NUMERICAL SIMULATION ON INFLUENCE OF LONG-TERM MEAN WATER LEVEL FLUCTUATION ON SAND WAVES IN THE KANMON WATERWAY, JAPAN

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In this study, the numerical simulation of tidal current and sediment transport in the Kanmon Waterway were performed by using a numerical simulation model FVCOM (Finite Volume Community Ocean Model (Chen et al. 2003)), in order to discuss the influence of the long-term fluctuation of mean water level on the sand waves. The numerical simulation results suggested that the spatial difference of the long-term fluctuation of mean water level in the Kanmon Straits slightly changes the tidal current around Tanoura Area, and consequently affects the development of sand waves.

Keywords: Kanmon Waterway, sand waves, numerical simulation, long-term fluctuation of mean water level

INTRODUCTION

The Kanmon Waterway is along the Kanmon Straits between Honshu Island and Kyushu Island (Figure 1). Its length is about 50 km, its width is about 500-2200 m and its minimum depth is 12 m. Since the straits are narrow, the fastest tidal current of 10 knot (about 18.5 km/h) occurs because of tide level difference between Sea of Japan and Seto Island Sea, and it is difficult for ships to pass there. The Kanmon Waterway is one of the most important international major navigation channel in Japan, and more than 40,000 ships pass there every year. In particular, the Kanmon Waterway supports the Japanese economy and industry not only as international navigation channel which connects East Asia, North America and Japan, but also as domestic navigation channel connecting many ports of Japan. Moreover, in order to allow large ships to pass there, improvements are being made to deepen the waterway to 14 m. Deeper waterway will enable an increase in cargo volume and mass transportation, and it is expected to reduce transportation costs and marine accidents.

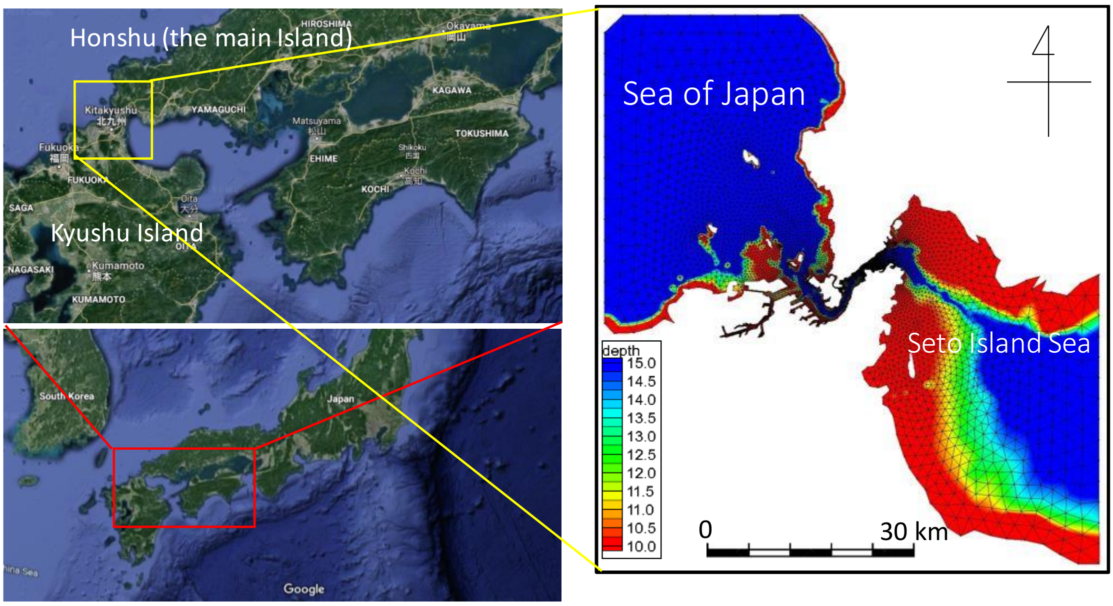

Figure 1. Location of the Kanmon Waterway and computational domain

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Sand waves, however, developed at several places in the waterway due to the complicated tidal current, and cause shoals which may be obstacle to safety navigations. Ministry of Land, Infrastructure, Transport, and Tourism (MLIT) has been continuing the yearly survey of bathymetry in the whole waterway since 1974. In particular, at four areas where the sand waves are formed frequently, the survey has been conducted several times a year. The ministry has also been continuously measuring tidal change at several locations in the straits. On the basis of these data set, it was clarified that the sand waves have relatively high correlation with the long-term fluctuation of sea level departure, i.e., the long-term fluctuation of mean water level (Figure 2) and that amplitude of the long-term fluctuation of mean water level is not spatially constant in the Kanmon Straits (Figure 3). This implies that the slight change in tidal current due to the imbalance of the long-term fluctuation of mean water level influences the development of sand waves.

