

ANALYSIS OF WIND DRIVEN CURRENT IN ISHIKARI BAY AND NEARSHORE CURRENT AT ISHIKARI-HAMA BEACH, JAPAN

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In August 2016, four swimmers were carried away by the waves and drowned at Ishikari-hama beach in Hokkaido. In recent years, several other similar accidents occurred around the Ishikari coast. Therefore, in this paper, we tried to comprehend the features of the current dynamics in Ishikari Bay and Ishikari-hama beach. As research contents, we grasped the accident that occurred in the past years around the Ishikari coast. In this case, we used the on-line database of the newspaper article. As the result, we comprehended the feature of the accident in Ishikari Bay. Secondary, we made a field survey at Ishikari-hama beach. Thirdly, we confirmed the fluctuation of the current in Ishikari Bay due to short time fluctuation of the wind direction. Finally, we simulated the rip current and the wind driven current in Ishikari Bay.

Keywords: Ishikari bay; rip current; wind driven current.

INTRODUCTION

Ishikari coast in Hokkaido has a sandy beach which is located in the back of Ishikari Bay. The total length of the coast is about 27 km. Ishikari New Port is located the center of Ishikari coast, and the estuary of Ishikari River is located the northeast extremity of the coast (see Figure 1).

Some drowning accidents occurred in this area. In recent years, the accident mainly occurred at Ishikari-hama beach (August 11, 2016), and at Zenibako beach (August 27, 2017). In particular, in 2016, 4 young people drowning at Ishikari-hama beach.

Near the shore, a nearshore current is generally dominant. However, the previous study grasped that the strong wind driven current sometimes occurred in this area due to the seasonal wind. For example, the northwest wind in the winter occurs the strong clockwise current in Ishikari bay (Yamashita, 1998 and 1999). However, the revealed currents studied at more than 10m depth area in the sea, and the current at near the shoreline has not been studied. Therefore, we tried to grasp the characteristics of the current at near the coast, and the reason why the accident occurred at Ishikari coast.



Figure 1. Location of the field

INVESTIGATION OF RECENT ACCIDENTS AND CHARACTERISTICS OF ISHIKARI-HAMA BEACH

In order to grasp the occurrence situation of drowning accident at the target coast, we searched the on-line database of Asahi Shinbun newspaper and Hokkaido newspaper etc. As the results, 12 accidents were extracted (see Figure 2). Furthermore, 7 of 12 accidents were “flowed” accidents.

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Figure 2 shows the accident location and the date of occurrence. The figure shows that many accidents occurred on Ishikari coast. Expressly, many accidents occurred at Zenibako beach (South-West of the coast) and Ishikari-hama beach (North-East of the coast).

Figure 3 shows the satellite photographs of Ishikari-hama beach and Zenibako beach. According to the photographs, Ishikari-hama beach is the sandy coast that has the cusp topography. The wavelength of the cups is about 200 m. Furthermore, Zenibako beach is the sandy coast that has the 200m wavelength cusp topography, and the several offshore breakwaters are set at off the beach. The past our research (Inukai, 2015 and 2017) confirmed that such cusp topography was formed by waves, and the nearshore current (include the rip current) occurs at these beaches.

