Modeling of The Climate and Anthropogenic Influences to The Eutro-dynamics in Dapen Bay, Taiwan

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***Abstract*-A three-dimensional numerical model has been constructed for simulating the hydrodynamics and the bio-geochemical responses in coastal lagoons. The model has been applied to study the eutro-dynamics in Dapeng Bay, southwest of Taiwan. Dapeng Bay is the largest single entry lagoon in Taiwan with a area more than 530 ha. The hydrodynamics in the lagoon is dominated mainly by tidal variations from the coastal seas through a tidal inlet during the dry season. Fresh water discharged into the lagoon is concentrated at the rainy season that comes with the southwest monsoon during summer. Constant freshwater sources are untreated domestic sewerages and aquaculture drainages surrounding the lagoon throughout the year. Vertical structure of the hydrodynamics are considered in order to take density effect into account, thus salinity and temperature has to be calculated for computing currents.**

The lagoon was an important fishery ground where various aquaculture activities had been settled, mainly oyster farming and cage net farming. An eutro-dynamic model has been constructed and coupled with the hydrodynamics for studying the water quality and the eutrofication conditions in the lagoon. Eight state variables have been included in the bio-geochemistry model, i.e. micro-plankton, detritus, dissolved nutrients and dissolved oxygen. The plankton growth is controlled by water temperature, light intensity and the nutrient supplies. The basic assumption for nutrient supply was that Silicate and phosphate are fully available in the lagoon. Therefore, the model only simulates the nitrogen cycle of the lagoon.

Tides predicted by a regional model are used for specifying the level at the mouth of the lagoon. Various boundary conditions are obtained from measurements. The responses of the eutro-dynamics to weather and anthropogenic influences are discussed in this paper.

I. INTRODUCTION

Coastal lagoons are interfaces between land and sea. The influences from sea and stream are both co-exist and often happened in the same time. Tide from sea causing tidal flushing and the fresh water from streams having impacts to the salinity variations of lagoon water. The confrontations from both ends of the forcing are important mechanisms and sources to maintain lagoon a highly productive ecosystem. Rich nutrients and organic sources received from the streams forming massive production of phytoplankton and macro-algae providing primary food source and the relatively calm water environments make coastal lagoon a perfect habitat and nursery ground. Bio-geochemical processes are complex in lagoon. Previous researches on this issue are mainly focus at in-situ survey and estimate the flux budgets using box model (Hung et al, 2003). Fine grid, high resolution multi-dimensional numerical models for studying the dynamics of bio-geochemical processes are quickly developed due to recent advancement of the computation technologies.

Dapeng-Bay is a semi-enclosed tropical lagoon, which has only one tidal inlet for exchanging lagoon water with the coastal currents along the Kaoping coast at southwest Taiwan. The lagoon is situated in a tropical climate zone where has sunshine through out the year except the rainy days. Rainfall is dominated by the southwest monsoon concentrated mainly in the summer season. The discharges from several drainage channels surround the lagoon collecting untreated domestic sewage and the wastewater discharged from fish farms usually low during the dry season. Solids in the water are mostly settled on channel beds. Sediments are flushed into the lagoon during the raining season by high storm discharges. These sediments contain high concentrations of organic solids and nutrients, which cause the bay water highly eutrophied after storms in summer.

A 3D numerical model has been constructed for studying the hydrodynamics and nutrient dynamics of the Dapeng Bay. The COHERENS model has been applied. Simulations were carried out to study the seasonal circulation patterns and nutrient variabilities in the lagoon affected by fresh water discharges and sewerage disposal.

II. GENERAL DESCRIPTION OF COHERENS MODEL

A consortium of European research institutes supported by EU/MAST program developed COHERENS (A coupled hydrodynamic-ecological model for regional and shelf seas) (Luyten et al, 1999). The aim was to study the detail interactions between the hydrodynamics and the marine ecosystems in the North Sea and associated estuaries. The anthropogenic impacts to the marine ecosystems can be simulated through modeling the hydrodynamics and nutrient dynamic processes. Among the complex modules, hydrodynamic module is the basic driven tool for carrying bio-geochemical processes. The ecosystem modules are divided into three major functional parts, micro-planktons, detritus and dissolved materials (Tett, 1990). Plankton growth is mainly driven by light and nutrients. COHERENS is using

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the most important nutrient, the nitrogen cycle, as the control for the biology. The hypothesis is that estuaries are mostly nutrient rich and the computations would be too heavy for the model including the complicated nutrient dynamic processes.

