Numerical Evaluation of Density-Current Generator to Oxygen-Deficient Water in Ariake Sea

Introduction

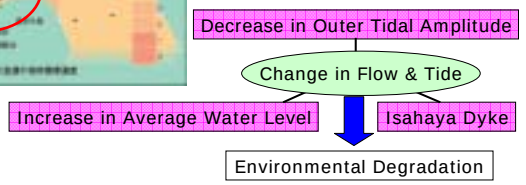
Ariake Sea

from Google Map

+ Has the largest tidal (wet) land in Japan.
+ Has very large tidal deference (5m).
+ Used to have a plenty of fishery production.

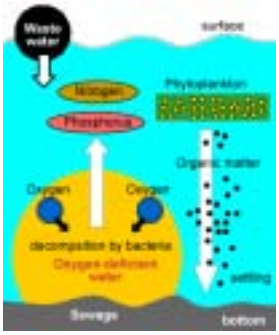
Isahaya Bay

+ Red tide
  → Damage of sea weed
+ Oxygen-deficient water
  → Damage of shell fish



Oxygen-deficient water

+ Dissolved oxygen concentration < 3.0mg/L



Occurrence of oxygen-deficient water

DO distribution at the bottom of Ariake Sea
(by Tsutsumi et al. 2003)

Objectives

- Numerical simulation of the emergence of oxygen-deficient water by physical ocean model + ecosystem model.
- Numerical prediction of the effect of water-quality enhancer.

MEC Ocean Model

Governing Equations ··· 2.5D NS & Continuity Eqs. with Boussinesq & Hydrostatic Approx.

Physical Model

$$\frac{\partial u}{\partial t} = -u\frac{\partial u}{\partial x} - v\frac{\partial u}{\partial y} - w\frac{\partial u}{\partial z} + fv - \frac{1}{\rho_0}\frac{\partial p}{\partial x} + A_M\left(\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2}\right) + \frac{\partial}{\partial z}\left(K_M\frac{\partial u}{\partial z}\right)$$

$$\frac{\partial v}{\partial t} = -u\frac{\partial v}{\partial x} - v\frac{\partial v}{\partial y} - w\frac{\partial v}{\partial z} - fu - \frac{1}{\rho_0}\frac{\partial p}{\partial y} + A_M\left(\frac{\partial^2 v}{\partial x^2} + \frac{\partial^2 v}{\partial y^2}\right) + \frac{\partial}{\partial z}\left(K_M\frac{\partial v}{\partial z}\right)$$

$$0 = -\frac{1}{\rho}\frac{\partial p}{\partial z} - g \qquad \frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} = 0$$

MEC Ocean Model

- Coordinates ··· Z-Coordinates
- Grid (Layered Model)
  - Horizontal⇒Variable-sized rectangular
  - Vertical⇒Step-like variable-sized rectangular
- Differencing in space
  - Convection⇒3rd-order Upwinding
  - Diffusion⇒2nd-order Central
- Eddy kinetic viscosity
  - Horizontal⇒Richardson 4/3 Power-Law
  - Vertical⇒Stratification Function

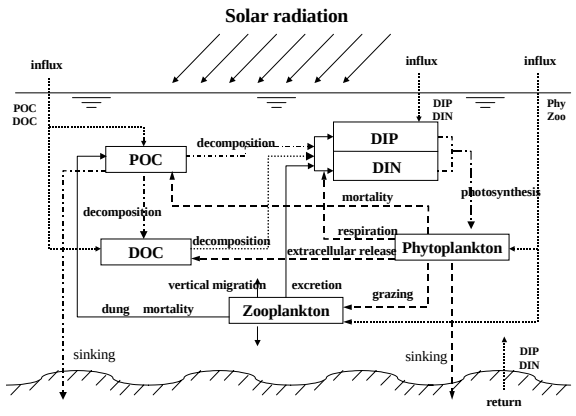
Ecosystem Model

Ecosystem Model

$$\frac{dC}{dt} = \frac{\partial C}{\partial t} + u\frac{\partial C}{\partial x} + v\frac{\partial C}{\partial y} + w\frac{\partial C}{\partial z} - K_B\left(\frac{\partial^2 C}{\partial x^2} + \frac{\partial^2 C}{\partial y^2}\right) - \frac{\partial}{\partial z}\left(K_B\frac{\partial C}{\partial z}\right) = \left(\frac{dC}{dt}\right)^*$$