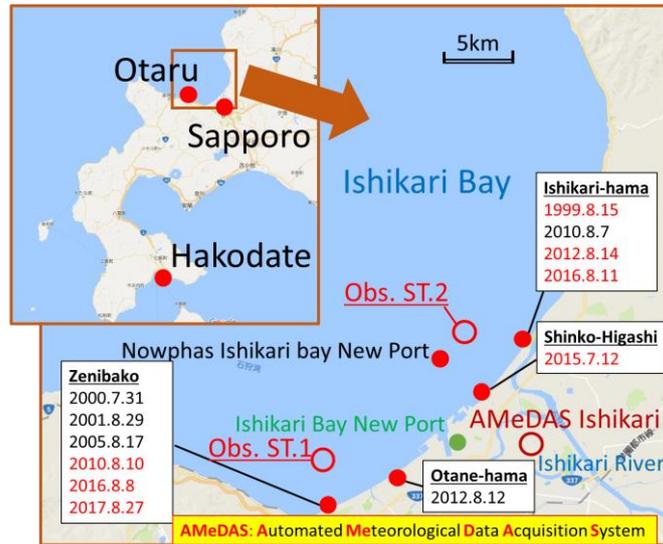


Figure 2. Location of the field, wave observed and wind observed points

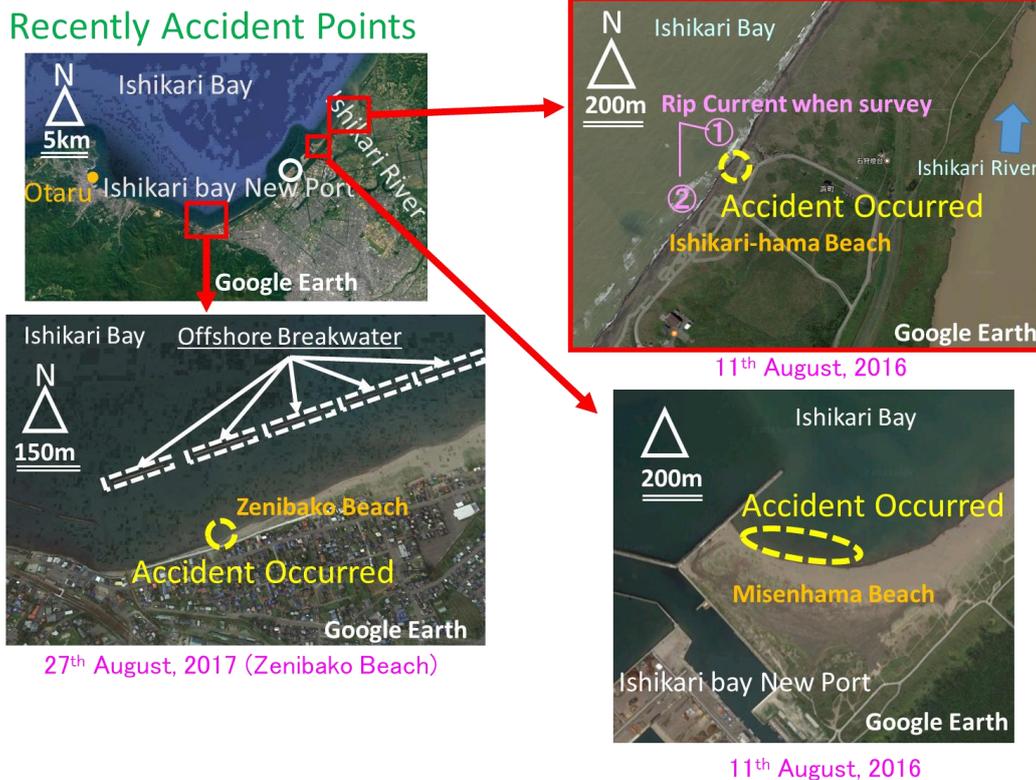


Figure 3. Satellite Image of Ishikari-hama Beach (cusp topography) and Zenibako Beach (cusp topography+breakwater)

METEOROLOGICAL AND SEA CONDITION WHEN PAST ACCIDENTS OCCURRED

In order to ascertain the meteorological and the sea condition when the accidents occurred, the weather and the wave condition are summarized in Table 1. The table shows the seven cases of "flowed to offshore" accidents in Figure 2. In the table, we used the ground weather data of AMeDAS Ishikari (located in Figure 2). These data is supplied by the Japan Meteorological Agency (JWA).

In Japan, surface observation is carried out at about 1,300 stations using automatic observation equipment collectively known as the Automated Meteorological Data Acquisition System (AMeDAS). Stations are laid out at average intervals of 17 km throughout the country, with about 1,200 of them unmanned. Observation at manned stations covers weather, wind direction/speed, amount of precipitation, types and base height of cloud, visibility, air temperature, humidity and atmospheric pressure. Data other than those relating to weather, visibility and cloud-related elements are automatically sent every ten seconds from manned stations and some unmanned stations, and every ten minutes from the remaining unmanned stations, of which about 700 observe four elements (precipitation, air temperature, wind direction/speed and sunshine duration) and about 300 observe precipitation. In addition to these elements, snow depth is also observed at stations in areas of heavy snowfall. All observational data are transmitted to JMA Headquarters via dedicated lines.

Furthermore, we used the wave data of the Nowphas Ishikari Shinko Port (located in Figure 2). The Nationwide Ocean Wave information network for Ports and HARbourS, NOWPHAS, is the wave information network in Japan.

In the table, the letters were written in red characters when the wind direction, wind speed, wave height, period or wave direction fluctuated largely before occurring the accident.

There were only 2 fluctuations of the wave condition before the accident, however there were 6 fluctuations of the weather condition, expressly, there were 4 large fluctuations of the wind direction.

Figure 4 shows the weather chart at 6 am on August 11, 2016, and Figure 5 shows the time variation of the wind speed and the wind direction at around Ishikari Bay. According to Figure 4, the high pressure moved to eastward on the south side of the field, and the wind direction at the field changed from SE to NW. Furthermore, Figure 5 shows that the wind direction changed from SE to N since 12am. It was 2 hours before the accident occurred. And the wind velocity also increased at the same time.

According to the above results, in all cases of fluctuating the wind direction, the wind direction always fluctuated over 90 °, and finally, the wind direction fluctuated to N. When the wind direction was N, this direction, the wind blew into inner Ishikari Bay from the sea. From the above results, in this area, the accident occurred due to not only the fluctuation of the wave height but also the fluctuation of the wind direction. When the accident occurred, the wind direction was to offshore, therefore, the victims was influenced by the current rather than the wind. In this case, the corresponded current was the nearshore current or the wind driven current. The tidal current is not distinguished in this area.