A. Hydrodynamic module

The hydrodynamics of COHERENS are modeled with finite difference method. Cartesian grid system is used to describe the dynamics for Dapeng Bay. Arakawa type C-grid is used in COHERENS horizontal descritization, and sigma grid is used to define the vertical circulations. The water movement is described by the continuity equation (1), momentum equations (2&3) with hydrostatic assumption and the equation of state (4) as

$$\frac{\partial u}{\partial x_1}+\frac{\partial v}{\partial x_2}+\frac{\partial w}{\partial x_3}=0 \tag{1}$$

$$\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x_1}+v\frac{\partial u}{\partial x_2}+w\frac{\partial u}{\partial x_3}-fv=$$
$$-\frac{1}{\rho_0}\frac{\partial P}{\partial x_1}+\frac{\partial}{\partial x_3}(\nu_T\frac{\partial u}{\partial x_3})+\frac{\partial}{\partial x_1}\tau_{11}+\frac{\partial}{\partial x_2} \tag{2}$$

$$\frac{\partial v}{\partial t}+u\frac{\partial v}{\partial x_1}+v\frac{\partial v}{\partial x_2}+w\frac{\partial v}{\partial x_3}+fu=$$
$$-\frac{1}{\rho_0}\frac{\partial P}{\partial x_2}+\frac{\partial}{\partial x_3}(\nu_T\frac{\partial v}{\partial x_3})+\frac{\partial}{\partial x_1}\tau_{12}+\frac{\partial}{\partial x_2} \tag{3}$$

$$\frac{\partial P}{\partial x_3}=-\rho g \tag{4}$$

Where,

$$\tau_{11}=2\nu_H\frac{\partial u}{\partial x_1}$$

$$\tau_{21}=\tau_{12}=\nu_H(\frac{\partial u}{\partial x_2}+\frac{\partial v}{\partial x_1})$$

$$\tau_{22}=2\nu_H\frac{\partial v}{\partial x_2}$$

u, v, w are Current velocities (ms^{-1}); x_1, x_2, x_3 are direction of X, Y, Z respectively; *f* is Coriolis force; P is atmosphere pressure (Nm^{-2}) ; ρ is density (kg m^{-3}); g is acceleration due to gravity (=9.81 ms^{-2}) ; ν_H is horizontal diffusion coefficient; ν_T is vertical eddy viscosity.

B. Biology module

The biology module has three major compartments, i.e. microplankton, detritus and dissolved nutrients. Dissolved oxygen and nitrogen cycles are the main processes controlling the mass balance of marine ecosystem. Eight state variables are included and only nitrogen availability is considered in growth and nutrient regeneration. Principle conceptual model is shown in Fig. 1. Dissolved oxygen is the most important variable reporting the health of the water, and its interactions with other variables are shown in Fig. 2.

