Investigation of A Red Tide pattern Observed in Osaka Bay by Landsat

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(ABSTRACT)

A red tide pattern like shape of waste thread at the coastal area of Osaka Bay was observed from Landsat MSS data of Osaka district (Path:118,Row:36) taken on 17 May 1982.

The characteristics of the MSS data and the red tide pattern shape are investigated. Furthermore,we analyze the relationship between the shaping of the red tide pattern and the tidal current in Osaka Bay using the water temperature and salinity measured on 19 May 1982 and the tidal current derived by numerical simulation.

We conclude from the results of the investigation that the organisms constructing the red tide have a tendency to swarm at the convergent area of the tidal current,and the estimated tidal convergent area of Osaka Bay at that time is similar to the shape of the red tide pattern.

1 Introduction

It is considered that one of the important causes of red tide blooms in the coastal area is accumulation of the micro-organisms constructing the red tide. Ryther (Ryther,1952) suggested that the red tide consist of Gymnodiniums were often observed in the shape of patch accumulated by three different spatial scales of tidal current. The largest scale of the tidal current have the characteristic size from several kilometer to tens kilometer,and the patchs of the red tide are often observed for tens kilometer around. Therefore,to research the spatial structures of the red tide pattern is important to clarify the growth mechanisms of red tide blooms.

Although,it is difficult to get the enough information of the spatial patterns of red tide from following reasons; i) the scale of the red tide patch is too large to observe on the sea surface directly, ii)one must watch and wait all the time because one can't forcast when the red tide will occur.

The remote sensing techniques using artificial satelite is considered usefull to get the informations of red tide patterns and to clarify the growth mechanisms of red tide blooms.

In this paper,we analyze a red tide pattern in Osaka Bay using Landsat MSS data taken on 17 May 1982. Further,analysis of the relation between the shaping of the red tide pattern and the convergent area of tidal current in Osaka Bay is performed using the numerical simulations of the tidal current and the diffusion of mico-organisms.

2 Analysis of Landsat MSS data and observed data in Osaka Bay

It was reported that a red tide pattern like shape of a waste thread at the coastal area of Osaka Bay was observed from Landsat MSS data of Osaka district(Path:118,Row:36) taken at 10 A.M. on 17 May 1982 (Earth Observation Center,NASDA ,1982).

The intensities of the electromagnetic wave in the Computer Compatible Tape(CCT) of Landsat MSS data we can get are stored as contrast streched digital values which were divided into 128 ranks. The MSS bands 4 and 5 at that time were gotten as high gain data.

The original digital values of the observed radiance are obtained using the conversion equation (U.S.Geological Survey,1979 ; NASDA,1987). The average values of each band data converted to original radiances at the area where the pattern was observed and normal sea surface near patterned area are shown in figure 1.

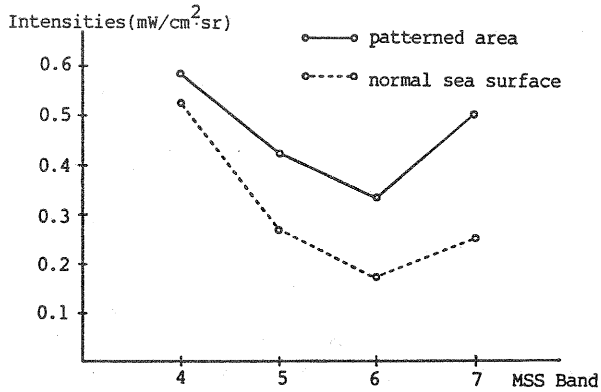

Fig.1 The intensities of Landsat MSS data of two sea areas.
The solid line indicates the intensity of the patterned area, and the doted line indicate the intensity of normal sea surface.

According to fig.1 ,average radiances of the area where the pattern was observed are larger in every bands than those of the normal sea surface. Looking into the differences of the average radiance between two areas,the differences of band 4 is relatively small and the differences of bands 5,6 and 7 are large. It was reported that the correlation coefficints between concentration of suspended sediment(SS) and Landsat MSS image densities have positive values for band 4,5 and 6 in Lake Kasumigaura (Yasuoka and Miyazaki,1985).

Therefore,the area where the pattern was observed can be considered the waste water.