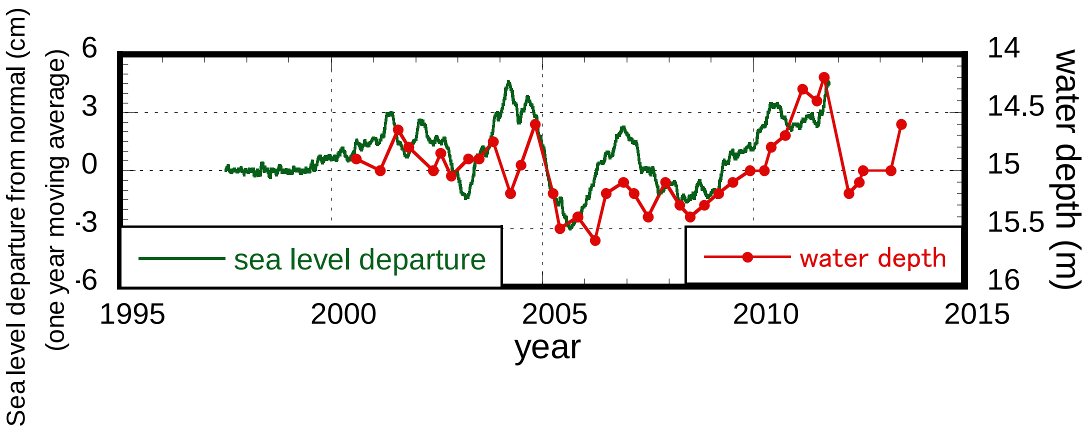

Figure 2. Correlation between topographic change at white point shown in Figure 3 and long-term the fluctuation of mean water level at KT4 shown in Figure 3

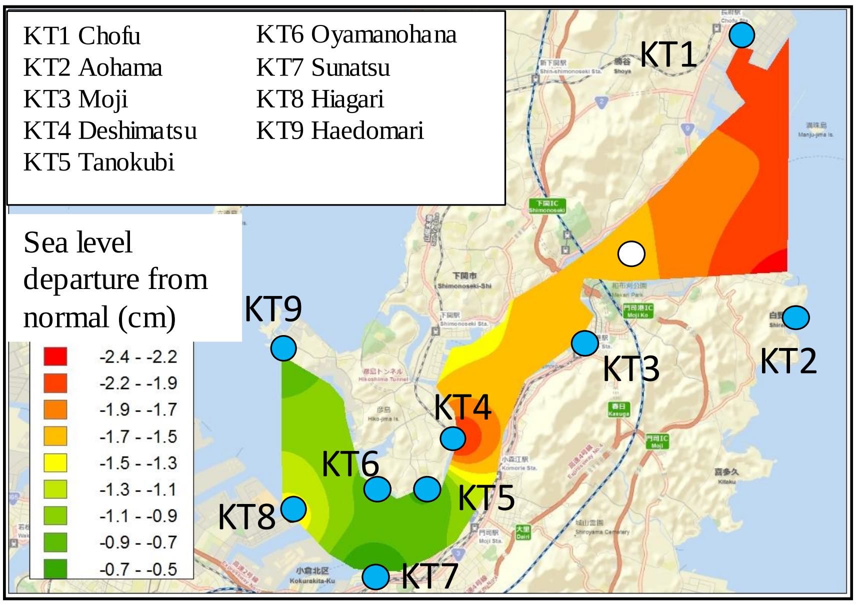

Figure 3. Distribution of sea level departure from normal (Distribution of the long-term fluctuation of mean water level)

In order to maintain, the waterway efficiency, it is necessary to clarify the mechanism of waterway sedimentation, and before that, it is extremely important to understand the characteristics of sea bottom topography change.

In this study, to clarify the influence of the long-term fluctuation of mean water level on the development of sand waves, the numerical simulation of tidal current and sediment transport in the Kanmon Waterway were performed by using a numerical simulation model, Finite Volume Community Ocean Model developed by Chen et al. [1].

NUMERICAL SIMULATION

FVCOM is the ocean current model with an unstructured-grid and σ-coordinate system, and therefore this model can reproduce complex topography. This model has various modules. In this study, we used Sediment Module to calculate sediment transport by bed load and suspended load. The computational domain is shown in Figure 1. The computational grid was made on the basis of the data from MLIT and NOAA (National Oceanic and Atmospheric Administration). The depth data was made on the basis of the data from JHA (Japan Hydrographic Association), JODC (Japan Oceanographic Data Center) and survey data by MLIT in the Kasase, Yamazokonohan, Mojikou, and Tanoura Areas where sand waves are developing (see Figure 4). We made computational grids of 2 patterns shown in Figure 4. One has high resolution throughout the straits (Grid A), the other has high resolution only in the Tanoura Area (Grid B). The grid size in Grid A is 6,000 m at boundary, 50 m in the straits and minimum 25 m in the Kasase, Yamazokonohan, Mojikou, and Tanoura Area. The grid size in Grid B is 3,000 m at boundary, 100 m in the straits and minimum 30 m in the Tanoura Area. The computational condition is shown in Table 1. The bottom sediment was uniformly sand and parameters are shown in Table 2