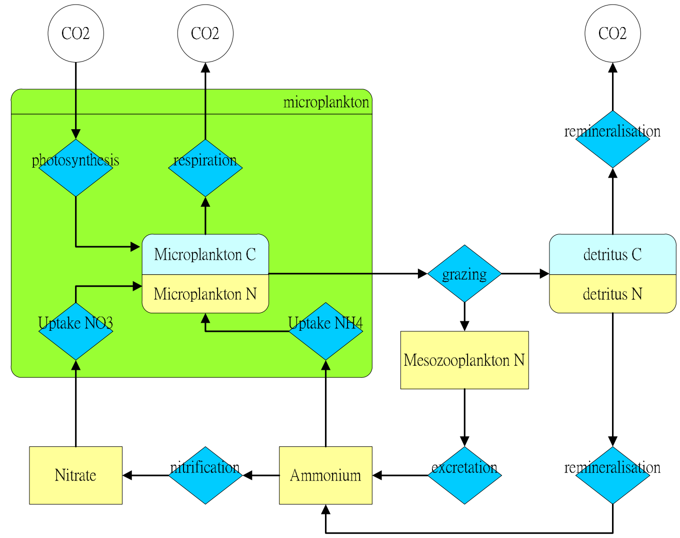


Fig.1 Conceptual model of the biological processes considered in COHERENS

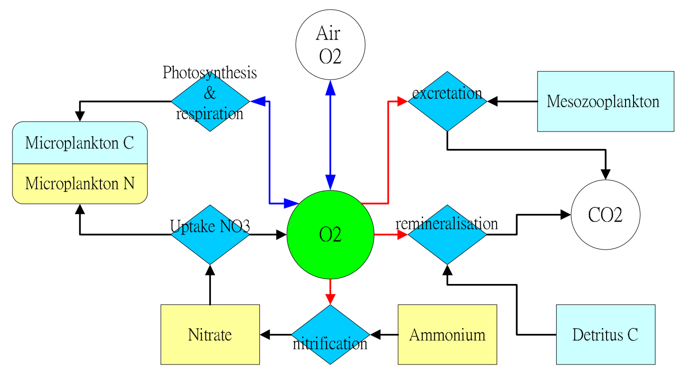


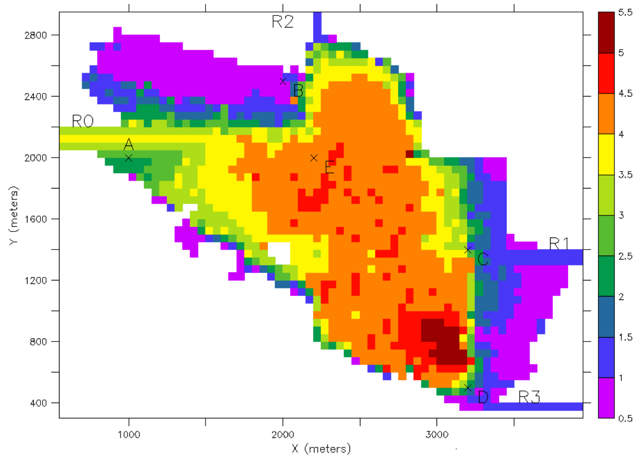
Fig. 2 Dissolved oxygen flows in COHERENS model

III. MODEL SETUP AND CASE SCENARIOS

The model domain for the study of Dapeng Bay includes all bay area, which is about 4500 meters wide and 3250 meters long. Grid size of fifty meters in both X and Y direction has been chosen for resolving the complex topography. In order to take considerations of the vertical exchange but keep reasonable computation time, three vertical layers are calculated using sigma-coordinate systems. With C.F.L limitation, 3-seconds is used for simulating the surface gravity propagated in the lagoon and complete baroclinic processes and biological processes are computed every 30-seconds.

There is only one tidal inlet (about 150-meter wide) responsible for exchanging bay water with the coastal water of southern Taiwan Strait. Tidal variations generated from an operational tide model (Yu et al., 2006) are used for setting as the model open boundary. Three major streams collecting run-offs and domestic discharges have been taken into account as the upstream boundaries. Measurements taken in various development projects are given for the case studies.

The bathymetry is derived from detailed sounding measurement shown as Fig.3. An island, which is formed by waste oyster shells, in the bay is kept in the model grids for keeping the circulation around it.



Bathymetry and Open Boundary input

Fig. 3 Bathymetry of Dapeng Bay (R0: tidal inlet; R1,R2 and R3 are the 3 streams; A to E: stations for the comparisons)

Two cases are set for study the bay water ecosystems response to the seasonal variations, mainly the impacts due to fresh water inflow during the rainy season. Case A is set as the situation for dry season with only a little base flow come in to the bay. This is the case considered as common situation for circulations and water quality distributions. Case B is set for the wet season condition. Freshwater discharges increase enormously due to heavy rains by either typhoon or monsoon. High discharges flush the organic matters settled at channel bottom into the bay. Oxygen at tidal boundary consider as saturated all the time (see e.g. Hung and hung, 2003), whereas free fluxes are set for the oxygen at the stream boundaries. Detailed boundary settings and forcing conditions are shown in Table 1 and 2.

The meteorological data observed at Dokang (2 km from Dapeng Bay) is obtained as the model surface forcing (Table 3). Daily averaged data of the air temperature, has been redistributed through out the day as equation (5). This equation assumes maximum heat happens at 13:00 pm and minimum value at 05:00 am.

$$\begin{cases} T = T_{\max} - dtemp*((t+11)/16) & when\ 0 < t \le 5 \\ T = T_{\min} + dtemp*((t-5)/8) & when\ 5 < t \le 13 \\ T = T_{\max} - dtemp*((t-13)/16) & when\ 13 < t \le 24 \end{cases} \quad (5)$$

T is air temperature; *dtemp* is temperature difference between $T_{\max}$ and $T_{\min}$; t is the hours within a day. 30% of cloud cover is assumed for the case A, as sunny.

