A Numerical Simulation on Red Tide Formation

Tetsuo YANAGI*

1. Introduction

Gymnodinium mikimotoi is one of several species of flagellates that cause harmful red tides. The red tides of *G. mikimotoi* have occurred only along 33-35° N, e.g. Chinhae Bay in Korea, the Seto Inland Sea and Kumano-Nada in Japan.

I try to reproduce the formation of red tides of *G. mikimotoi* at Suo-Nada and Iyo-Nada, the western part of Seto Inland Sea, Japan in July 1985 with the use of four-dimensional assimilation model including the biological process of *G. mikimotoi* in this paper.

2. Numerical model

The horizontal mesh size of numerical model is 2 km x 2 km and it is vertically divided into three layers of 0 - 10 m, 10 - 30 m and 30 m - bottom as shown in Fig.1. This model can reproduce tide and tidal current in this region (Yanagi and Igawa, 1992). The temporal variations in water temperature, salinity, residual flow and nutrients in this region are calculated by the procedures shown in Fig.2. The residual flow on 1 July 1985 is estimated diagnostically with the use of observed water temperature, salinity and wind data and those from 2 July till 17 July are calculated prognostically day by day by the assimilation method (Yanagi and Yamamoto, 1993). The temporal variation in the distribution of nutrients is estimated by the objective and linear interpolations with the use of observed data.

* Department of Civil and Ocean Engineering, Ehime University
Matsuyama 790, Japan

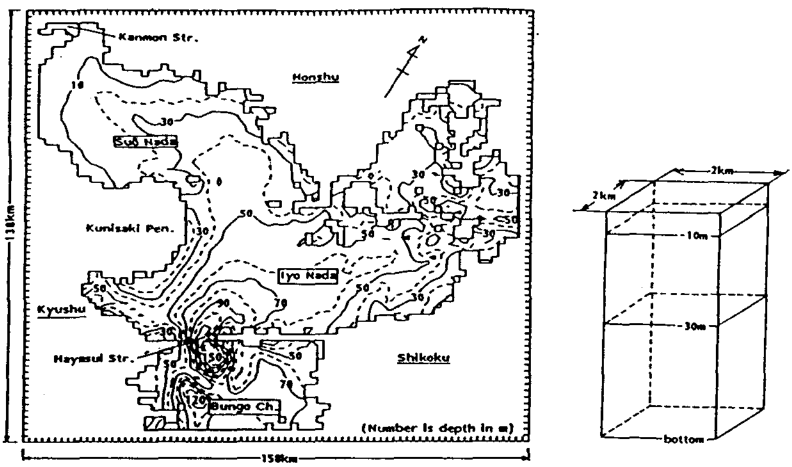

Kanmon Str.
Honshu
Suo Nada
Kunisaki Pen.
Iyo Nada
Kyushu
Hayasui Str.
Shikoku
Bungo Ch.
(Number is depth in m)
130km
150km
2km
2km
10m
30m
bottom