Table 1. Date of accident, locates, wind and wave information

Date	Area	Wind , Wave condition
15 th August, 1999	Benten, Ishikari city	Wind Dir: SE, Vel:3-4m/s Wave H _{1/3} :0.26m, T:3.9s
10 th August, 2010	Zenibako, Otaru city	Wind Dir:NW-N-E, Vel:2.5-3m/s Wave H _{1/3} :0.15m, T:3.7s
14 th August, 2012	Oyadune, Otaru city	Wind Dir:NW-N, Vel:4-5m/s Wave H _{1/3} :0.40-0.93m, T:4s, Dir:NW
12 th July, 2015	Shinko-Higashi, Ishikari city	Wind Dir:SE-N, Vel:3.3-4m/s Wave H _{1/3} :0.6-0.8m, T:5.1s, Dir:NW
8 th August, 2016	Zenibako, Otaru city	Wind Dir:SE-NNW, Vel:6-2.9m/s Wave H _{1/3} :0.31m, T:3.0s, Dir:W
11 th August, 2016	Benten, Ishikari city	Wind Dir:SE-NNW, Vel:1.5-3.5m/s Wave H _{1/3} :0.25m, T:2.6s
27 th August, 2017	Zenibako, Otaru city	Wind Dir:W-NNW, Vel:1.5-2.6m/s Wave H _{1/3} :1.03m, T:5.2s, Dir:WNW

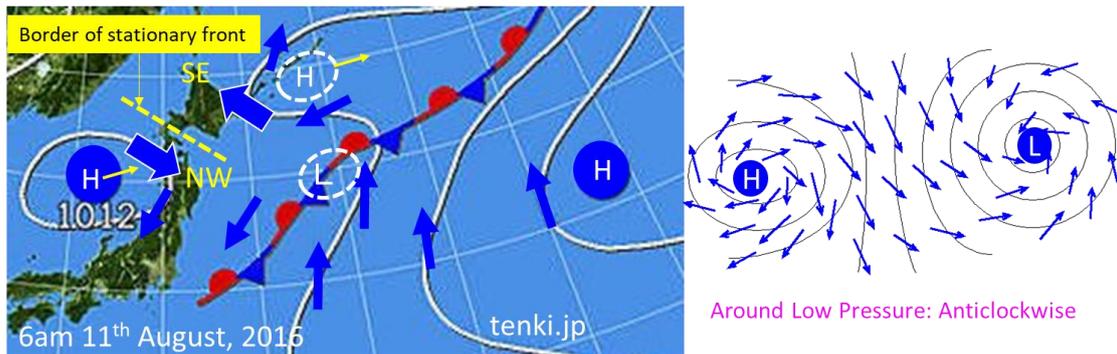


Figure 4. Weather Chart (6am 11th August, 2016)

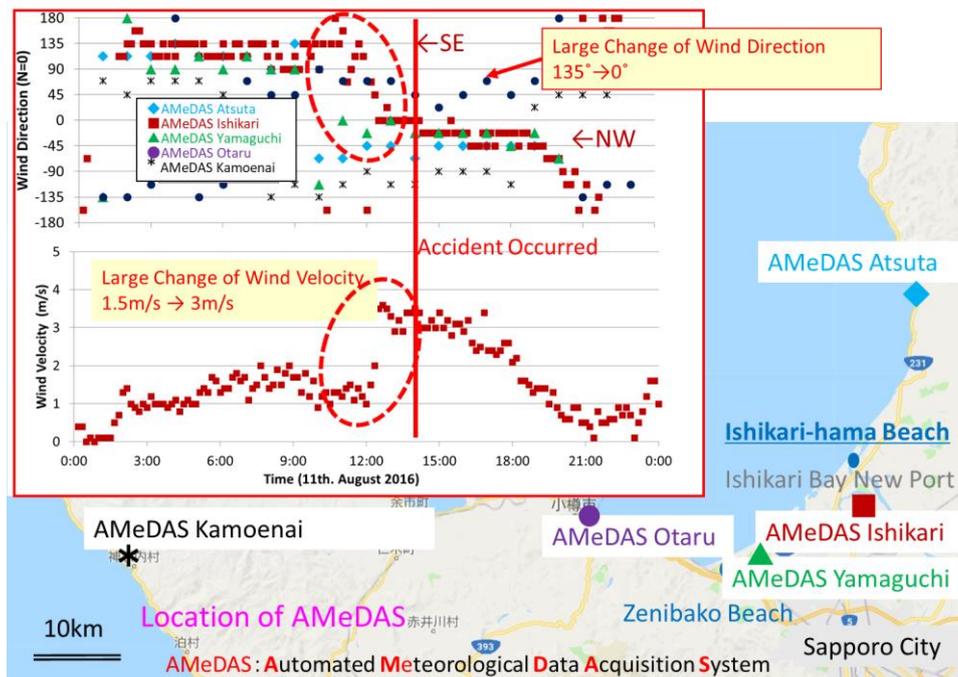


Figure 5. Time change of wind velocity and wind direction (AMeDAS around Ishikari, 11th August, 2016)