The reflected intensities of the sea water including high concentrated chlorophyll are large when the wave lengths are from 0.56 to 0.60μm, and are small when the wave lengths are from 0.66 to 0.68μm(Ramsey,1968). Therefore,the biband ratio between band 4 and 5 (band4/band5) is large to the sea water whose chlorophyll concentration beeing high,theoretically. Though, the correlations between Landsat MSS data and chlorophyll-a are not always good to the actual cases because of the broadness of the widths of Landsat MSS bands (Yasuoka and Miyazaki,ibid.).

Further,in our previous examination for Osaka Bay, the correlation between the surface truth data of transparency and Landsat MSS band4/band5 had the positive value (Fujita et al.,1983).

The values of band4/band5 for patterned area and normal sea surface are 1.046 and 1.497. It is considered that the concentrations of SS in the patterned area are rather high and transparency of this area is low.

We shows the results of principal component analysis for two sea areas (patterned area and the normal sea surface) in table 1. Further, we show the visual image of first principal component in figure 2.

Tab. 1 The results of the principal component analysis.

principal component	eigen value	accumulate propotion	coefficient of Band 4	coefficient of Band 5	coefficient of Band 6	coefficient of Band 7
1	0.0373	0.960	0.233	0.461	0.447	0.730
2	0.0010	0.987	-0.098	0.670	0.384	-0.628
3	0.0003	0.994	0.968	-0.041	-0.073	-0.238
4	0.0002	1.000	0.004	-0.580	0.804	-0.128

According to the Annual Report of Osaka Prefectural Fisheries Experimental Station (Yamochi et al., 1982) , the red tide constructed by Noctilca scintillans was observed in the off coast of Kobe on May 19 in 1982,and the red tide constructed by Gymnodinium simplex,Nitzshia seriata and Prorocentrum minimum was observed at the coastal area of Osaka Bay during May 10 to May 26 in 1982 (see figure 3).

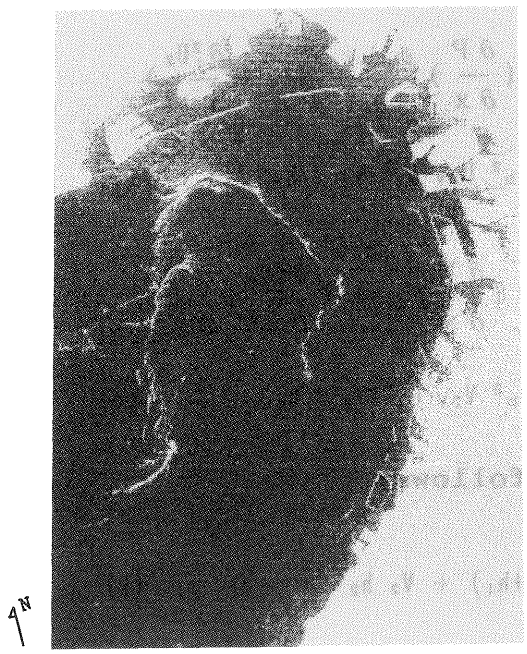

Fig.2 The visual image of the first principal component.

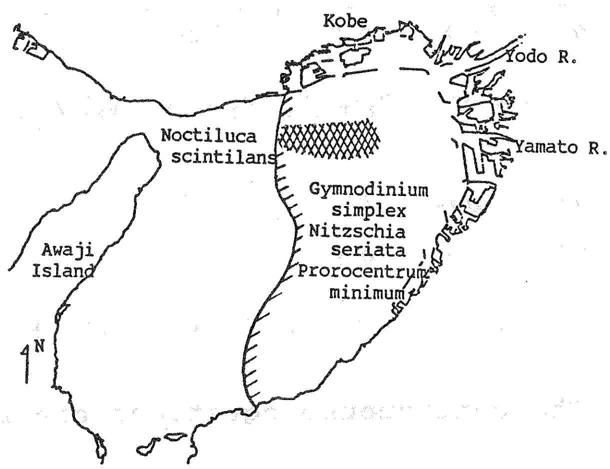

Fig.3 The red tides observed in Osaka Bay.
The populations of G.simplex,N.seriata and P.minimum are 4.7×10^3 Cells/ml, 3.1×10^3 Cells/ml and 1.0×10^3 Cells/ml.