Fig.1

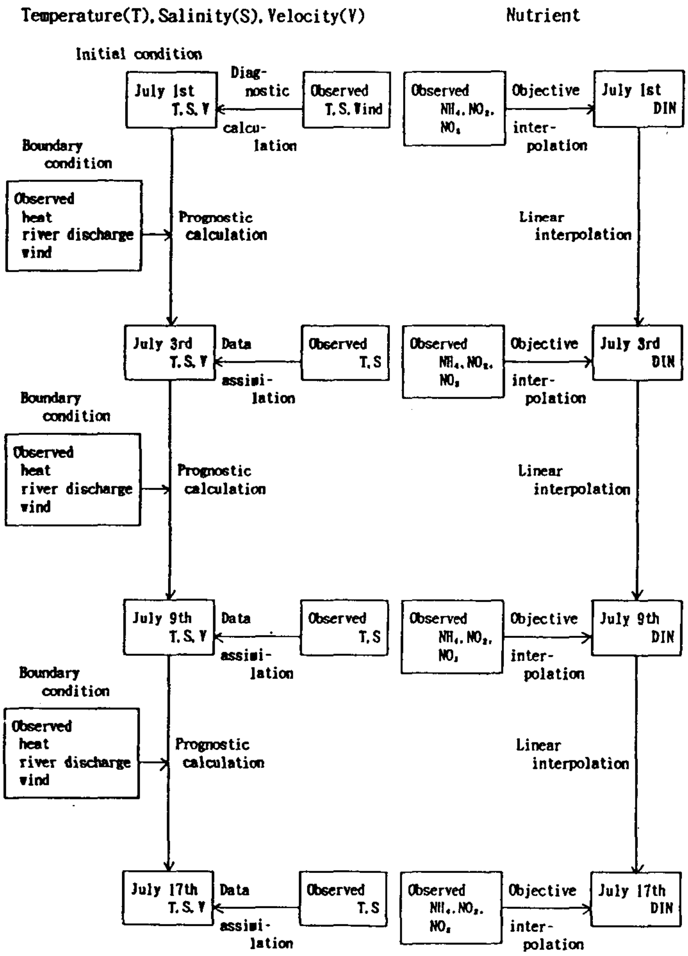

Temperature(T), Salinity(S), Velocity(V)
Nutrient
Initial condition
July 1st T.S.V
Diag-nostic calcu-lation
Observed T.S.Wind
Observed NH4, NO2, NO3
Objective inter-polation
July 1st DIN
Boundary condition
Observed heat river discharge wind
Prognostic calculation
Linear interpolation
July 3rd T.S.V
Data assimi-lation
Observed T.S
Observed NH4, NO2, NO3
Objective inter-polation
July 3rd DIN
July 9th T.S.V
July 9th DIN
July 17th T.S.V
July 17th DIN

Fig.2

The calculated water temperature, salinity, residual flow and DIN in the upper and middle layers on 9 July are shown in Fig.3

The biological process of *G.Mikimotoi* is formulated on the basis of laboratory experiments (T.Ishimaru, 1993, personal communication). The diel vertical migration of *G. mikimotoi* (daytime: upper layer, night: middle layer) is considered and the non-dimensional nitrogen content q (t) in the cell of *G.Mikimotoi* is changed by the following Michaelis-Menten equation.

daytime (6h.-18h.)

$$\frac{d\,q(t)}{d\,t} = V_{mdNH4}\frac{N_{NH4}(t)}{K_{sdNH4}+N_{NH4}(t)} + V_{mdNO3}\frac{N_{NO3}(t)}{K_{sdNO3}+N_{NO3}(t)}$$

night (18h.-6h.)

$$\frac{d\,q(t)}{d\,t} = V_{mnNH4}\frac{N_{NH4}(t)}{K_{snNH4}+N_{NH4}(t)}$$

V_{mdNH4} ; maximum intake rate of ammonium at daytime (0.014/hour)

V_{mnNH4} ; maximum intake rate of ammonium at night (0.0076/hour)

V_{mdNO3} ; maximum intake rate of nitrate at daytime (0.016/hour)

N_{NH4} ; concentration of ammonium (μM)

N_{NO3} ; concentration of nitrate (μM)

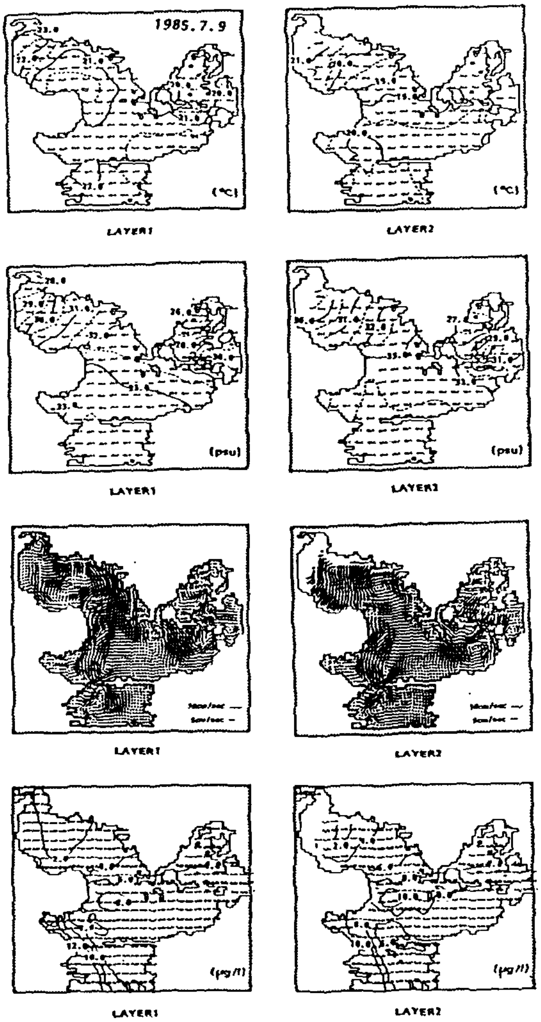
K_{sdNH4} ; half-saturation constant of ammonium at daytime (0.58 μM)

