1.88	-0.84	1.06	0.55	3	0.63	-1.90	0.89	1.73	5	-1.46	0.96	0.73	-1.29	9	-1.42	1.36	0.84	-0.71
		0.80	0.58	0.24	0.47		0.50	0.22	0.36	0.68		0.80	0.46	0.15	0.30		0.87	0.84	0.30	0.51
	2	2.35	-0.30	0.66	0.98	3	2.13	-0.53	0.64	2.33	0					3	-1.57	1.13	0.75	-1.16
		0.35	0.20	0.11	0.23		0.17	0.41	0.09	0.16							0.34	0.45	0.13	0.08
2	14	0.52	-1.79	1.13	-0.07	10	0.66	-1.93	1.31	0.24	1	-1.20	0.70	0.65	-1.19	5	-0.42	1.72	0.94	-0.48
		0.89	0.76	0.37	0.81		1.32	0.92	0.41	0.41		—	—	—	—		0.97	0.67	0.14	0.72
	5	1.34	-1.48	0.95	0.85	3	1.93	-0.80	1.31	0.92	3	-1.33	1.20	0.83	-0.76	13	-1.33	1.31	0.78	-0.74
		0.79	0.56	0.15	0.96		0.90	0.80	0.26	0.20		0.62	0.75	0.16	0.49		0.97	0.74	0.19	0.61
	1	1.90	-0.40	0.55	0.75	3	2.30	-0.27	0.67	1.63	1	-1.20	1.10	0.99	-1.04	2	-1.75	1.15	0.59	-0.94
		—	—	—	—		0.62	0.31	0.03	0.38		—	—	—			0.15	0.55	0.05	0.43
3	13	0.55	-1.71	1.09	-0.04	5	0.74	-1.70	1.15	0.35	1	-2.10	0.80	0.33	-0.04	3	-0.57	1.30	0.80	-0.61
		1.12	0.78	0.28	0.77		0.37	0.57	0.58	0.19		—	—	—	—		0.55	0.41	0.13	0.48
	6	1.35	-1.22	0.99	0.90	1	0.80	-2.20	1.04	0.83	6	-1.10	1.42	0.70	-0.82	7	-1.21	1.39	0.79	-0.34
		0.63	0.69	0.13	0.89		—	—	—	—		1.10	1.03	0.31	0.44		0.64	0.25	0.14	0.30
	1	2.30	-0.90	0.89	2.50	3	2.43	-0.39	0.62	1.63	2	-1.70	0.90	0.77	-0.86	1	-1.30	1.60	0.50	-1.19
		—	—	—	—		0.26	0.29	0.04	0.38		0.40	0.30	0.30	0.18		—	—	—	—

$\Delta H(P)$, ΔP , ΔT : S.D. unit, *₁: mean, *₂: S.D. of each sub group

Table 8. Criteria for unusual sea level change in Tokyo Bay.

	$\Delta H(P)/\sigma(P)$	$\Delta P/\sigma(P)$	V/V_0	$\Delta T/\sigma_T$
$\oplus$ southerly	(> 2.0)	(> -0.5)	(< 0.8)	(> 0.7)
northerly	> 2.0	> -1.0	< 0.7	> 1.2
$\ominus$ southerly	(< -1.3)	(< 1.2)	(< 1.1)	(< -0.7)
northerly	< -1.2	< 0.6	< 0.9	< -0.5

Fig. 9. Typical unusual sea levels at Daini-kaiho in Tokyo Bay.

from 31-day running mean. The S.D. unit is more useful in studies of sea-level variation than the ordinary length unit.

The meteorological conditions for the occurrence of the unusual sea level change are as follows. Atmospheric pressure around the bay shows a rather small deviation of about 1.2 times S.D. which is estimated from the same filtering scheme as in the sea level. Wind directions on the unusual days agree with the direction of prevailing land and sea breezes and the speed of the prevailing breeze is rather weak compared to the normal wind field. Therefore, the unusual sea level does not originate directly from any severe meteorological condition such as storm surges.

Meanwhile, the oceanographical condition shows that when the surface water temperature at Habu, Ooshima is higher (lower) the unusual rising (falling) of sea level takes place. It is fairly difficult to distinguish the difference of mechanism between rising due to warmer water and falling due to colder water. Nevertheless it is indisputable that southerly wind (sea breeze) promotes unusual rising under warmer sea conditions, and northerly wind (land breeze) promotes falling under colder conditions, in the inner part of the bay.

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1971年9月の本州南岸の異常潮位について

—第2部. 東京湾における異常潮位—統計的調査—

蔵 重 清

“1971年9月異常潮位”で問題にされた、広範囲のしかも長期間にわたった現象に着目して東京湾における過去事例の抽出を試みた。この際、日平均潮位偏差に対しさらに31日移動平均よりの偏差を求め、この偏差の度数分布の標準偏差を単位に用いて潮位を測り、湾における浅水効果の除去を行なった。異常潮位は東京湾においては年に1～2回程度生じ、湾全体にわたって標準偏差の2～3倍程度の変動が少なくとも3日間持続するものであることが、潮位変動の解析から分った。

異常潮位時の気象・海象の特性を平年のそれと比較することにより抽出した。その結果、おだやかな気象条件の下で生じ、波浮(大島)の海水温と関係が深いことが分った。すなわち高(低)水温時に潮位上昇(下降)が対応し、しかもこの時弱風ではあるが、海風(南風系)が高水温時の潮位上昇を、陸風(北風系)が低水温時の水位下降をそれぞれ助長していることが判った。