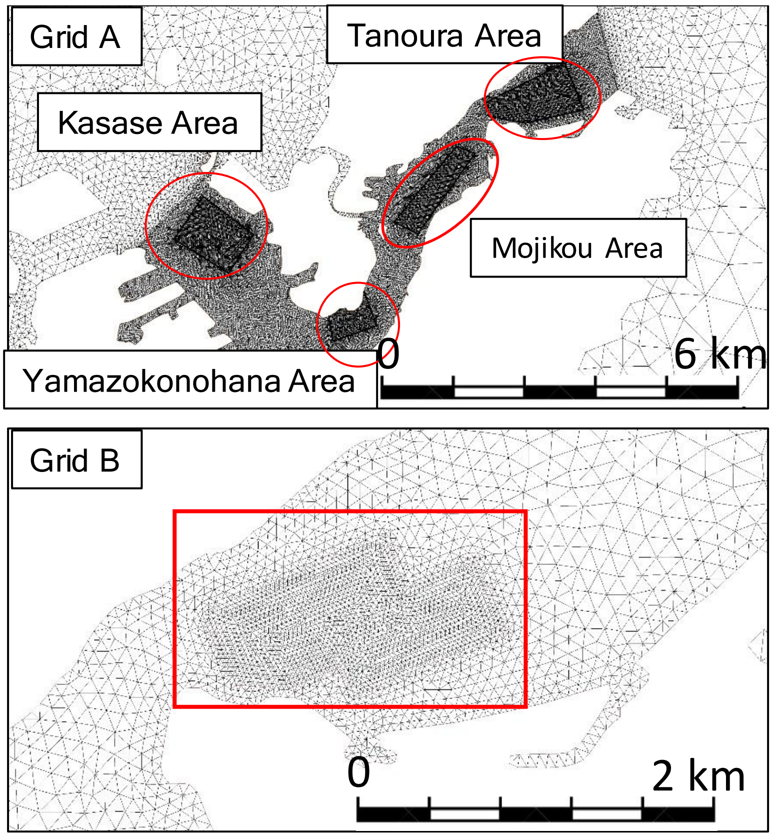

Figure 4. Computational grid
Grid A: high resolution throughout the straits
Grid B: high resolution only in the Tanoura Area

Table 1. Computational condition

Number of layers		5
Δt	External mode	0.05 s
	Internal mode	0.5 s
Calculation period		30 days
		Nov, 2, 2010, 0:00- Nov, 16, 2010, 23:00
Boundary condition		Water level, NAO99.jb

Table 2. Sediment conditions

Mean sediment diameter (mm)	1.34
Sediment settling velocity (mm/s)	128.07
Surface erosion rate (kg/m^2/s)	0.0105
Critical shear stress (N/m^2)	0.81
Porosity (non-dimension)	0.45
Sediment dry density (kg/m^3)	1436.60

In this study, the tide level fluctuation at the open boundary was calculated by NAO99jb [2)]. In order to consider the long-term fluctuation of mean water level, the average of the long-term fluctuation of mean water level at KT1 and KT2 (see Figure 3) are given at the eastern boundary, and the average of the long-term fluctuation of mean water level at KT8 and KT9 (see Figure 3) are given at the western boundary. The period was 2 year and 9 months from March 2005 when sand waves began to develop, and the long-term fluctuation of mean water level was averaged every 3 months (CASE-01). The computational period is 1 month (30 days). For comparison, simulation with normal tide (without the long-term fluctuation of mean water level) was performed (CASE-00). The period for simulation is 11 months. Table 3 shows the fluctuation of mean water level given in CASE-01. The right column of Table 3 shows the difference between east and west (west-east).

By the way, the reproduction of sand wave is very difficult, therefore the purpose of this study is to examine how the current and sediment transport change due to the long-term fluctuation of mean water level, and the relationship between them and sand waves.

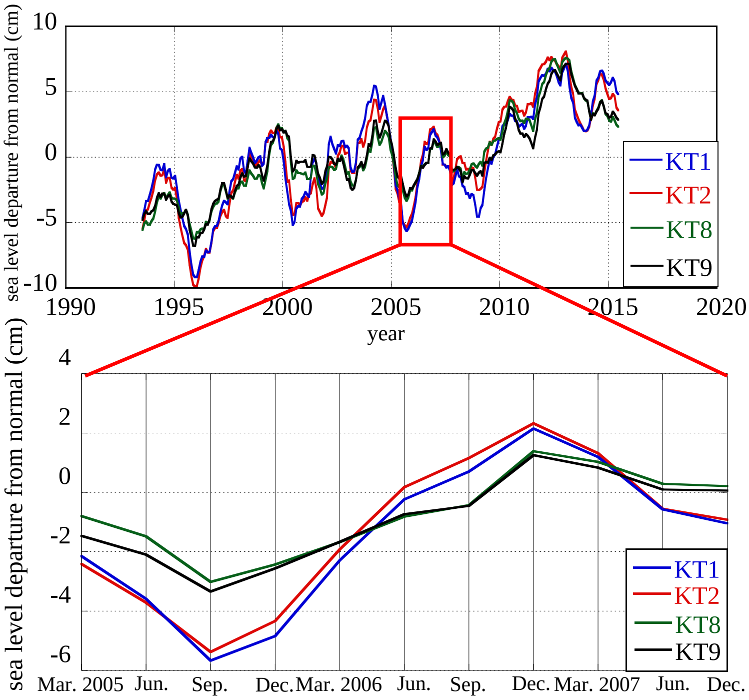

Figure 4. The long-term fluctuation of mean water level (See Figure 3 for location of KT1,2,8 and 9)