FIELD SUEVEY

A field survey was conducted on Ishikarihama beach (Figure 1) where the accident occurred on August 11, 2016. The enforced date was on July 8, 2017. During conducting the survey, we confirmed the occurrence of a rip current at point ① and point ② (Figure 3). We visualized the rip current by Inukai's method (Inukai, 2015, 2017). In this method, we pigmented the current by the water colorant, and we got the aerial photograph by Unmanned Aerial Vehicle (UAV). We also installed the weather station on site. Furthermore, we measured the water depth along the measure line from the shoreline to 100m off the coast. The lines were set at every 50m along the shoreline.

At the field, we set the weather station when we conducted the field survey (Figure 6). Figure 7 and Figure 8 show the time fluctuation of the wind direction and the wind velocity at AMeDAS Ishikari and the survey field. Figures show that the wind directions of the weather station and AMeDAS during the field survey were almost N. According to Figure 1, the site of AMeDAS Ishikari is opened to the north direction on the sea. Therefore, when the wind direction is N, the wind direction of the weather station and AMeDAS were almost same. However, although the wind speed gradually increased, the difference between the weather station data and AMeDAS was about twice as large. As the cause, the AMeDAS was influenced by the land friction. When the wind direction fluctuated to N on August 11, 2016, AMeDAS wind velocity increased from about 1 m/s to about 3.4 m/s. Therefore,

we considered that the real local wind velocity increased from about 2 m/s to 8 m /s on the accident date.

When the field survey was conducted, the significant wave height was 0.43 m and the period was 5.1 seconds at Nowphas Ishikari Bay New Port (MIG, 2012) where is located near the field (Figure 1). The wave height at the shoreline always increases due to the influence of the water depth, therefore, we calculated the wave height at the shoreline, and the breaking wave height H_b . The breaking wave height has the relationship with the wave height and the depth (Horikawa, 1991). Figure 9 shows the change of water depth and the change of wave height in the offshore direction. According to Figure 9, when the field survey was conducted, the breaking wave height was about 0.6 m, and the wave broke at the sandbar on the offshore side. However, when the accident occurred, the breaking wave height was 0.26 m. Therefore, we considered that the wave broke at near the shoreline.

Figure 10 shows the visualized rip current by the water colorant at point ① in Figure 3. And, Figure 11 shows the average current speed which was calculated by the average moving distance in every 30 seconds. Figures show that the rip current generated at the point ①, and the current velocity was about 0.15 m/s. The occurrence situation of the rip current about the wave height was similar to the other example (Inukai, 2015 and 2017). However, after flowing out to the offshore, the current velocity changed to about 0.19 m/s, and the current direction changed to SW. This direction means, the current flowed parallel to the coast. It seems that this current was influenced by the coastal current (include the wind driven current).



Figure 6. Weather Station (8th July, 2017)

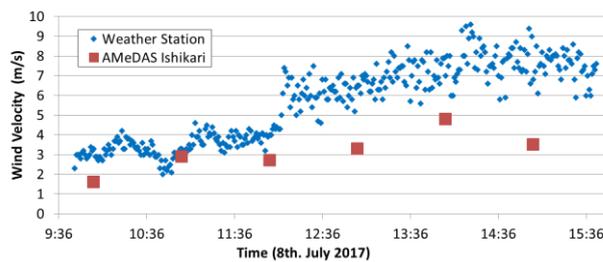


Figure 7. Time change of wind velocity (8th July, 2017)

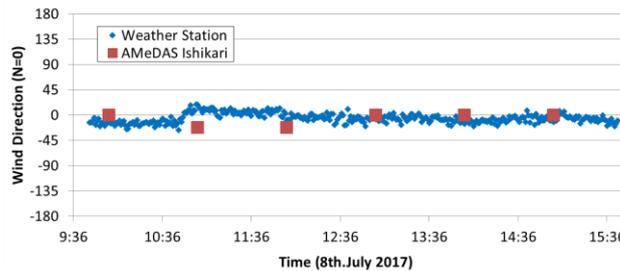


Figure 8. Time change of wind direction (8th July, 2017)

