Visual Demonstration of Tidal Movement with Clear Cycles by Time Frequency Analysis

Sumitoshi Ogata[1], Takahiro Kawakami[2], Kenta Kirimoto[3]

[1] *Kyushu Kyoritsu Univ., 807-8585, +81-93-693-3192, ogata@kyukyo-u.ac.jp*
[2]*Kinden co., +81-090-4341-6970, kawakami_takahiro@kinden.co.jp*
[3] *Kitakyushu College of Technology, kiromoto@kct.ac.jp*

Abstract- The present study deals with tidal movement in a Japanese coastal area where the half day and one day tidal periods are generally observed. We aim to make the dynamics of this tidal movement much clearer from a point of view of time frequency analysis using a short time Fourier transform(STFT) and a wavelet transform(WT) in addition to a conventional fast Fourier transform(FFT). These three approaches are complementary each other and available for the comprehensive understandings of complicated, oceanic phenomena. The STFT analysis reveals that the four tidal periods are observed only when the tidal power becomes relatively weak around every low tide. On the other hand, two of four periods become indiscriminating around every high tide due to a masking effect of the major, strong tidal powers. We also demonstrate that the WT analysis is exclusively available for visualizing the phase shift process of these two major tidal periods.

I. Introduction

In almost all of Japanese sea areas, four tidal periods are generally observed. The major half day period is attributed to the interaction between the moon and the earth, while the major one day cycle is due to the interaction between the sun and the earth. In addition, there are also minor half day and one day periods related to these two major periods, respectively. [1],[2],[3]

Table 1 represents the four periods related to the tidal movements. [4] These values in Table 1 are verified once again by using a FFT and a shot time Fourier transform(STFT) , while the phase gap between half day and one day periods is visually demonstrated by wavelet transform(WT) with its better time resolution.

II. Data and Methods

II-1. Tidal data

The tidal data used here were acquired on hourly basis with no defect at an observation station in the central Japan. The station facing the pacific ocean is under an influence of strong oceanic current "Kuroshio".[4] To reveal this current's influence on the tidal movements, four series of data were employed (Table 2).

The one-year data ranging from January 1st to December 31st, 1975 were also used for phase analysis concerned with four tidal periods.

Table 1 Major tidal periods and minor periods*

Period	Moon	Sun
half day period	**12.4 hrs(M2 tide)**	12.0 hrs(S2 tide)
one day period	25.5 hrs(O1 tide)	**23.9 hrs(K1 tide)**

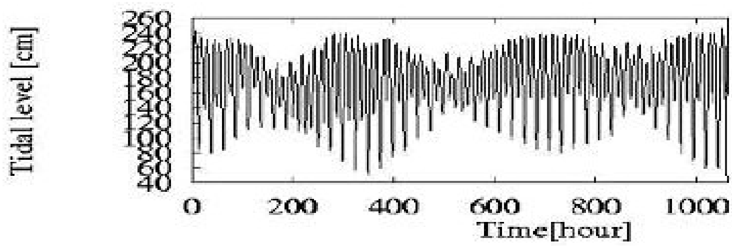


Fig.1 Profile of tidal movement

II-2. Methods

In addition to conventional FFT, STFT with a Gabor window function is employed. The best result is expected when the optimal window width is chosen and applied to STFT.[2]

WT is employed with the Gabor window function as well. It is said that WT and STFT are complementary each other with respect to time resolution and frequency resolution.

degree of disturb.	Data No. and acquired data range	data length
strong	I Jul.,'75 – Aug.,'75	1488
weakest	II May,'76 – Jun.,'76	1464
strong	III Mar.,'80 – Apr.,'80	1464
weak	IV Jun.,'81 – Jul.,'81	1464

Namely, the WT's time resolution is better than STFT, while the STFT's frequency resolution is, therefore, superior to WT.

III. Results

III-1. FFT

We obtained four power spectrum distribution (psd) diagrams corresponding to the data shown in Table 2. Fig.2 shows a typical psd pattern obtained by processing the data No.1. There are two major peaks corresponding to half day and one day periods. This figure also shows that these major peaks have their minor peaks, respectively. The values related to individual peaks are very close to the literature cited in Table 1.[4] In addition, very little difference was found through these four psd diagrams regardless of the oceanic current's disturbance on the tidal level.[6] This fact suggests that the same psd patterns can be observed everywhere around the Japanese main islands in accordance with our previous studies.[6],

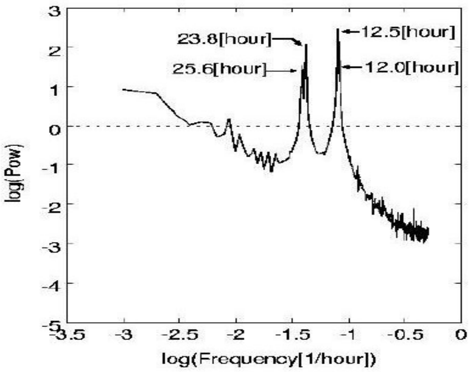


Fig.2 Typical psd diagram by FFT

III-2. STFT

The results for the data I through IV are shown in Fig.3. Here, the intensity of the tidal power is displayed by brightness values ranging 0-255 in gray scale, i.e., the brighter, the stronger. The tidal power's envelopes repeat a cyclic pattern according to high tide and low tide.