Therefore,the pattern observed from Landsat MSS can be considered mixed area of red tide constructed by these micro-organisms and SS.

3 Numerical simulation of Osaka Bay (Simulation of tidal flow at that time)

The two-dimensional Navier-Stokes equation with latitudinal and longitudinal direction is used for the simulation of tidal current. The sea depth is divided into two layers where the waters are interchangeable. This model is called the two-level model(Rand Corporation,1973). The model was applied to simulate the tidal current of Osaka Bay, and relatively accurate

results was obtained for general condisions (Oonishi, 1979).
The equations of motion are as follows;

upper layer,

$$\frac{\partial U_1}{\partial t}+U_1\frac{\partial U_1}{\partial x}+V_1\frac{\partial U_1}{\partial y}+W\frac{U_1-U_2}{2(\zeta+h_1)}=f\ V_1-\frac{1}{\rho_1}\left(\frac{\partial P}{\partial x}\right)_1+A_h\left(\frac{\partial^2 U_1}{\partial x^2}+\frac{\partial^2 U_1}{\partial y^2}\right)$$

$$-\gamma_i{}^2(U_1-U_2)\sqrt{(U_1-U_2)^2+(V_1-V_2)^2}/(\zeta+h_1)\quad, \tag{1}$$

$$\frac{\partial V_1}{\partial t}+U_1\frac{\partial V_1}{\partial x}+V_1\frac{\partial V_1}{\partial y}+W\frac{V_1-V_2}{2(\zeta+h_1)}=-f\ U_1-\frac{1}{\rho_1}\left(\frac{\partial P}{\partial x}\right)_1+A_h\left(\frac{\partial^2 V_1}{\partial x^2}+\frac{\partial^2 V_1}{\partial y^2}\right)$$

$$-\gamma_i{}^2(V_1-V_2)\sqrt{(U_1-U_2)^2+(V_1-V_2)^2}/(\zeta+h_1)\quad, \tag{2}$$

lower layer,

$$\frac{\partial U_2}{\partial t}+U_2\frac{\partial U_2}{\partial x}+V_2\frac{\partial U_2}{\partial y}+W\frac{U_1-U_2}{2\ h_2}=f\ V_2-\frac{1}{\rho_2}\left(\frac{\partial P}{\partial x}\right)_2+A_h\left(\frac{\partial^2 U_2}{\partial x^2}+\frac{\partial^2 U_2}{\partial y^2}\right)$$

$$+\gamma_i{}^2(U_1-U_2)\sqrt{(U_1-U_2)^2+(V_1-V_2)^2}/\ h_2-\gamma_b{}^2\ U_2\sqrt{U_2{}^2+V_2{}^2}/\ h_2, \tag{3}$$

$$\frac{\partial V_2}{\partial t}+U_2\frac{\partial V_2}{\partial x}+V_2\frac{\partial V_2}{\partial y}+W\frac{V_1-V_2}{2\ h_2}=-f\ U_2-\frac{1}{\rho_2}\left(\frac{\partial P}{\partial x}\right)_2+A_h\left(\frac{\partial^2 V_2}{\partial x^2}+\frac{\partial^2 V_2}{\partial y^2}\right)$$

$$+\gamma_i{}^2(V_1-V_2)\sqrt{(U_1-U_2)^2+(V_1-V_2)^2}/\ h_2-\gamma_b{}^2\ V_2\sqrt{U_2{}^2+V_2{}^2}/\ h_2, \tag{4}$$

The continuouse equations are as follows;

$$\frac{\partial\zeta}{\partial t}+\frac{\partial}{\partial x}\left[\ U_1(\zeta+h_1)+U_2\ h_2\ \right]+\frac{\partial}{\partial y}\left[\ V_1(\zeta+h_1)+V_2\ h_2\ \right]=0\quad, \tag{5}$$

$$\frac{\partial(U_2\ h_2)}{\partial x}+\frac{\partial(V_2\ h_2)}{\partial y}+W=0\quad, \tag{6}$$

Where, ζ is water elevation, U_i and V_i are the velocities of the tidal current in the direction x and y of the i-th layer, w is the vertical velocity, A_h is the horizontal eddy viscosity, f is the coriolis parameter, γ_i and γ_b are the coefficients of internal and bottom friction, P is the pressure, h_i is the thickness of the i -th layer, ρ_i is the density of the i-th layer.