TABLE I

River discharge input

Unit: CMS	R1	R2	R3
Dry Season	2.662	0.1388	0.0347
Wet Season	12.662	50.1388	3.0347

TABLE II

Open Boundary input

Open Boundary	Boundary Input							
	R0		R1		R2		R3	
	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet
Temperature(℃)	24.1	30.5	24.3	31.5	24.7	31.9	24.4	32.6
Salinity(PSU)	34.2	33.5	23.0	13.0	26.0	18.7	26.0	13.6
Ammonium (mmol N/m3)	6.0	5.0	12.2	22.7	8.5	8.6	15.3	10.0
Nitrate (mmol N/m3)	2.0	12.8	12.8	19.6	3.3	23.1	10.3	11.5
Microplankton C(mmol C/m3)	1.8	3.2	12.8	44.6	32.3	131.9	32.3	101.8
Microplankton N(mmol C/m3)	0.3	0.5	2.1	7.31	5.3	21.6	5.3	16.7
Detritus C (mmol N/m3)	9.5	30.2	9.0	73.0	12.8	401.8	8.4	157.2
Detritus N (mmol N/m3)	1.1	3.6	1.3	9.7	1.5	52.5	1.1	22.8
Inorganic sediment(g/m3)	23.2	23.1	20.8	11.7	27.3	24.9	11.1	26.7
DO (mmol O_2/m3)	200.0	180.0	Free flux					

TABLE III

Meteo-forcing Input

Meteo-forcing	Input		Unit
	Max	Min	
Air temperature	24.3	16.4	℃
Average Wind Speed	2.9(NE)		ms^{-1}
Atmosphere Pressure	101600		(Pa)Nm^{-2}
Rainfall	0		$Kgm^{-2}s^{-1}$
Relative Humidity	73		%
Cloud Cover	30		%

IV. MODEL SETUP AND CASE SCENARIO

Modeled temperature ranges from 23 to 28℃ (Fig. 4) and the chlorophyll-a concentration from 0 to 40 mgm^{-3} (Fig. 5) during the dry season. During the summer, water temperature and chlorophyll-a concentration increase up to 30-34℃ (Fig. 6) and 0-130 mgm^{-3} (Fig. 7), respectively. Fresh water discharges from the streams during the rainy summer season are clearly observed from the model results, and it remains at the surface layer rush out to the sea during the ebbing. This also has an impact to the chlorophyll-a, most of the surface plankton is flush away whereas the particles settled at the bottom layer getting accumulated at the region close to R1 and R3.

Humidity and cloud cover affect salinity during the dry season, and rainfall is the major factor dominating the salinity distribution in storm season (Fig. 8-10). Tide dominates the results shown at station A, which is located near the tidal. The area near the river input (R2, R3) is relatively shallower than the central bay, which causes little variations between surface and bottom. Stations C and E have distinct stratification since they are in the deeper bay (Fig. 9-10). Results are also shown that stations B and C are influenced from the discharges from R1 and R2.

The sediment concentrations increase during the wet season and subsequently cause chlorophyll-a concentration changed. This change takes about 20 days to recover to the value observed before rainfall start. Station A has the lowest sediment concentration due to tidal flushing. Station B is similar to A, but sediment concentrations are both increase during the rain (Fig. 11). The stations near the channel input (C and D) show high concentration of sediment during the rainfall (Fig. 12). Station D is shallower and, therefore, the difference between surface and bottom is not clear as the station E, which is deeper (Fig. 13).

