Continental Shelf Research 117 (2016) 20–29

Contents lists available at ScienceDirect

Continental Shelf Research

journal homepage: www.elsevier.com/locate/csr

Research papers

Simulation of the effects of bottom topography on net primary production induced by riverine input

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A R T I C L E I N F O

Article history:
Received 23 March 2015
Received in revised form
20 September 2015
Accepted 31 January 2016
Available online 1 February 2016

Keywords:
Biogeochemical cycles
3-D modeling
Riverine input
ROFI
Phytoplankton bloom
Bottom slope angle

A B S T R A C T

Riverine input often leads to high biological productivity in coastal areas. In coastal areas termed as region of freshwater influence (ROFI), horizontal anticyclonic gyres and vertical circulation form by density differences between buoyant river water and sea water. Previous physical oceanography studies have shown that the horizontal pattern of anticyclonic gyres and the strength of vertical circulation are dependent on the bottom topography of ROFI. However, the dependencies of biogeochemical cycles such as the net primary production (NPP) on the bottom topography have not been verified. In order to clarify how the bottom topography affects the NPP in phytoplankton blooms caused by riverine input through the physical processes in ROFI, we used an ocean general circulation model (OGCM) including a simple ecosystem model and conducted several case studies varying the bottom slope angle in the ideal settings. We estimated NPP categorized into three nutrients supplied from the river, the sea-subsurface layer and via regeneration: RI-NPP, S-NPP and RE-NPP. S-NPP and RE-NPP are larger and smaller with a steeper slope, respectively, while RI-NPP is not affected by the slope angle. As a result, total NPP is weakly dependent on the slope angle, *i.e.*, because S- and RE-NPPs cancel each other out through two physical processes, (1) S-NPP is controlled by the strength of the vertical circulation and (2) RE-NPP is controlled by the shape of the horizontal gyre, which both vary with the bottom slope angle. We also conducted realistic simulations for Ishikari Bay, Japan and confirmed a similar dependency to that in the above ideal settings. That is, the simulation results are consistent with the regime of ideal settings and show that RI- and RE-NPPs are important variables for Ishikari Bay which has a gentle slope.

1. Introduction

Rivers transport both fresh water and nutrients from the land to the sea. Discharge from the river mouth influences adjacent coastal areas where biological productivity is high. Fresh water is supplied as a buoyant input into large areas of shelf seas adjacent to estuaries which were termed as region of freshwater influence (ROFI) by Simpson (1997). ROFIs play an important role in coastal regions through physical, biogeochemical and ecological functions (Lihan et al., 2008). Rivers directly supply dissolved inorganic nutrients to ocean system. Indirectly, buoyant freshwater inputs induce horizontal river plumes and vertical upwellings which transport nutrients from the deeper nutrient-rich layer to the surface layer. That is, net primary production (NPP) with nutrient cycles in ROFI is determined by these complex physical and biogeochemical processes above.

In ROFI, plankton blooms often occur especially when flooding occurs due to snowmelt and/or heavy rains (*e.g.*, Agboola et al., 2009). Hoshiba and Yamanaka (2013) investigated the temporal and spatial shift of phytoplankton blooms induced by large amounts of riverine discharge. The study found that NPP is induced by nutrient supplies not only from the river input but also from the subsurface layer through upwelling and by regeneration. We expect that the nutrient supplies are controlled by the topographic features of ROFIs such as the bottom slope angle of the continental shelf, because two important physical processes are dependent on the topography as follows.

Firstly, buoyant water inputs with low salinity induce vertical circulation, composed of surface water flows from the coast to the offshore and subsurface counter-flows with upwelling near the coast (Rattray and Hansen, 1962). The strength of the vertical circulation depends on the depth of ROFI, the density difference between the river water and the coastal sea water, and the coefficient of eddy viscosity (Unoki, 1993). As the strength is proportional to the cube of depth of the flat bottom (Unoki, 1993), the vertical circulation is expected to depend strongly on the bottom slope angle.