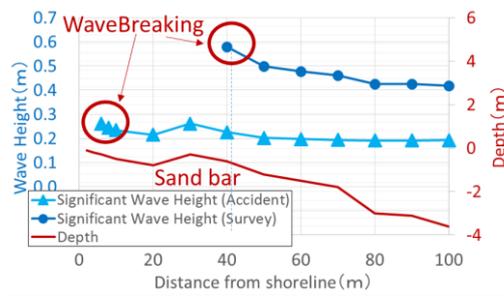


Figure 9. Shallow water deformation of Ishikari-hama beach (Accident and Field Survey)



Figure 10. Visualized Rip Current

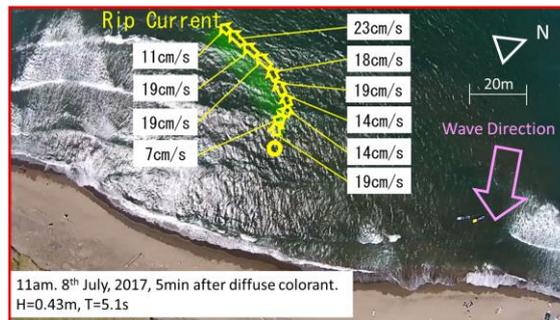


Figure 11. Velocity profiles of Rip Current (at point 1 in Figure 2)

GRASP CHANGE OF CURRENT CAUSED BY METEOROLOGICAL CHANGE IN ISHIKARI BAY

Grasp relationship between change of current direction and change of wind direction

According to the above results, when the accident occurred, the wind direction fluctuated the current condition. Therefore, we tried to grasp how the current condition fluctuated by the change of the wind direction when the low pressure or the high pressure passed through Ishikari Bay. Here, we used observation data (Yamashita, 1998 and 1999). We grasped the direction change of the current when the wind direction fluctuated. Furthermore, we grasped the weather chart. In this case, the current data were observed at St.3 and St.4, and the wind data were observed at Ishikawa Bay New Port (Figure 2). Furthermore, we classified the pass type, i.e., which area (the north side or the south side of Ishikari Bay) the high and low pressure passed. As the result, we acquired 14 cases as shown in Table 2.

The table shows that the wind direction fluctuated clockwise when the low pressure and the high pressure passed the north side. On the other hand, the wind direction fluctuated counterclockwise when the low pressure and the high pressure passed the south side. Furthermore, the current direction always fluctuated clockwise independently of fluctuation of the wind direction. Therefore, we considered that the current direction fluctuated clockwise when the accident occurred. Incidentally, when the accident

occurred, the wind direction fluctuated counterclockwise as shown in Figure 4. Because the high pressure moved to east and it passed the south side.

Table 2. Relationship between change of wind direction and change of current direction

Date, Time	Change Wind Dir	Classification by Weather Chart	Change Current Dir
1996/10/4/12:00	↖ → ↘	Low pressure passed North	↑ ↘ ↙
1996/10/7/9:00	↖ ↑ ↘	Low pressure passed North	↗ → ↘
1996/10/10/7:00	↗ → ↘	Low pressure passed North	↑ ↗ ↘
1998/1/25/10:00	↖ → ↘	Low pressure passed North	↖ → ↘
1998/2/10/9:00	↗ ↘ ↘	Low pressure passed North	↗ ↘ ↘
1998/2/13/0:00	↖ ↗ ↘	Low pressure passed North	↗ ↘ ↘
1996/10/5/6:00	↖ ← ↘	Low pressure passed South	↖ ↗ ↘
1998/1/21/14:00	↖ ↓ ↘	Low pressure passed South	↓ ↙ ↖
1998/1/24/0:00	↖ ↑ ↘	Low pressure passed South	↙ ← ↖
1996/10/5/14:00	↘ ↙ ↖	High pressure passed North	↓ ↙ ↖
1998/2/7/0:00	↘ ↓ ↖	High pressure passed North	↓ ← ↖
1996/10/7/18:00	↘ ↗ ↖	High pressure passed South	↘ ↙ ↖
1998/2/11/17:00	↘ ↗ ↖	High pressure passed South	↓ ↙ ↖
1998/2/13/21:00	↘ → ↖	High pressure passed South	↘ ↙ ↖

Rotation: ○clockwise, ○Counter-clockwise

Time to maximum current velocity from change of wind direction

We tried to grasp the time/date and the maximum current velocity when the wind direction fluctuated. We used the observation information obtained by Yamashita et al (1998 and 1999). However, the data were observed at 3m water depth. Therefore, we converted the data into the surface current velocity by the equation (1).

$$u=v(1+z/h)(1+3z/h) \tag{1}$$

where, u: current velocity at the water depth z, v: surface layer current velocity, z: water depth at which the current velocity was measured, and h: water depth.

Figure 12 shows the relationship between the time after starting the fluctuation of the wind direction and the maximum velocity of the current. Figure shows that the current became in 3 to 5 hours after starting the fluctuation, and the current velocity became about 70 cm/s.