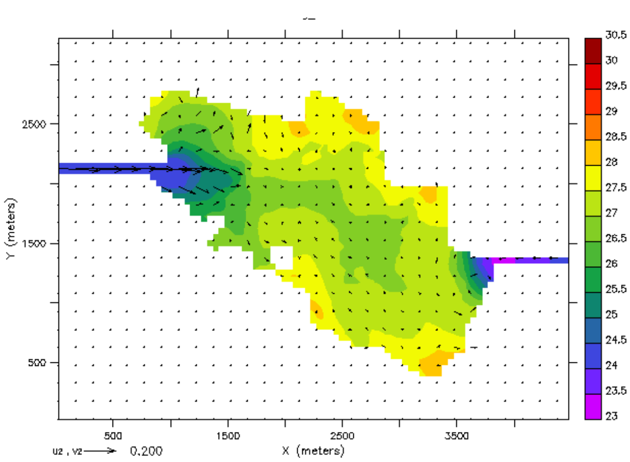


Fig.4 Temperature Distribution during Dry season

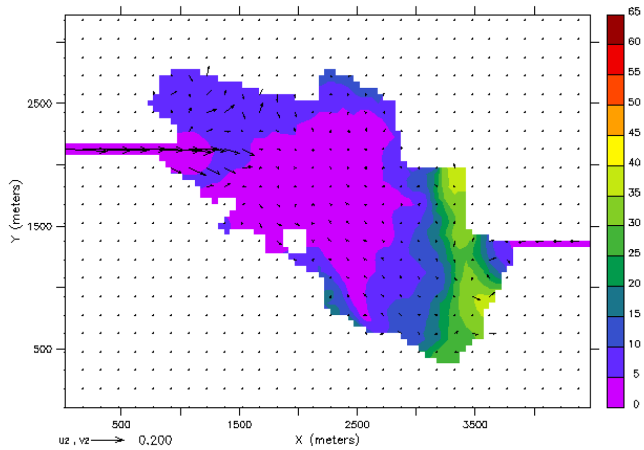


Fig.5 Chorophyll-a Distribution during Dry season

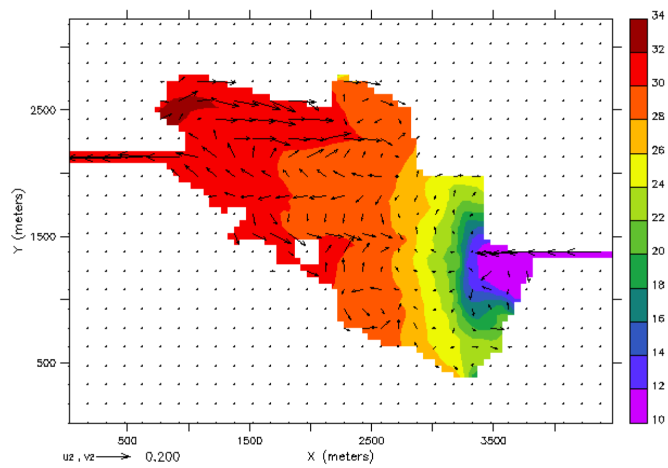


Fig.6 Temperature Distribution during Wet season

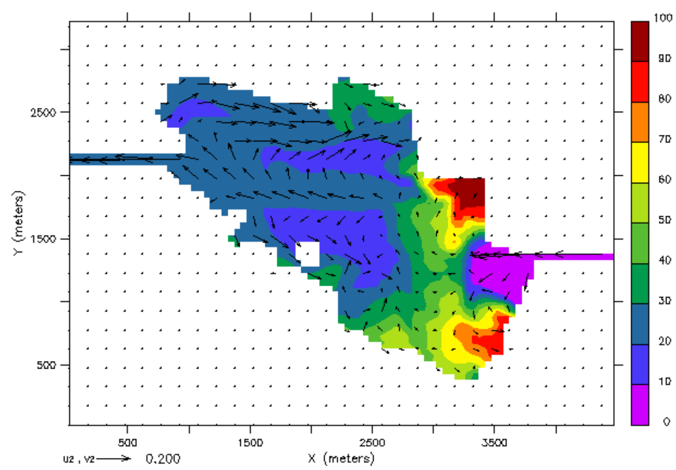


Fig.7 Chl-a Distribution during Wet season