Table 3. Fluctuation of mean water level given in CASE-01

CASE-01			
Month	Fluctuation of mean water level (cm)		Difference (cm)
	West	East	
1	-1.127	-2.276	1.149
2	-1.784	-3.647	1.863
3	-3.178	-5.519	2.341
4	-2.490	-4.582	2.092
5	-1.202	-1.467	0.265
6	-0.769	-0.027	-0.742
7	-0.438	0.932	-1.370
8	1.323	2.240	-0.917
9	0.933	1.257	-0.324
10	0.196	-0.556	0.752
11	0.139	-0.979	1.118

Reproducibility of long-term fluctuation of mean water level in the numerical simulation

Using the grid which has high resolution throughout the straits, high-accuracy simulation is expected. However computational load is very high. Therefore, if we can get result with similar accuracy by using the grid which has high resolution only in the Tanoura Area, we can reduce the computational load. We verified the reproducibility of the spatial distribution of mean water level fluctuations under the condition of CASE-01 (1st month).

Figure 5 shows the spatial distributions of mean water level fluctuations which is calculated by using Grid A and Grid B. The water level on the east side is low and that on west side is a little higher. Figure. 3 shows the distribution of the mean water level created from the observed values at the same time (Mar. 2005). Comparing Figure 3 and Figure 5(a), simulation with Grid A was able to reproduce the spatial distribution of the mean water level well. Comparing results of Grid A and Grid B, the mean water level on the east side is roughly the same, but on the west side that is different.

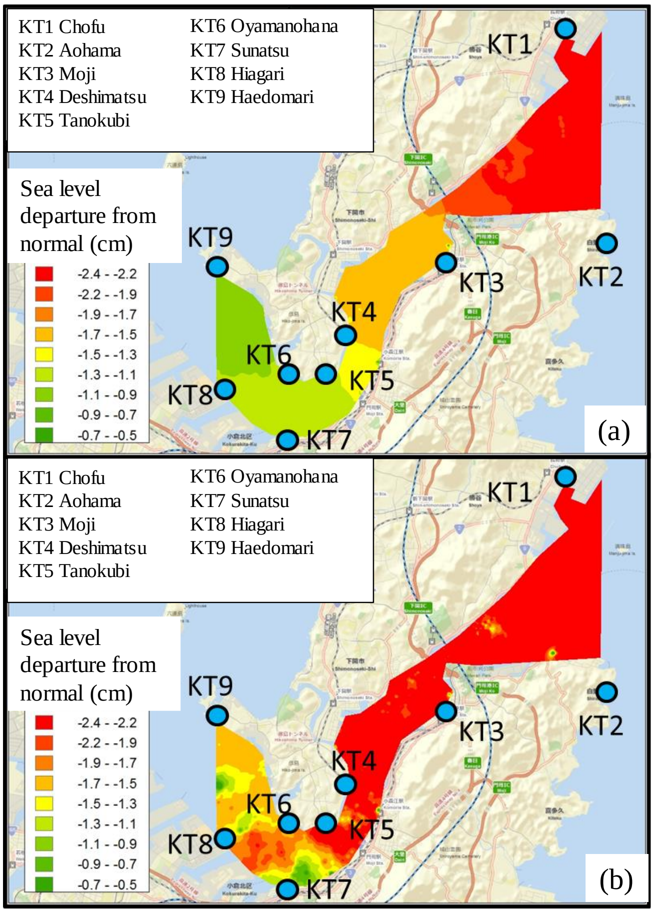

Figure 5. Distribution of mean water level fluctuations calculated by using (a) Grid A and (b) Grid B

Figure 6 shows a comparison of water level fluctuations between Grid A and Grid B at the Choufu (KT1) and the Haedomari (KT9). The both results are almost the same, and similar results were obtained at other points. From these results, we decided that the simulation using Grid B could sufficiently reproduce the water level fluctuation and reduce the calculation load. Therefore, we used Grid B in numerical experiments of the study.

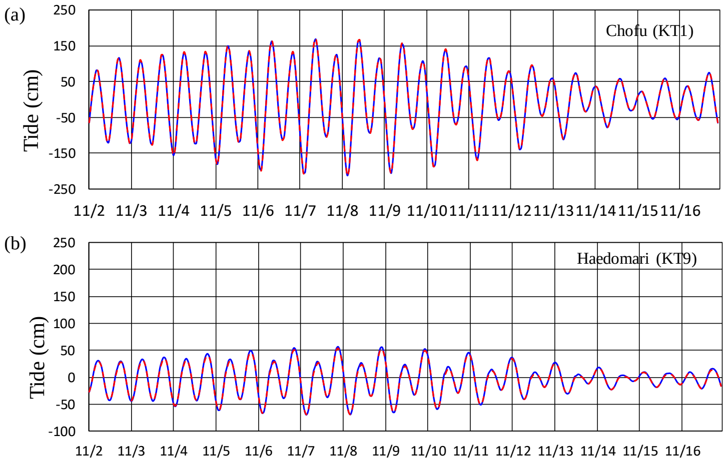

Figure 6. Water level fluctuations calculated by using Grid A (red) and Grid B (blue) (a) Chofu (KT1) and (b) Haedomari (KT9)