Through these four cases, we see two main frequencies of tidal power(around 0.08(1/hr)Hz and 0.04(1/hr)Hz according to their tidal periods, respectively.

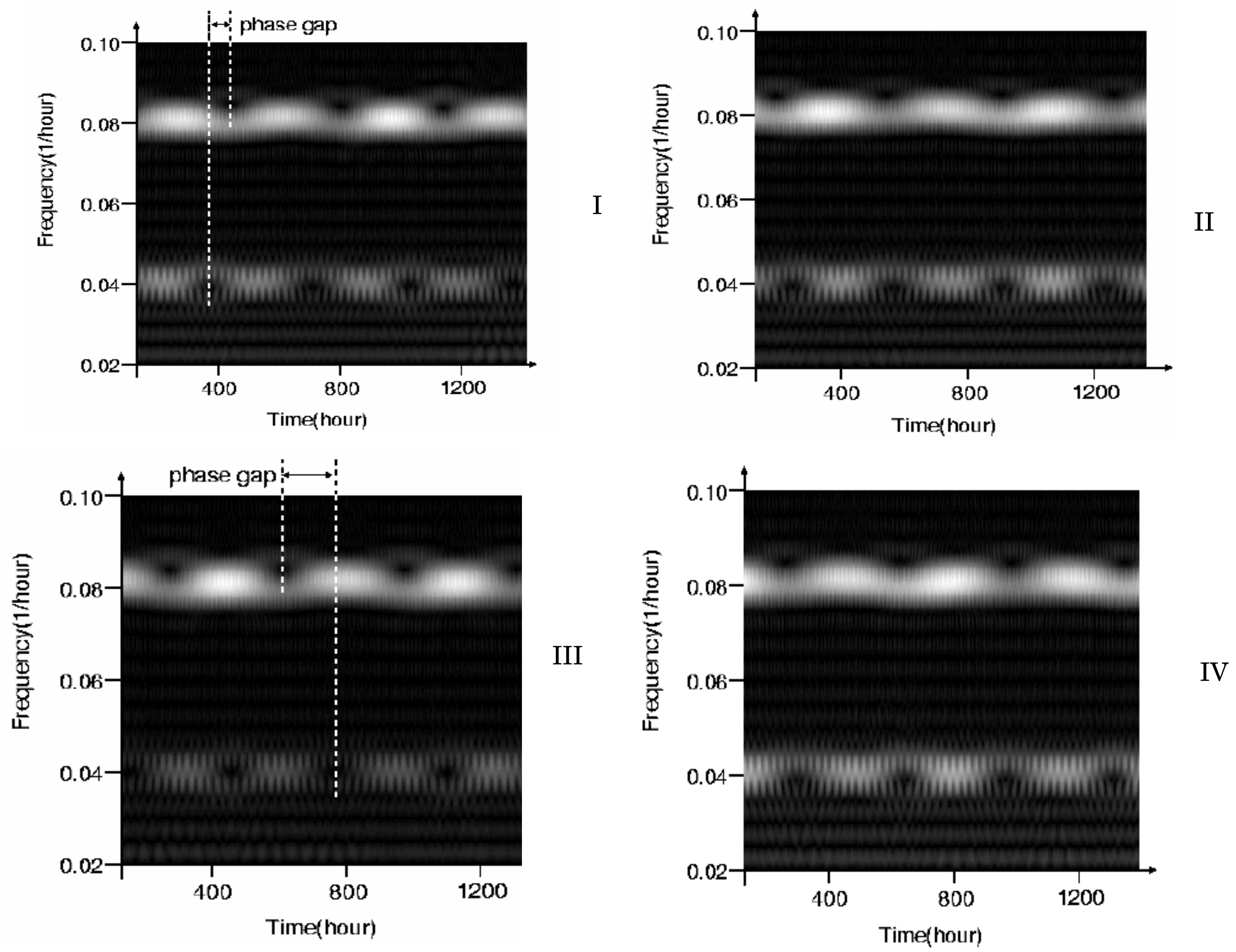


Fig.3 Power cycles by STFT for data listed in Table 2(upper left through lower right)

In addition, another two frequency components are seen at every low tide not only half day period (above) but one day period (below) as marked with double white frames(Fig.4, same as Fig.3(b) for data II in Table 2). The two frequency components in the one day period(below) are seen much clearly than those of above.