Compartments (C)

- phytoplankton (PHY)
- zooplankton (ZOO)
- particulate organic matter (POC)
- dissolved inorganic carbon (DIC)
- dissolved inorganic nitrogen (DIN)
- dissolved inorganic phosphorus (DIP)
- dissolved oxygen (DO)



DO mg/l

$$\frac{dDO}{dt} = [TOD:C_P]\cdot(B_1 - B_3) - [TOD:C_Z]\cdot B_9 - [TOD:C_{POM}]\cdot B_{12} - [TOD:C_{DOM}]B_{15} - D_6 + D_7$$

- B_1 : supply by photosynthesis
- B_3 : consumption by respiration of phytoplankton
- B_9 : consumption by respiration of zooplankton
- B_{12} : consumption by making POC inorganic
- B_{15} : consumption by making DOC inorganic
- D_6 : consumption by bottom mud
- D_7 : aeration

Process	Value		
Phytoplankton		Particulate Organic Matter	
Growth Rate	α_1=0.9 β_1=0.063	Decomposition Rate	α_6=0.2 β_6=0.0693
Respiration Rate	α_2=0.03 β_2=0.0519	Sinking Velocity	0.432 m/day
Optimum Light Intensity	200 ly/day	Araction Transfer	ζ =0.25
Extinction Coefficient	k_2=0.1 γ_2=0.0179	$[C_{POM}:P]$	172
$(=k_0+\gamma[Chl\text{-}a{:}C_P]\cdot P)$		$[C_{POM}:N]$	8.4
Day Length)	0.587	Dissolved Organic Matter	
Mortality Rate	α_3=0.05 β_3=0.0693	Decomposition Rate	α_7=0.045 β_7=0.0693
Sinking Velocity	0.173 m/day	$[C_{DOM}:P]$	337
$[C_P:P]$	117	$[C_{DOM}:N]$	11.2
$[C_P:N]$	7.1	Others	
$[TOD:C_P]$	0.00347	Half Saturation Constant	DO_1= DO_2=1 mg/l
$[C_P:Chl\text{-}a]$	50	Reaeration Coefficient	k_a=0.15
Half Saturation Coefficient	K_N :3.0(μg･at/l)	Dissolution rate	Phosphorus ; 2.45
Half Saturation Coefficient	K_P :0.1(μg･at/l)		Ammonium ; 24.5
Extracellular Release	13.50%		mg/m^2･day
Zooplankton		Oxygen Consumption	1500 mgO_2/m^2･day
Grazing Rate	α_4=0.28 β_4=0.0693	In Mud	
Ivlev Coefficient	0.082	$[TOD:C_Z]$	0.000347
Mortality Rate	α_5=0.04725 β_5=0.0693	$[TOD:C_{POM}]$	0.000347
Threshold Concentration	50 mgC/m^3	$[TOD:C_{DOM}]$	0.000347
Assimilation Efficiency	0.7		
Total Growth Efficiency	0.3		
$[C_P:P]$	124		
$[C_P:N]$	6.34		

parameters (Nakata, 1993)