Simulation results

Figure 7 shows topographic change in the Tanoura Area (surrounded by red line shown in Figure 4). In right figure of Figure 7, the red ellipses indicate the area where sand waves develop remarkably. In the 1st month, there was no significant difference in topographic changes between both cases. In 2nd month, a linear shallow place occurred. In 3rd month, the linear shallow area was developing, and another shallow area also occurred on the right side. In 4th month, the linear shallow place was developing. In 5th month multiple linear shallow place occurred in both cases. In 6th month, multiple shallow areas were developing. After 7th month, it can be seen that multiple shallow areas were greatly developed. Focusing on difference between CASE-01 and CASE-00, CASE-01 is shallower than CASE-00 in the area surrounded by red ellipse until 7th month, but not after the 8th month. This cause seems that the given fluctuation of mean water level became positive. Then, it is found that a water depth difference (maximum over 10 m) occurs. The long-term fluctuation of mean water level affects the topographic change in the area where the sand waves are developing.

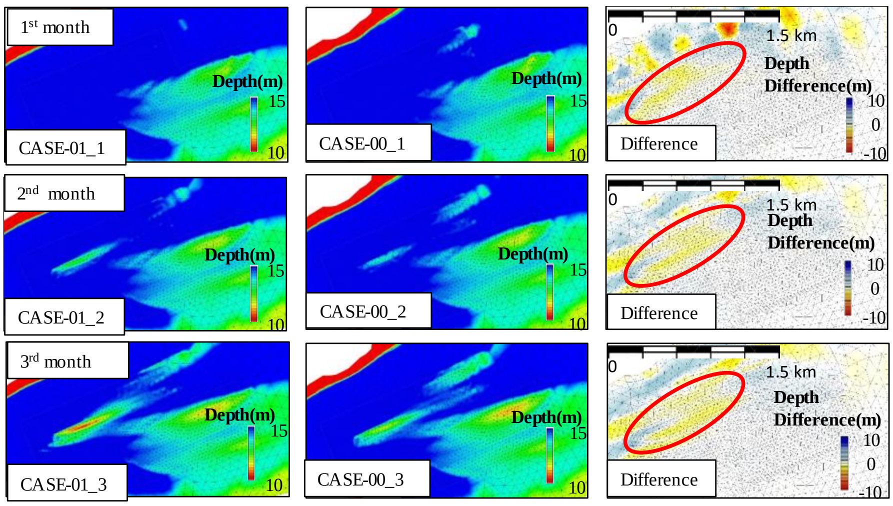

Figure 7. Simulation result of topographic change
Left: CASE-01, Center: CASE-00, Right: Difference (CASE-01 - CASE-00)