The density distribution of the sea water are estimated from the salinities and water temperatures measured at the twenty monitoring points on 19 May 1982 (Abe et al.,1982). The density distribution and the depth of Osaka Bay are shown in figures 4 and 5.

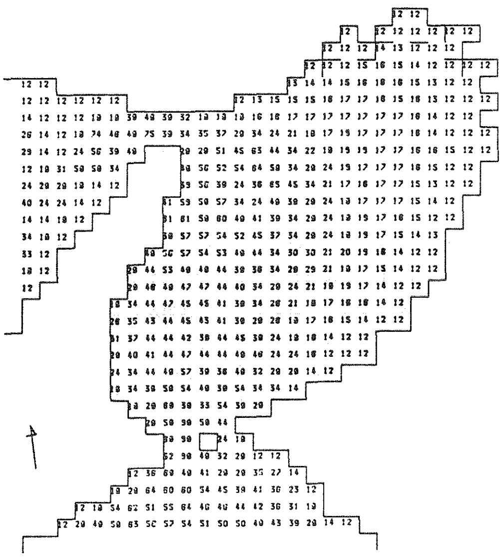

Fig.4 The depth of Osaka Bay.

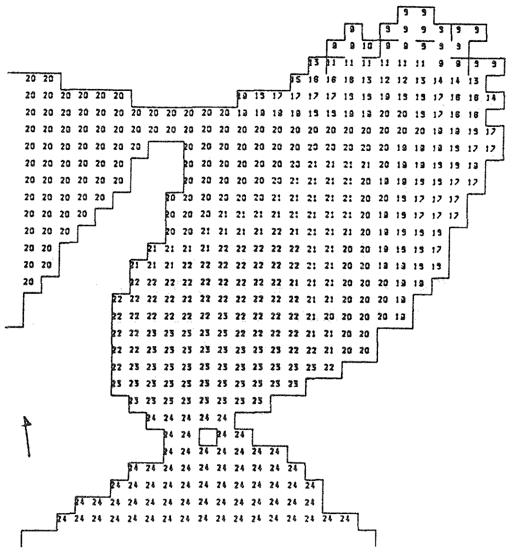

Fig.5 The distribution of σ_t Osaka Bay.
The relation between density and is $\rho = 1 + 10^{-3} \cdot \sigma_t$.

The water inflows from Yodo River and Yamato River whose inflows are about 60 percent of the total inflows to Osaka Bay are adopted the daily average inflows measured by Ministry of Construction on 17 May 1982,and the other inflows are estimated from year average inflow in 1982. The inflows from Yodo River and Yamato River are 247.85㎥/sec and 9.13㎥/sec,respectively.

The equations are approximated by finite-difference methods using the grid size $4Km^2$ and a time interval of 30 sec. The boundary condisions and the other parameters are adopted the values which were used in the simulation of Osaka Bay(Oonishi, 1979).

The horizontal residual current of upper layer and vertical residual flow at 8-th tidal period are shown in figures 6 and 7.

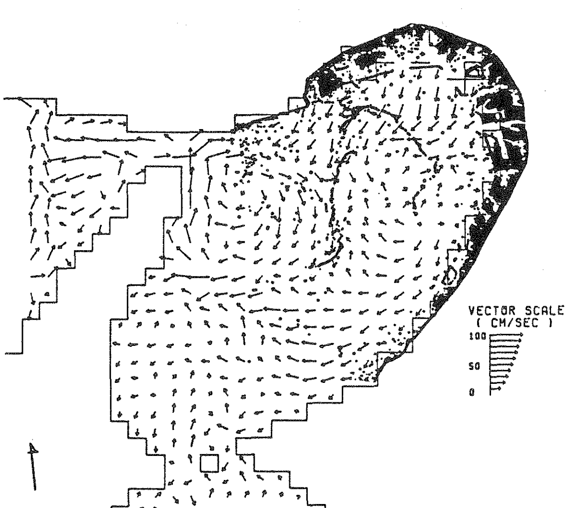

Fig.6 The calculated residual current of the upper layer.
The image map of the Landsat MSS data is overlapped.