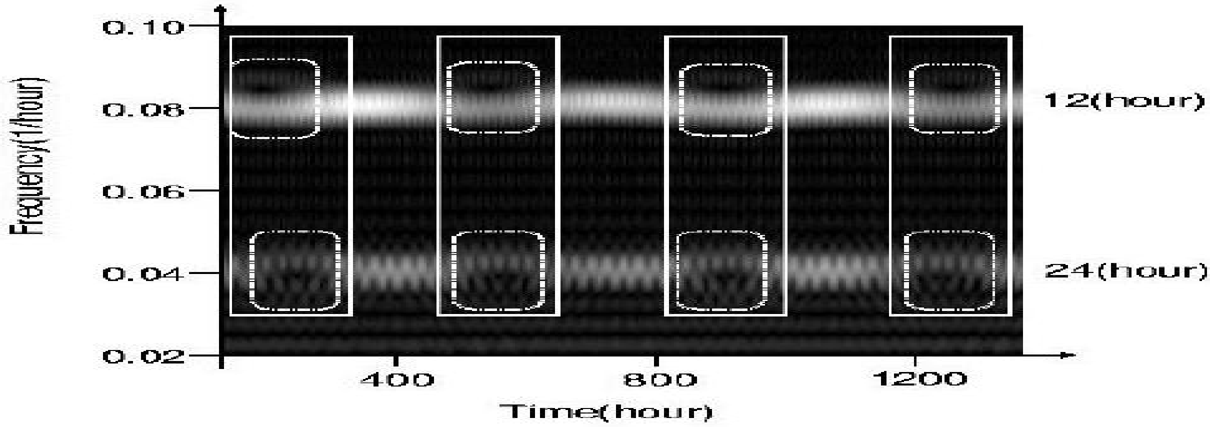


Fig.4 Four power cycle by STFT(Fig.3 II)

III-3. WT

The analysis was also carried out for the data II through IV in comparison with the result by STFT. Its time resolution was highly improved although their visualization was abbreviated here. According to the results, the half day cycle repeats high tide and low tide every 700[hrs], while the one day cycle' s period is 650[hrs] The half day period is longer than the one day period by 50[hrs], i.e., about two days. This difference is explained through the revolution of the earth around the sun and that of the moon around the earth.[6],[7]

Fig.5 shows a series of recurring tidal power from Jan.1st to Dec.31th in 1975. The figure shows that the both phases get close around the winter solstice and the summer solstice, while the phase gap between two cycles increases toward the vernal equinox and the autumnal equinox as marked with vertically long, white frames, respectively.