Furthermore, it was classified into two groups by the time to reach the maximum velocity of the current after starting the fluctuation of the wind direction. As the reason, the move speed of the low pressure/ the high pressure and the magnitude of the pressure gradient were different. When the move speed or the magnitude of the pressure gradient was high, the fluctuation time became be short.

Incidentally, the high pressure passed fast the south side of the field in the accident day. Therefore, the trend fluctuated in a short time.

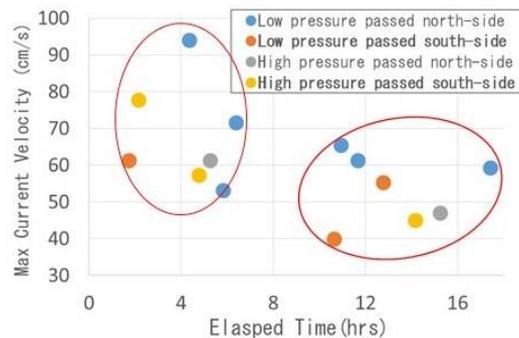


Figure 12. Relationship between maximum velocity and reach time after starting wind direction changed

NUMERICAL EXPERIMENT

Current situation near the coast when field survey

We tried to grasp the nearshore current condition of the survey time by the numerical wave model (Inukai, 2015). In this case, as shown in Eqs. (2)-(4), we used modified Boussinesq equations and continuous equations to calculate the wave condition and the nearshore current.

$$\begin{aligned} & \frac{\partial Q_x}{\partial t} + \frac{\partial}{\partial x} \left(\frac{Q_x^2}{D} \right) + \frac{\partial}{\partial y} \left(\frac{Q_x Q_y}{D} \right) + gD \frac{\partial \eta}{\partial x} - MD_x + \tau_x \\ &= \left(B + \frac{1}{3} \right) h^2 \frac{\partial}{\partial x} \left(\frac{\partial^2 Q_x}{\partial t \partial x} + \frac{\partial^2 Q_y}{\partial t \partial y} \right) + \\ & \quad Bgh^3 \left(\frac{\partial^3 \eta}{\partial x^3} + \frac{\partial^3 \eta}{\partial x \partial y^2} \right) \end{aligned} \quad (2)$$

$$\begin{aligned} & \frac{\partial Q_y}{\partial t} + \frac{\partial}{\partial x} \left(\frac{Q_x Q_y}{D} \right) + \frac{\partial}{\partial y} \left(\frac{Q_y^2}{D} \right) + gD \frac{\partial \eta}{\partial y} - MD_y + \tau_y \\ &= \left(B + \frac{1}{3} \right) h^2 \frac{\partial}{\partial y} \left(\frac{\partial^2 Q_x}{\partial t \partial x} + \frac{\partial^2 Q_y}{\partial t \partial y} \right) + \\ & \quad Bgh^3 \left(\frac{\partial^3 \eta}{\partial y^3} + \frac{\partial^3 \eta}{\partial y \partial x^2} \right) \end{aligned} \quad (3)$$

$$\frac{\partial \eta}{\partial t} + \frac{\partial Q_x}{\partial x} + \frac{\partial Q_y}{\partial y} = 0 \quad (4)$$

where, Q_x and Q_y : the current volume, g : the gravitational acceleration, D : the total water depth, η : the water surface variation amount, MD_x and MD_y : the break wave attenuation term, τ_x and τ_y : the sea floor friction term using Manning formula, and B : the constant $1/21$, h : the hydrostatic depth.

When the field survey was conducted, the sea water colorant was sprayed and the diffusion situation was observed. Therefore, we modified the model to be able to simulate the diffusion (Inukai, 2015, 2017). Specifically, this model simulates the diffusion process with Boussinesq equation and the continuous equation at each calculate time step. In the diffusion simulation, the density was virtually given by the point source using the following Eq. (5).

$$\frac{\partial C}{\partial t} + u \frac{\partial C}{\partial x} + v \frac{\partial C}{\partial y} - A_h \left(\frac{\partial^2 C}{\partial x^2} + \frac{\partial^2 C}{\partial y^2} \right) = 0 \quad (5)$$

where, u : the flow velocity in the x direction, v : the flow velocity in the y direction, C : the concentration, and A_h : the horizontal vortex viscosity coefficient. In this case, the concentration was set as 1 of the number at the point source, and the result of the simulation shows the profile of the relative concentration in the simulation area. Therefore, the unit of Figure 13 has not the unit.