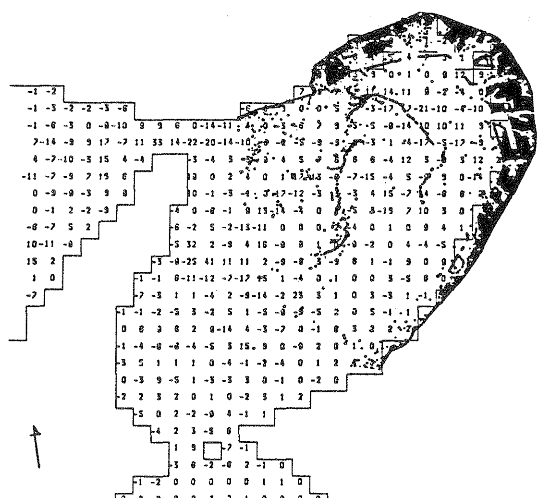

Fig.7 The calculated residual vertical flow.
The unit of the velocity is 0.1cm/sec.

It can be appreciate that the convergent areas of tidal current is almost similar to the shape of the red tide pattern. The convergent area means the area where the tidal currents run againt and go downward.

4 Numerical Simulation of Osaka Bay(Simulation of diffusion of the micro-organisms)

To clarify the accumulation mechanisms of the micro-organisms,a simulation of the immigration and diffusion of micro-organisms is performed. The diffusion and immigration equation is usually adopted to study the behaviours of the micro-organisms (Fujita and Watanabe,1986;Harashima et al. ,1988). In the governning equations,the sea depth is divided into four layers.

first layer,

$$\frac{\partial c_1}{\partial t} = -U_1\frac{\partial c_1}{\partial x} - V_1\frac{\partial c_1}{\partial y} - K_v\frac{c_1 - c_2}{h_1} + K_h\left(\frac{\partial^2 c_1}{\partial x^2} + \frac{\partial^2 c_1}{\partial y^2}\right) + w_1\frac{c_{1w}}{h_1} + U\frac{c_{1w}}{h_1}, \qquad (7)$$

second layer,

$$\frac{\partial c_2}{\partial t} = -U_2\frac{\partial c_2}{\partial x} - V_2\frac{\partial c_2}{\partial y} + K_v\frac{c_1 - c_2}{h_2} + K_v\frac{c_2 - c_3}{h_2} - K_h\left(\frac{\partial^2 c_2}{\partial x^2} + \frac{\partial^2 c_2}{\partial y^2}\right) - w_1\frac{c_{1w}}{h_2} + w_2\frac{c_{2w}}{h_2} + U\frac{c_{2w}}{h_2}, \qquad (8)$$

third layer,

$$\frac{\partial c_3}{\partial t} = -U_3\frac{\partial c_3}{\partial x} - V_3\frac{\partial c_3}{\partial y} + K_v\frac{c_2 - c_3}{h_2} - K_v\frac{c_3 - c_4}{h_2} + K_h\left(\frac{\partial^2 c_3}{\partial x^2} + \frac{\partial^2 c_3}{\partial y^2}\right) - w_2\frac{c_{2w}}{h_3} + w_3\frac{c_{3w}}{h_3} + U\frac{c_{3w}}{h_3}, \qquad (9)$$

4-th layer,

$$\frac{\partial c_4}{\partial t} = -U_4\frac{\partial c_4}{\partial x} - V_4\frac{\partial c_4}{\partial y} + K_v\frac{c_3 - c_4}{h_2} + K_h\left(\frac{\partial^2 c_4}{\partial x^2} + \frac{\partial^2 c_4}{\partial y^2}\right) - w_3\frac{c_{3w}}{h_4} + U\frac{c_{4w}}{h_4}, \qquad (10)$$

boundary condisions,

$$\frac{\partial c_i}{\partial n} = 0 \quad \text{at the rigid boundaries,} \qquad (11)$$

$$\frac{\partial c_i}{\partial n} = 0 \quad \text{at the open boundaries ,} \qquad (12)$$

$$c_{iw} = 0 \quad \text{at every boundaries} \quad , \qquad (13)$$

Further,we add the following condision for the convenience of the calculation.

$$\Sigma \int c_i h_i \, dV = const \quad \text{for every time}, \qquad (14)$$

where, c_i is the concentration of the micro-organisms of i-th layer, c_{iw} is the concentration between i-th and i+1-th layers, K_h is the horizontal eddy diffusivity, K_v is exchange rate of the density between the lower and upper layers, w_i is the vertical velocity between i-th and i+1-th layers,and U is the vertical immigration velocity of the micro-organisms. The thicknesses of the first,second and third layers are setted 4m. Therefore,the thicknesses of the 4-th layer are the values subtracting 12m from the depth of the sea.