K_{snNH4} ; half-saturation constant of ammonium at night (0.60 μM)

K_{sdNO3} ; half-saturation constant of nitrate at daytime (0.47 μM)

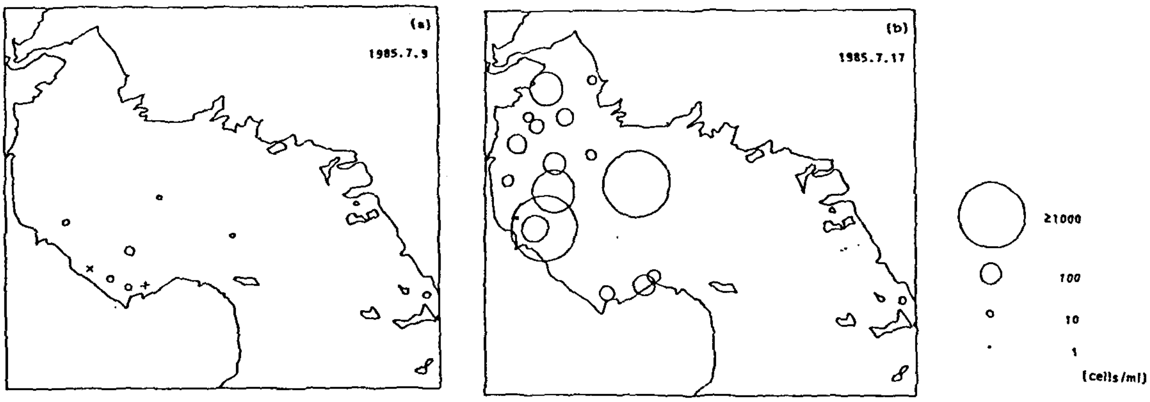
If q (t) exceeds 2.0 at mid-night, the cell is divided into two cells and q (t) becomes 1.0. If it is less than 2.0 at mid-night, q (t) continues to increase till next mid-night.

The growth rate of *G. mikimotoi* μ is obtained by the Droop's equation with the use of nitrogen content in the cell q^* (t) { = 1 mole x q (t) /cell }, minimum cell quota of *G. mikimotoi* q_0 (= 1.25 x 10^{-5} mole/cell) and maximum growth rate of *G. mikimotoi* μ_m (= 0.033/hour).



1985.7.9
(°C)
LAYER1
LAYER2
(psu)
(μg/l)

Fig.3



(a)
1985.7.9
(b)
1985.7.17
≥1000
100
10
1
(cells/ml)

Fig.4

$$\mu = \mu_m \left(1 - \frac{q_0}{q^*} \right)$$

The nitrogen concentration of *G. mikimotoi* G (t) is obtained by the following formula,

$$\frac{dG(t)}{dt} = \mu G(t) - \delta G(t)$$

where δ is the rate of death or predation of *G. mikimotoi*. The nitrogen concentration G (t) is converted to the cell density of *G. mikimotoi* C (t) by the following formula,

$$C(t) = \frac{G(t)}{q^*(t)}$$

As for the water temperature, salinity and light intensity, we can neglect here because their observed data in this region at this time do not affect largely the growth rate (Yamguchi and Honjyo, 1989).