Grid System

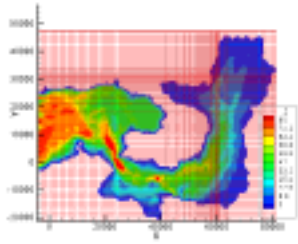
Emergence of oxygen-deficient water

- Domain size: 85km×70km
- Grid number: 100×80×20

JODC Data Base (500m Mesh)

dz(m)×Grid number

4×1
1×6
2×4
3×2
4×2
5×2
10×3

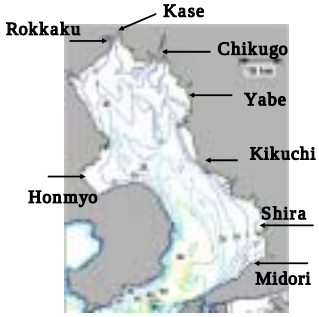


Grid system

Simulation Conditions

Domain Size	85km×70km
Grid Number	100×80×20
Time Step	6.0sec
Time Span	8months
Tidal Condition	Neap tide
Tidal Amplitude at Boundary	0.27m
River	First class 8 rivers

At Open Boundary,
Temperature : 15.5℃～25℃
Salinity : 33.6psu～34.55psu



1st-class Rivers

Simulation Conditions

Averaged in Summer in 2001
Always neap tide

Condition of weather

Albedo	0.06
Sea Surface Emissivity	0.97
Cloud Effect Coefficient	0.65
Maximum Global Solar Radiation	900 (W/m^2)
Cloud Index	6.37
Precipitation	0.6(mm/h
Vapour Pressure	27.9
Wind Amplitude	3.7(m/sec
Atmosphere Temperature	29(deg)

Inflow from River in July 2001

Honmyo	8.97	Yabe	151.29
Rokkaku	45.59	Kikuchi	127.13
Kase	55.40	Shira	39.53
Chikugo	396.89	Midori	120.94

(m^3/sec)

Inflow of compartments from River

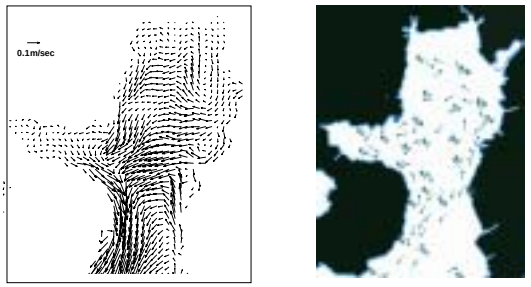
Phytoplankton	0 mgC/m^3
Zooplankton	0 mgC/m^3
POC	1000 mgC/m^3
DOC	2000 mgC/m^3
DIP	6 m mol/m^3
DIN	100 m mol/m^3
DO	8 mg/l

Simulation Results

Tidal Ellipse：measurement data (Japan Coast Guard, 2001)

Simulation Results

Residual Current at Surface

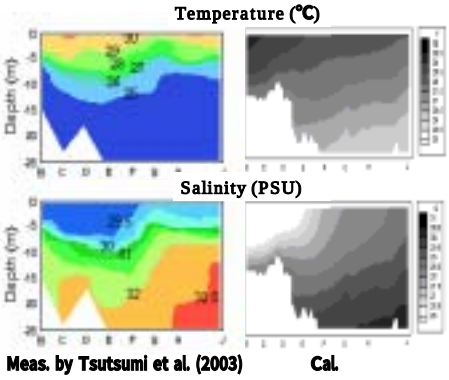


cal.

meas. (Jpn Coast Guard, 1974)

Simulation Results

Stratification



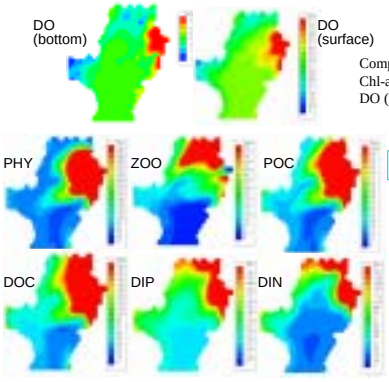
Meas. by Tsutsumi et al. (2003)

Measurement Points

Cal.