The vertical immigration velocity of the micro-organism is estimated from the experimental results for Gymnodiniums (Forward,1974;Watanabe and Harashima,1982),because the preference species of this red tide are Gymnodiniums. The vertical velocity of the micro-organisms is setted 1m/hour.

The other parameters are adopted the values to calculate the diffusion of COD (Fujita and Koi,1984).

The tidal velocities of fist and second layers are used the calculated tidal current in upper layer derived from tidal simulation descrived in previous section, and tidal velocities of third and 4-th layer are used these of lower layer. The vertical velocities are estimated from calculated tidal currents to satisfy the continuouse condisions.

The average concentration of micro-organisms between first and second layers at 10 A.M. at the 20-th tidal period is shown in figure 8.

The concentration of mocro-organisms can be considered almost similar to the red tide pattern at the coastal area in Osaka Bay.

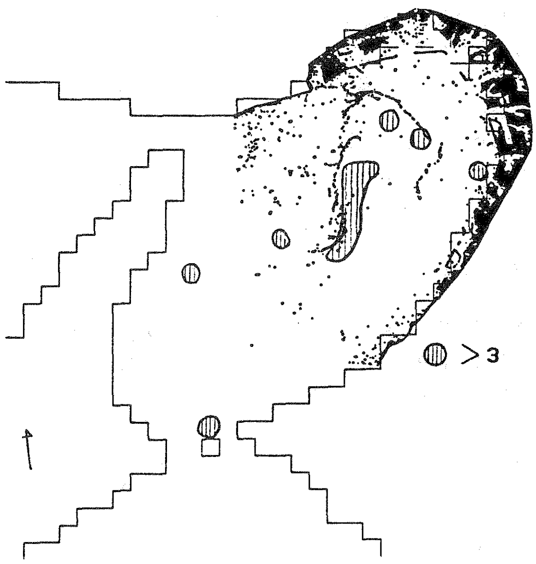

Fig.8 The average concentration of micro-organisms between first and second layers.

Accordingly,the motile micro-organisms constructiong the red tide have a tendency to swarm at the convergent area of tidal current.

5 Conclusion

In this calculation,we simulate the vertical immigration and diffusion of the micro-organisms only. Though,the small chips of woods or dust whose specific gravity beeing smaller than water's have vertical velocities caused by bouyancy. The vertical velocities of small chips of woods lager than about 0.07mm are so larger than those of Gymnodiniums that those suspendded matters act the same manner as motile micro-organisms. In fact,in the convergent area of inner sea,suspended matters are often observed joined with the red tide.

It is considered that this is the reason why the values of band4/band5 for normal sea surface beeing larger than those of patterned area.

In the results of the calculation,the high concetration of micro-organisms are appeared at the coastal area in Osaka Bay,however, these area didn't appear the off coast of Kobe.

The reasons why the high concentrated area aren't observed at the off coast of Kobe in our simulations are considered that the effects of wind are not included in our tidal simulation or the micro-organisms constructing the red tide at the off coast of Kobe are converged by another mechanisms.

Further,high concentrated areas are appeared at the sea near Awaji Island. The reason why the high concentrations beeing appeared at those areas while no appearance of red tide reported at those areas is as fllows; the growth of the red tide blooms depend strogly on the distribution of nutrient,however we did not consider the effects of growth of the micro-organisms. Our primary aim in this article is to study the convergent mechanisms of micro-organisms by the tidal current using Landsat MSS data. A investigation of the vortex of Osaka Bay was attempted using Landsa MSS data (Nishimura et al.,1983).

In this article, we analyze a red tide pattern in Osaka Bay using Landsat MSS data taken on 17 may 1982, and show a useful -ness of the remote sensing techniques using satelite to the study of convergent mechanisms of red tide blooms.

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