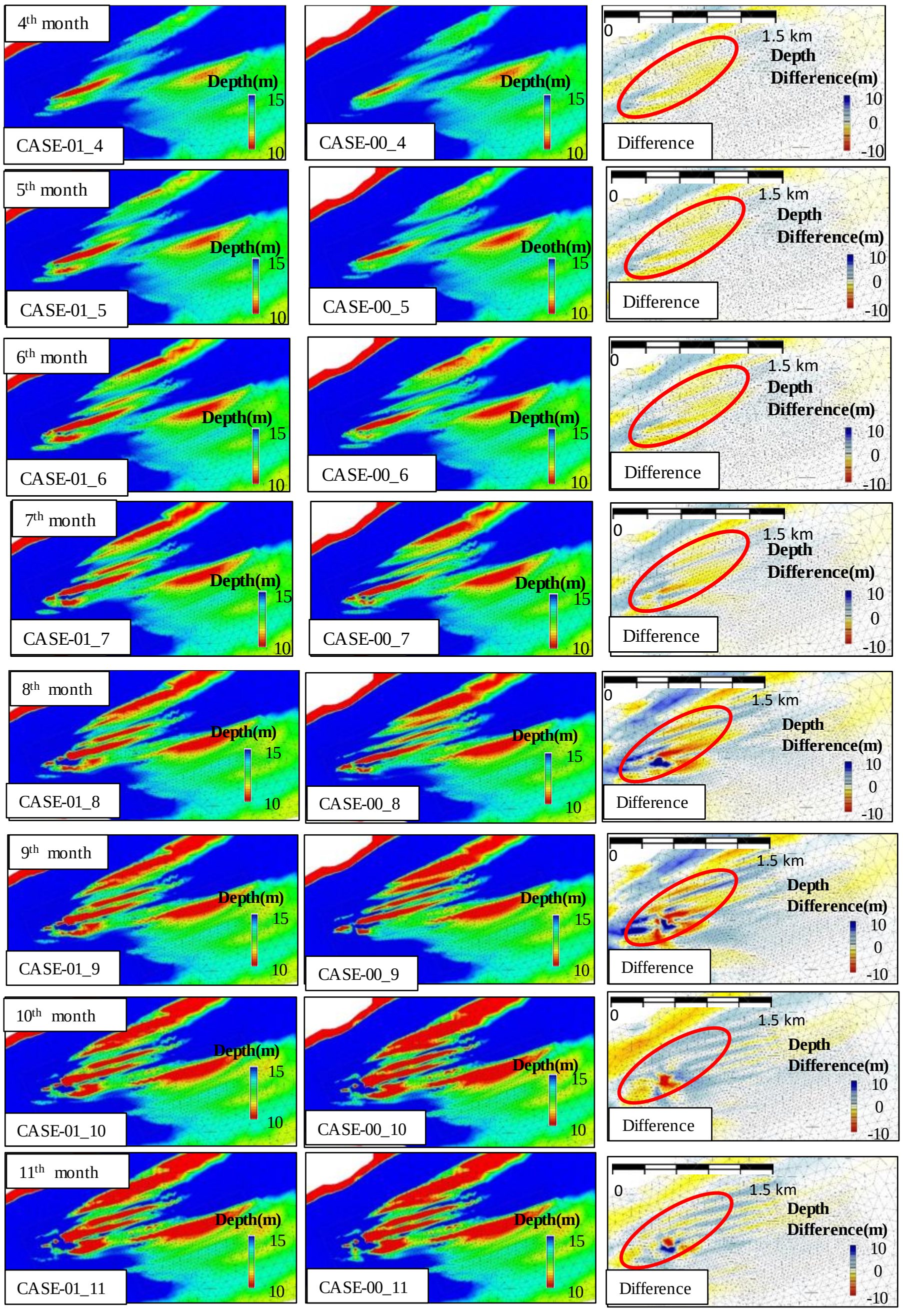

Figure 7. Simulation result of topographic change (continued)
Left: CASE-01, Center: CASE-00, Right: Difference (CASE-01 - CASE-00)

We discussed the relationship between long-term fluctuation of mean water level and topographic change from focusing on monthly topographic changes. Figure 8 shows monthly topographic changes during 2nd month, 4th month, and 6th month (CASE-01_2 means topographic change in 2nd month). Red and blue mean sedimentation and erosion, respectively. In CASE-01_2 and CASE-01_6, sedimentation is larger than CASE-01_4. At the bottom right of each panel, the difference between the fluctuation of mean water level in east and west is shown (a positive values indicate that the west side is high). When difference of mean water level is somewhat small, sedimentation increased. When that is large, sedimentation decreased.

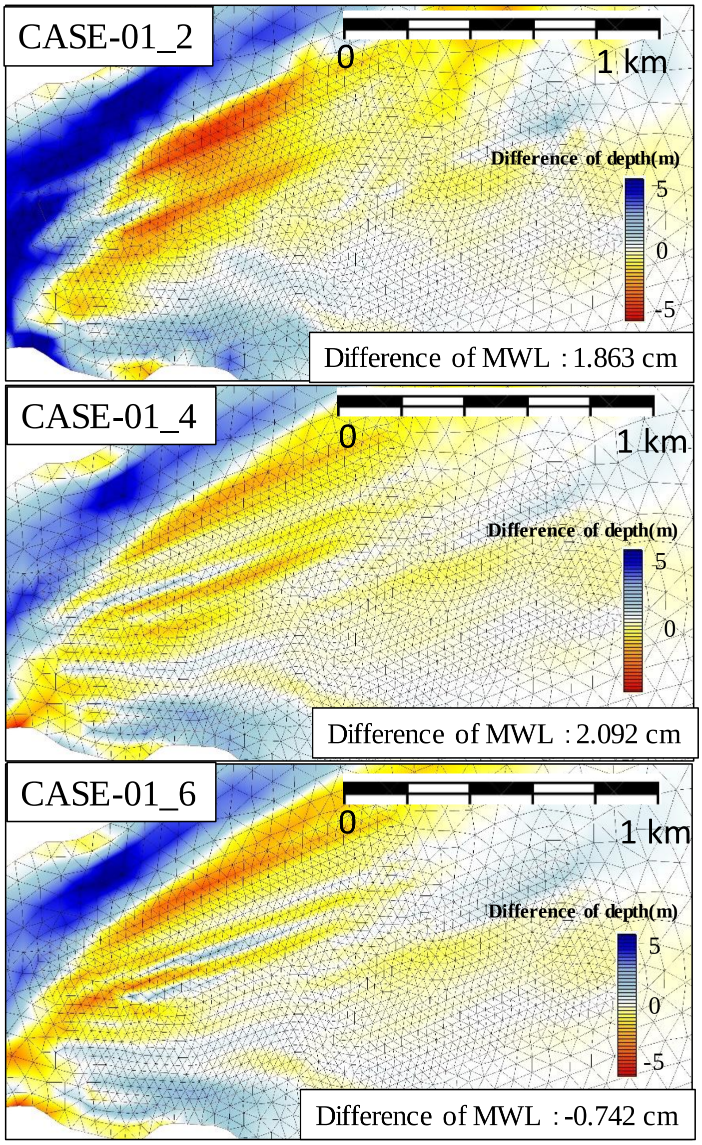

Figure 8. Monthly topographic change

Figure 9 shows the difference in bottom current velocity due to fluctuations in mean water level at 1st month (CASE-01-CASE-00). When westward current is fastest, there is almost no difference in current. However, when eastward current is fastest, there is difference at the area surrounded by the red ellipse in Figure 9 (b). This place coincides with the place where the sand waves are developing.