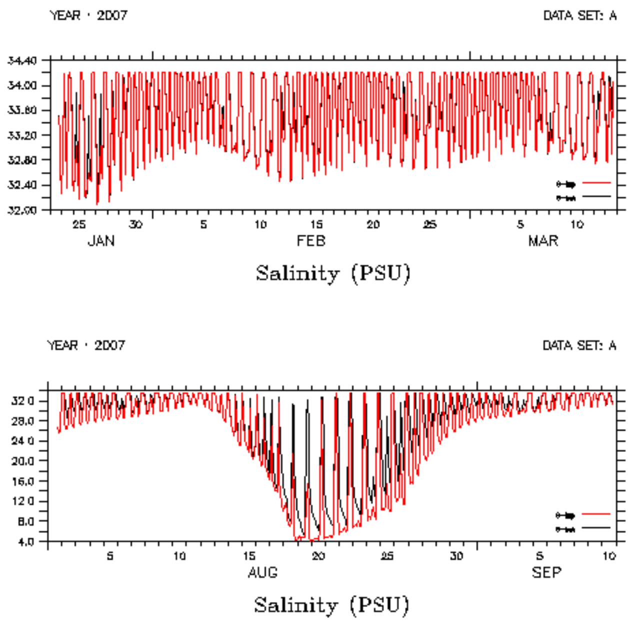


Fig.8 Salinity at Station A

(Upper: Dry season; lower: Wet season)

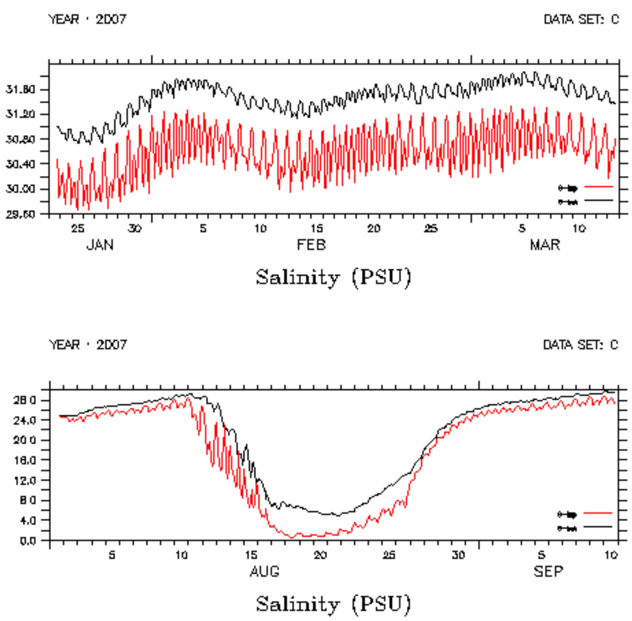


Fig.9 Salinity at Station C

(Upper: Dry season; lower: Wet season)

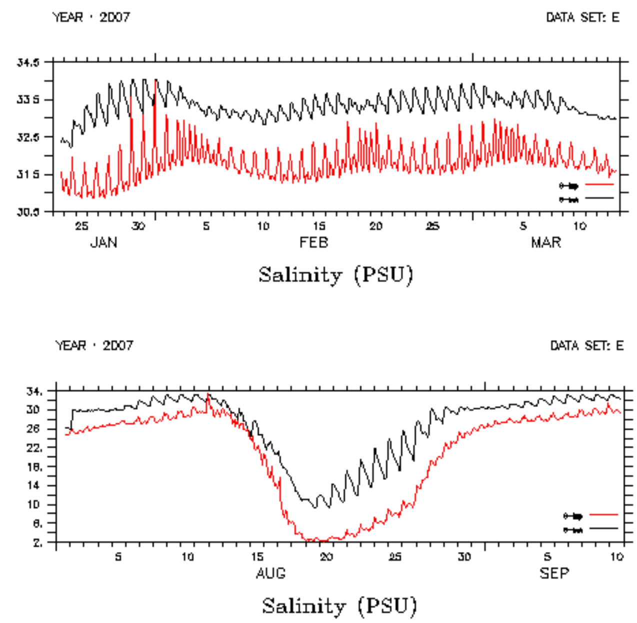


Fig.10 Salinity at Station E

(Upper: Dry season; lower: Wet season)