3. Results

The observed cell density of *G. mikimotoi* on 9 and 17 July 1985 are shown in Fig.4. The red tides are formed at the central and southern parts of Suo-Nada on 17 July because the cell density exceeds 10^3 cell/ml there. The calculated distribution of cell density on 10 and 17 July with the initial condition of the observed distribution on 9 July are shown in Fig.5. The red tides are also formed at the central and southern parts of Suo-Nada on 17 July in the numerical model. The result in the case where we ignore night intake of ammonium (a), vertical migration (b) and the tidal current and residual flow (c) are shown in Fig.6. The red tides are not formed at the central part of Suo-Nada in (a) and (c) and these results suggest that night intake of nutrient and current play very important role on the formation of red tides in the field.

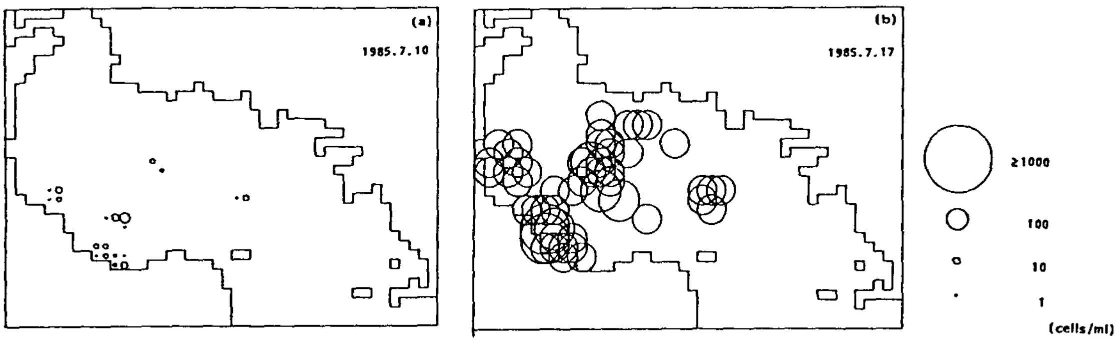


Fig.5

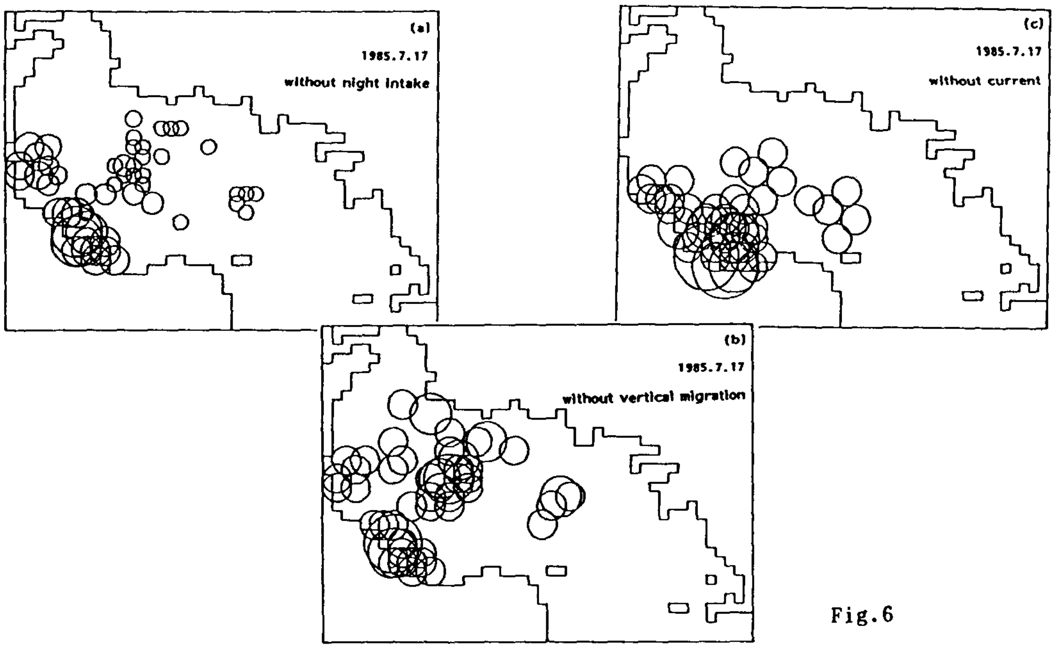


Fig.6

References

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Yanagi,T. and S.Igawa (1992) A diagnostic model in the coastal sea - application to Suo-Nada and Iyo-Nada. Bulletin on Coastal Oceanography, 30, 108-115.

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