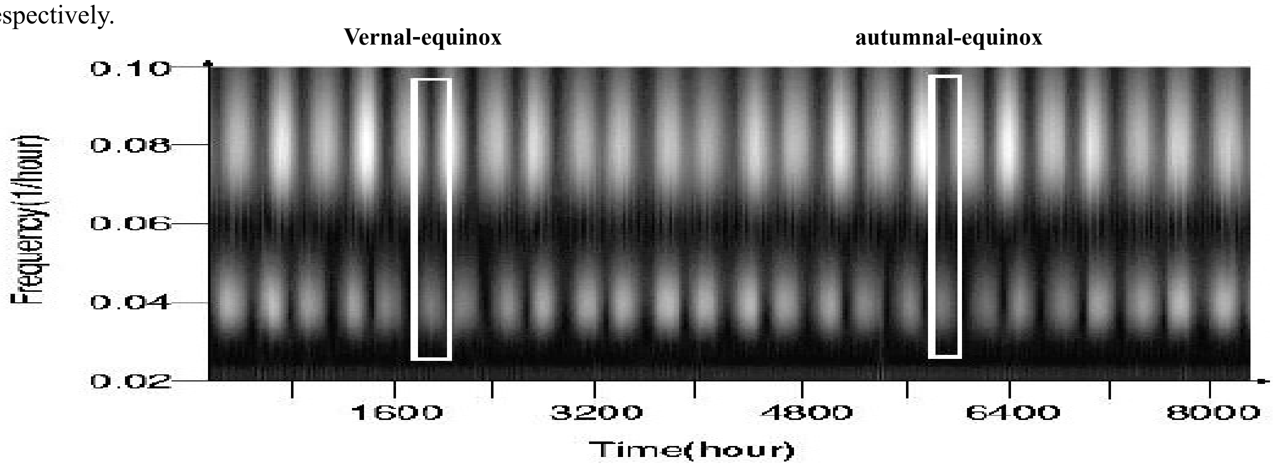


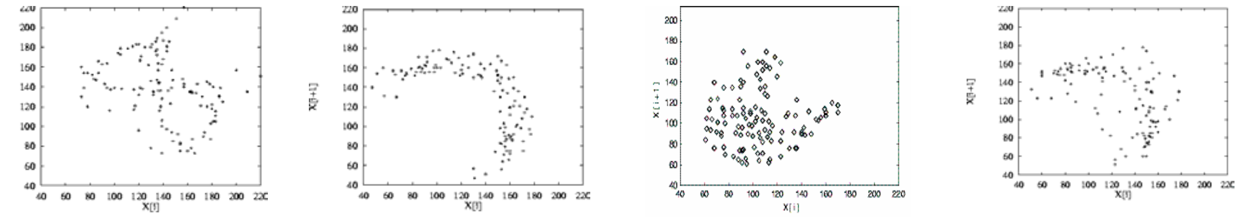
Fig.5 Phase transitional pattern of two series of tidal powers

III-4. Description of tidal patterns

The tidal behaviors should be based on a mutual interaction among three objects, i.e., earth, moon and sun. The universal gravitation between moon and earth is much stronger than that of between sun and earth. This makes a typical movement shown in Fig.1 and four different tidal modes represented in Table 1. To confirm the oceanic current's influence on the tidal power, we employed a pattern-describing technique called Poincare's return map.[3]

Poincare's return map method was found to be the most instructive for those tidal behaviors mentioned above. By taking local maximum (upper peak) or minimum(lower peak) of tidal levels x_n, and plotting x_n v.s. x_{n-1} on a plane, we obtained Poincare's return maps. In this case, the choice of lower peaks resulted in clear return maps. Fig.6 shows a typical example of the results.

The strong current flow of Kuroshio influences the tidal level at the observation station. In the above case, the degree of its disturbance was in the order of (a) > (c) > (d)> (b) according to the flow condition of Kuroshio. Fig.6(b) shows a stable semi-sphere pattern with the least disturbance during Kuroshio's long meandering. Even (a) and (c), i.e., both transient states from non-meander to meander and vice versa, we can recognize this future yet in spite of the Kuroshio's disturbance.



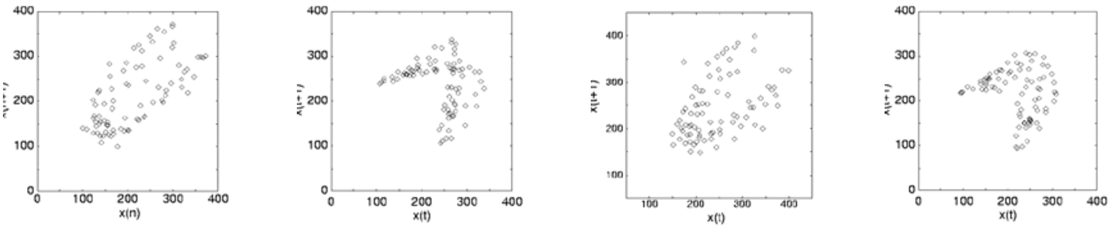
(a) data I (b) data II (c) data III (d) data IV

Fig.6 Poincare's return maps for four different current flow conditions in Table 1

IV. Comparison with observations in calm bay area without current's disturbance

For better understandings of the behaviors of the tidal movement, further observation was carried out at the inner most of the Ariake Bay, southern west Japan where there was no oceanic current's disturbance.

The Poincare's return maps correspond to Fig.6 are shown below(Fig.7). The pattern in spring resembles that of autumn with little disturbance, while those of summer and winter also resemble each other.



(a) spring(Mar –May) (b) summer(Jun-Aug) (c) autumn(Sep-Nov) (d) winter(Dec-Feb)

Fig.7 Poincare's return maps for four seasons at inner most of Ariake Bay

In comparison with Fig.6, the present result indicates that the return map method is much susceptive than STFT and WT with respect to the current's influence ,and that the difference between high tide and low tide becomes larger in spring (a) and autumn (c) than summer(b) and winter(d).

V. Conclusions

The present study has revealed that FFT, STFT and WT are complementary each other and available for the comprehensive understandings of the tidal movement. The STFT analysis disclosed co-existing four tidal periods only when the tidal power became relatively weak around every low tide. However, the two minor periods were apparently masked by the strong major tidal power and became invisible around every high tide. We also demonstrated that the WT analysis was exclusively available for visualizing a phase shift process of the two major tidal power cycles.

References

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