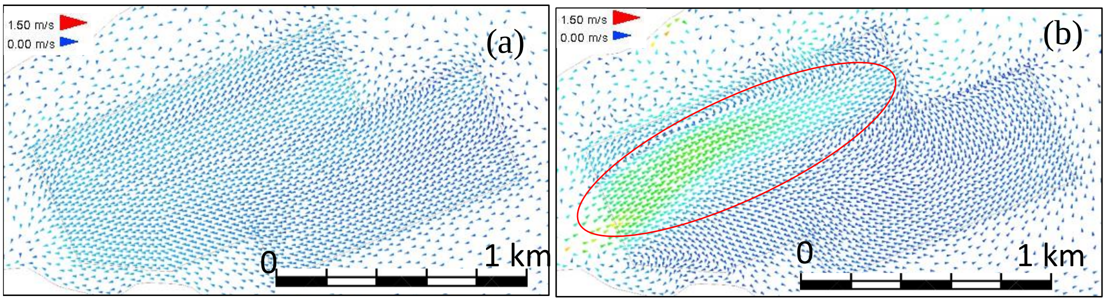

Figure 9. Distribution of current difference between CASE-01 and CASE-00
(a) When westward current is fastest (b) When eastward current is fastest

Figure 10 shows the distribution of bottom current velocity in the straits when eastward current is fastest. When difference of mean water level is small (CASE-01_2), the current in the west of the Tanoura Area shown by arrows in each panel is fast and current in the center of the straits is somewhat slow. Next, when difference of mean water level is large (CASE-01_4) the current in the west of the Tanoura Area is slow and current in the center of the straits is fast. Finally, when the east-west water level difference becomes negative and difference is small (CASE-01_6), the current in the west of the Tanoura Area is fast. Therefore, the difference of mean water level changes the current in the west of the Tanoura Area and sediment transport in the Tanoura Area.

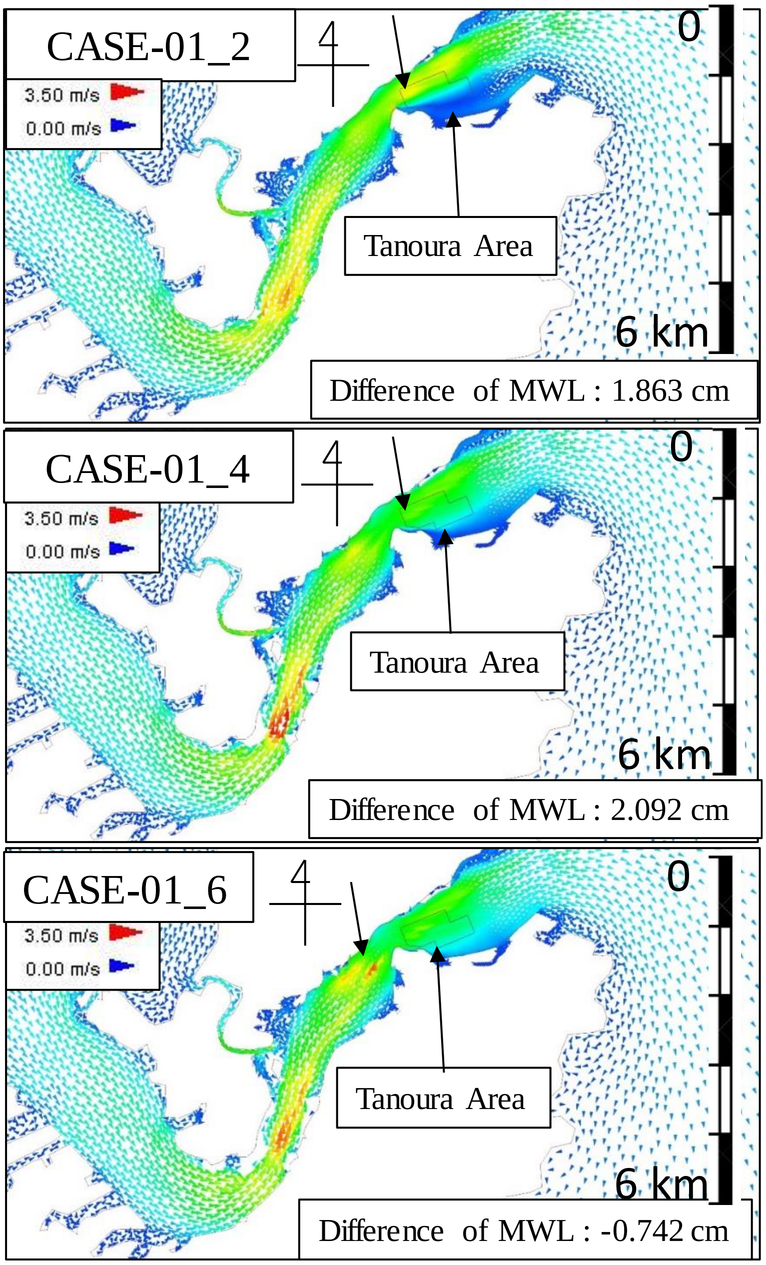

Figure 10. Distribution of bottom current velocity when eastward current is fastest