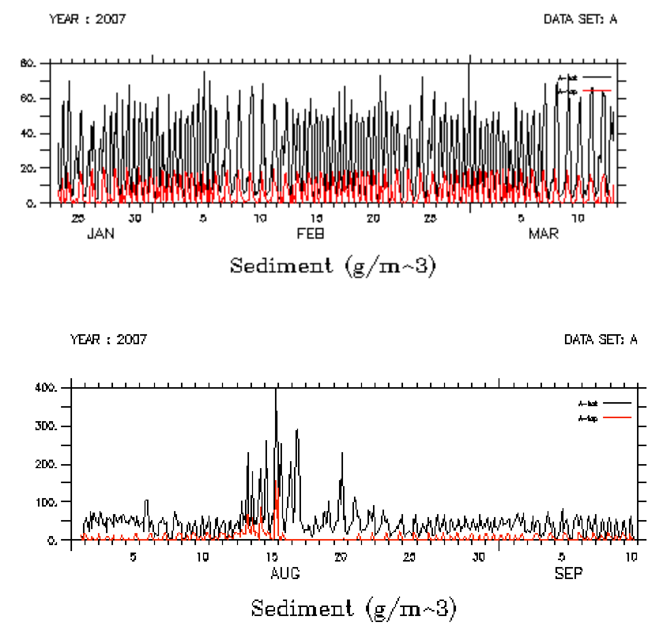


Fig.11 Sediment at Station A

(Upper: Dry season; lower: Wet season)

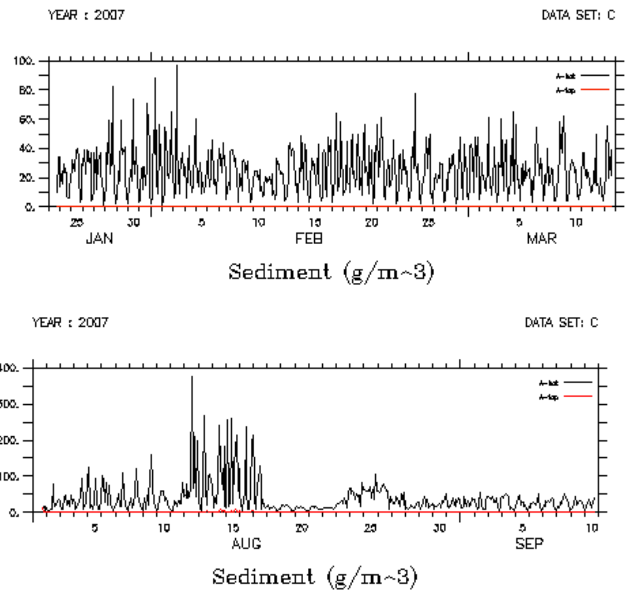


Fig.12 Sediment at Station C

(Upper: Dry season; lower: Wet season)

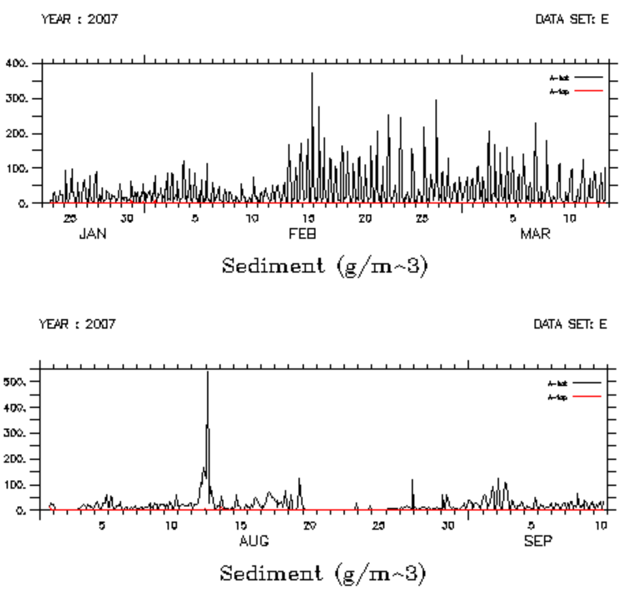


Fig.13 Sediment at Station E

(Upper: Dry season; lower: Wet season)

V. CONCLUSIONS

The application of a 3D numerical eutro-dynamic model for the study of Dapeng-Bay is presented. Seasonal variations of the lagoon are compared and discussed. The primary production is dominated by nutrients availability. Nutrients but also the circulations inside the bay control the micro-plankton distribution. The region near the tidal inlet shows lower phytoplankton concentration due to high exchange rate of water. The flushing effect is stronger than growth rate. Area with lower circulation speed and nutrient rich region, phytoplankton has enough time to grow and shows higher production. Vertical distribution of the nutrients shows bottom concentrations are higher than surface in the deep bay, which is mainly caused by surface detritus settling and bottom organic matter re-entering the water. More observation is required and on-going for further studies. However, this study demonstrates the possibility of using a fine grid numerical ecosystem model for studying the bio-geochemical response of the environments.

ACKNOWLEDGMENT

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