Simulation Results

Oxygen-deficient water



Compartment	Cal.	Meas.
Chl-a (μ g/L)	4.4	4.1～5.5
DO (mg/L)	3～5	3～5

PHY limited by nutrients

Rate control index of nutrients

	DIP	DIN
near Dyke	0.89	0.80
Chikugo Estuary	1.0	1.0

Effect of water-quality enhancer

Density-Current Generator

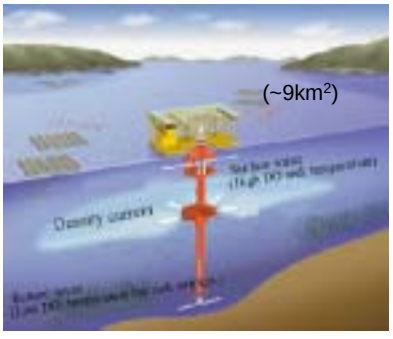


Image of DCG setting

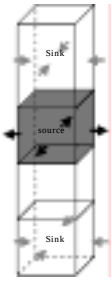
+ Mixing surface and bottom waters
+ Discharging it at the middle layer

+ Well achievement in Gokasho Bay since 1997
 - no red tide
 - no oxygen-def water
 - reproduction of marine forests

Simulation Conditions

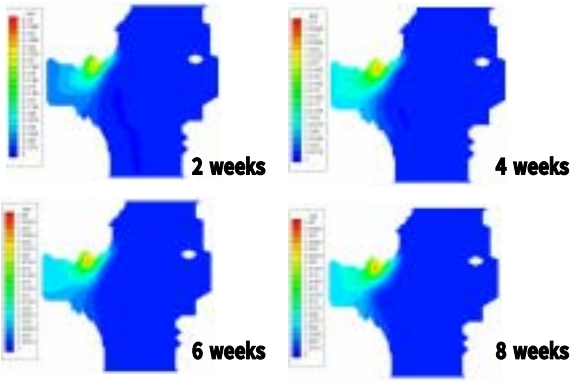
Flow rate

1 Mt/day
3 Mt/day
5 Mt/day
10 Mt/day



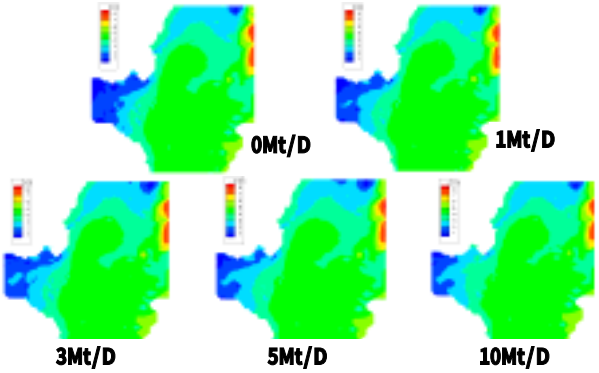
Simulation Results

Dye Distribution



Simulation Results

Oxygen-deficient water (2 months later)



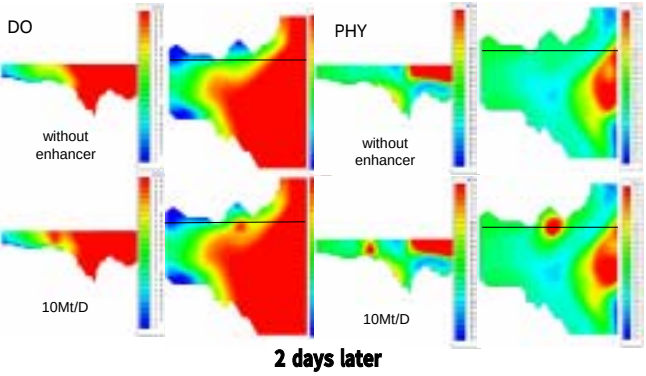
Simulation Results

Oxygen-deficient water

Area Decrease at which DO<2mg/L

	1Mt/D	3Mt/D	5Mt/D	10Mt/D
4 weeks	1.47%	32.9%	16.7%	43.7%
8 weeks	16.3%	18.4%	34.4%	51.9%

Simulation Results



Simulation Results