The model which we use in this study calculate for suspended load and bed load. However, bed load is dominant for development of sand waves, and we calculated the sand drift vector due to bed load from the bottom current velocity and sediment condition. Figure 11 shows the sand drift vector in the Tanoura Area. The vector in the figure shows the cumulative sand drift over a month. The unit is the volume of sand that has moved per width in the current direction ($m^3/m=m^2$). In CASE-01_2 and

CASE-01_4, there is a lot of eastward sand drift on the north side of the Tanoura Area because the mean water level in west side is high. On the other hand, in CASE-01_6, there is a lot of westward sand drift throughout the Tanoura Area because the mean water level in east side is high. However, in all cases there is eastward sand drift on the north side of the Tanoua Area and westward sand drift on the south side of the Tanoura Area. Sand waves are developing at boundary between these areas.

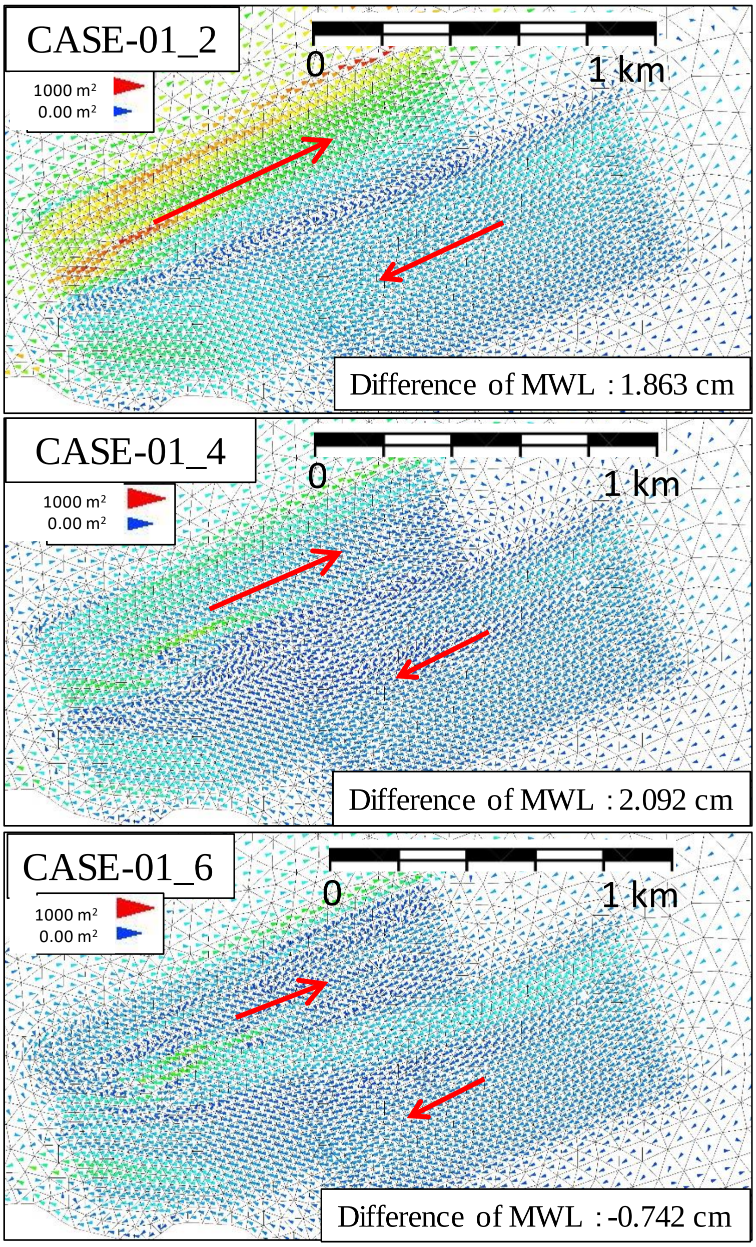

Figure 11. Distribution of sand drift vector

CONCLUSIONS

We expected that the long-term fluctuation of mean water level affects development of sand waves in the Kanmon Waterway, we investigated the effect of the long-term fluctuation of mean water level on the development of sand waves by using a numerical simulation model FVCOM. We performed calculation considering the long-term fluctuation of mean water level and using the computational grid which has high resolution only in the Tanoura Area. As a result, we clarified that slight fluctuation of mean water level changed the current condition throughout the straits and also changed the topographic change in the Tanoura Area. Moreover, focusing on the difference in the spatial distribution of fluctuation of mean water level, it is found that the magnitude of the difference in the fluctuation of mean water level between east and west affects current conditions throughout the straits and topographic change in the Tanoura Area. Finally, from the examination of sand drift vector, it is found that there is eastward sand drift on the north side of the Tanoua Area, westward sand drift on the south side of the Tanoura Area and Sand waves are developing at boundary between these areas.

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