The simulation area was 250 m in the shoreline direction and 500 m in the offshore direction. The grid space was 1 m and the wavelength of the cusp topography was set to 100 m. The interval time of the simulation was set to 0.1 second. The seabed gradient was set to 1/40 gradient by the depth information in Figure 9. In the simulation, the wave condition was set to be same condition of the field survey in July 8, 2017. Specifically, the wave height was set to 0.5m and the period was set to 5 seconds, and the wave was entered at the outer boundary, and the wave direction was set to 78 degree to shoreline. Furthermore, when the field survey was conducted, the current after flowing out from the shoreline moved to the left direction in 20 cm/s. Therefore, the uniform current was set in 20 cm/s at the outer boundary of the perpendicular direction to the coast. In the diffusion simulation, the vortex viscosity coefficient was set to 4 cm² /s. The calculation result is shown in Figure 13. Figure shows that the pigment water flowed out to the offshore by the rip current from the side of the cusp topography. After flowing out, the current diffused to the left due to the coastal current. Furthermore, the current velocity at the near shoreline was about 15 cm/s and the velocity at the offshore was about 20cm/s. These results were qualitatively reproduced the results of the field survey.

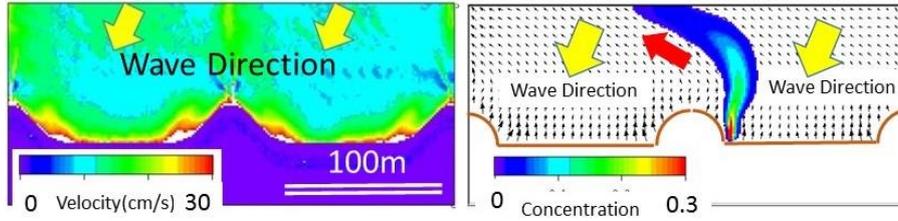


Figure 13. Profile of current velocity and diffusion of virtual water colorant

Wind Driven Current of Ishikari Bay when field survey and accident occurred

Here, we used the numerical model in reference to Inukai (2001). In this case, the explicitly differentiates hydrostatic pressure approximation equations and continuous equations were shown in Eq. (6) to Eq. (9), and the wind driven current was simulated by the model.

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} = 0 \quad (6)$$

$$\begin{aligned} \frac{\partial u}{\partial t} + u \frac{\partial u}{\partial x} + v \frac{\partial u}{\partial y} - fv + g \frac{\partial \zeta}{\partial x} \\ - A_h \left(\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2} \right) - A_v \frac{\partial^2 u}{\partial z^2} = 0 \end{aligned} \quad (7)$$

$$\begin{aligned} \frac{\partial v}{\partial t} + u \frac{\partial v}{\partial x} + v \frac{\partial v}{\partial y} + fu + g \frac{\partial \zeta}{\partial y} \\ - A_h \left(\frac{\partial^2 v}{\partial x^2} + \frac{\partial^2 v}{\partial y^2} \right) - A_v \frac{\partial^2 v}{\partial z^2} = 0 \end{aligned} \quad (8)$$

$$-\rho_w g - \frac{\partial P}{\partial z} = 0 \quad (9)$$

where, u, v, w : current velocity, h : depth of water, f : Coriolis coefficient, A_h : horizontal viscosity coefficient, A_z : vertical viscosity coefficient.

The topographical information was 500 m grid size (JODC), and we updated the topography of Ishikari Shinko. In this case, the model simulated in 4 layers, i.e., divided into 1 m, 5 m, 10 m, and deeper. Firstly, the wind direction was set to N and the wind velocity was set to 8 m/s for 6 hours in accordance with the field survey. Secondary, the wind direction was set to SE and the wind velocity was set to 2 m/s for 5 hours in accordance with the accident day. After the current was stabilize, the wind direction was set to NNW and the wind velocity was set to 8 m/s for 8 hours.

Figure 14 shows the profile of the current velocity when the field survey was conducted. Figure shows that the current velocity was about 20cm/s at Ishikari-hama. This result was same with the result of the field survey. Therefore, we considered that this model qualitatively reproduced the current.

Figure 15 shows the time change of current velocity of surface layer, and the inflection of the wind condition at Ishikari-hama when the accident occurred in 11th August, 2016. The figure shows when the wind direction changed, the current direction changed for 1 hour and the velocity increased to 0.8m/s for 2 hours.

Figure 16 shows the current velocity of the surface layer when wind direction was SE (5hours after staring simulation). The figure shows that the current velocity at Ishikari-hama was about 0.2m/s and the wind direction was N.

Figure 17 shows the current velocity of the surface layer when the wind direction was NNW (8hours after staring simulation). The figure shows that the current velocity at Ishikari-hama was about 1m/s due to concentrate the current. Furthermore, the wind direction was SW. This direction was parallel to the coast. According to above results, we confirmed that the current at inner Ishikari Bay area increase rapidly for 2 hours after the wind direction fluctuates.

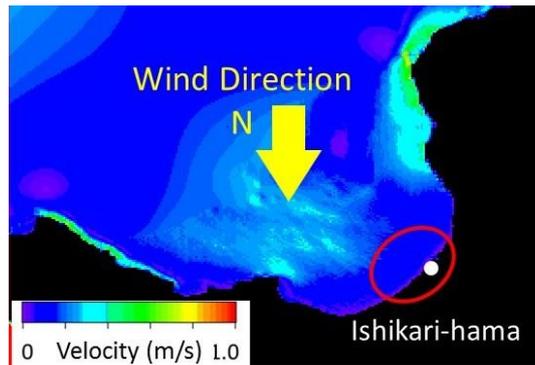


Figure 14. Profile of current velocity when field survey

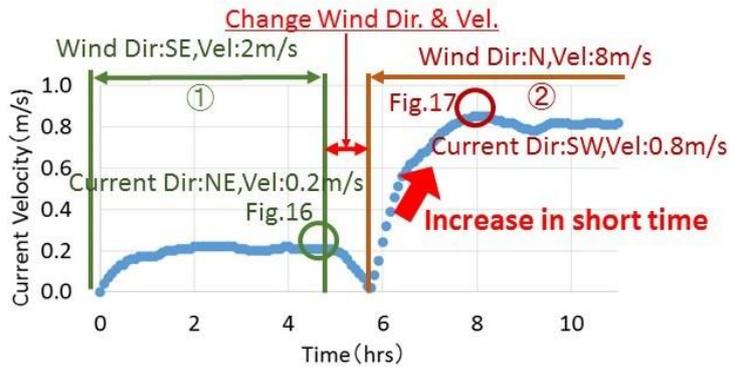


Figure 15. Simulation result of time change of current velocity due to change of wind condition (Ishikari-hama, 11th August, 2016)

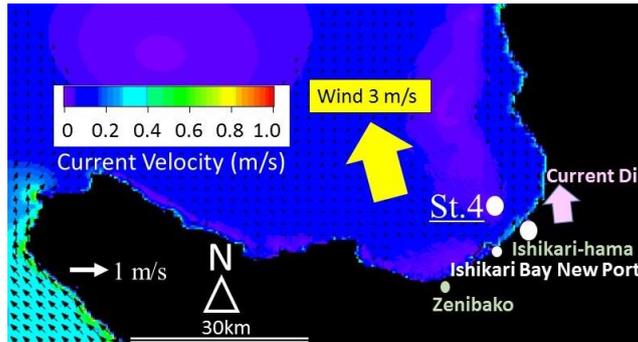


Figure 16. Profile of current velocity when wind direction was SE (5 hours after starting simulation)

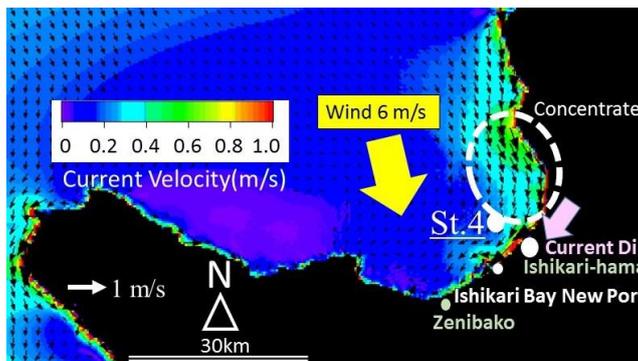


Figure 17. Profile of current velocity when wind direction was NNW (8 hours after starting simulation)

CONCLUSION

In this study, we grasp the characteristics of the topography around Ishikari coast, and grasp the location of the past accident. As the result, we confirmed that many accidents occurred near Ishikari-

hama beach and Zenibako beach. The common point of these accident, the wind direction changed largely before the accident occurred. Therefore, we considered that these accident were influenced by not only the nearshore current but also short-term fluctuations of the wind driven current. When the field survey was conducted at Ishikari-hama beach, the sea and the wind direction were constant, however, we confirmed the occurrence of the rip current at near the beach and the coastal current at the offshore area. As this result, we confirmed that the rip current occurred at Ishikari coast when the climate is stable. Therefore, the swimmer should be paid to the occurrence of water accident even if the wave condition is calm. When the wind direction and the current direction fluctuate greatly, the low pressure or the high pressure passing near Ishikari Bay, and the direction of the wind rotation is decided by the pass course. When the low pressure and the high pressure passed the north side, the wind direction fluctuated clockwise. When the low pressure and the high pressure passed the south side, the wind direction fluctuated counterclockwise. On the other hand, the current direction always fluctuated clockwise without regard for the direction of the wind rotation. Furthermore, when the current direction greatly fluctuates in several hours after fluctuating the wind direction, the current velocity increase close to 1 m/s. Finally, the numerical simulation of the wind driven current of Ishikari Bay was carried out. As the result, when the wind direction fluctuates from SE to NNW, the current condition fluctuates greatly especially at the surface layer. Furthermore, the strong SW direction current in the vicinity of Ishikari-hama beach occurs in about 2 hours after fluctuating the wind direction. Therefore, the swimmer should be take care the strong current, when the wind direction fluctuates greatly

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