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http://dx.doi.org/10.1016/j.csr.2016.01.020

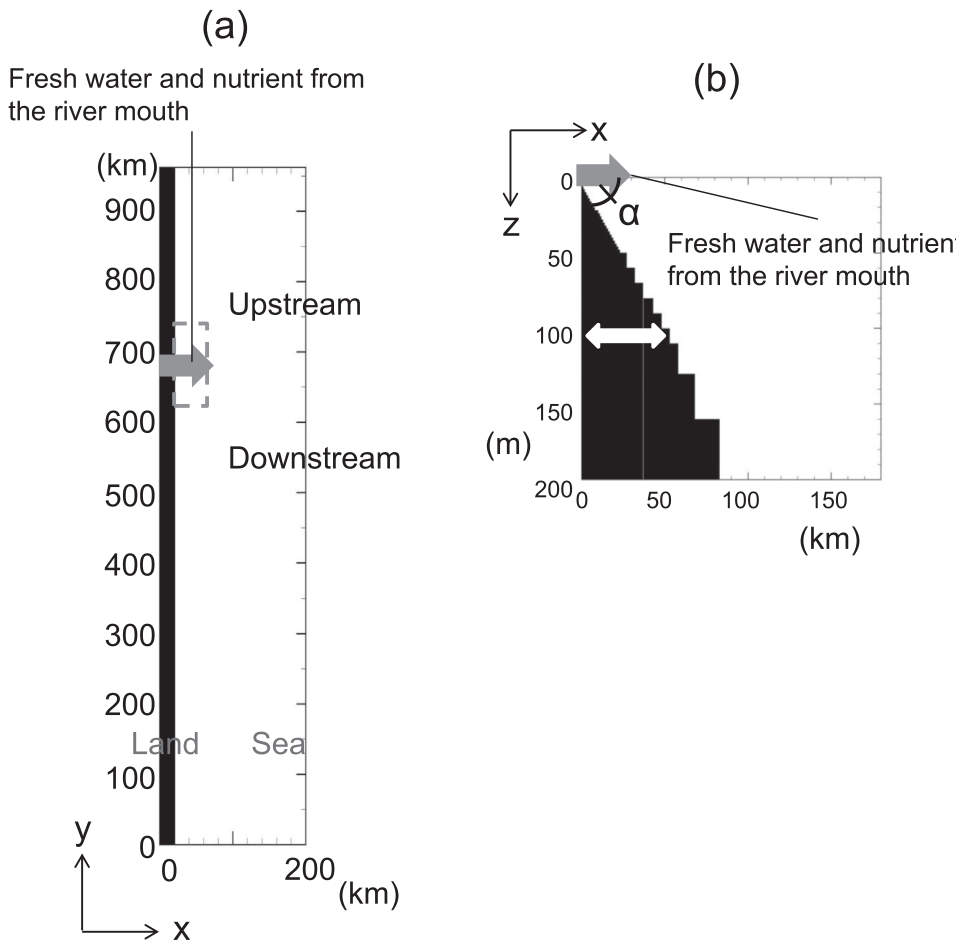

Fig. 1. (a) Horizontal geography and (b) vertical topography used in the model. The width of the river mouth is 3 km. The width of the region shallower than 100 m with the angle alpha was changed. The area surrounded by the dashed line shows the area drawn in Figs. 5 and 9.

Table 1
Experiments.

Experiment No.	1	2	3	4	5[a]	6	7	8	9	10
Shallow width (km)[b]	90	80	70	60	50	40	30	20	10	0
Slope angle α (deg)[c]	0.06	0.07	0.08	0.09	0.11	0.13	0.16	0.27	0.54	–

[a] Experiment No. 5 is the control case approximating the actual shallow area width.
[b] Width of the region shallower than 100 m depth (km) (see Fig. 1).
[c] Slope angle is determined from the shallow area width.

Table 2
Sinking rates of detritus in Exp. 1 and 8.

Sinking rate (m/day)	2	10	20	50	100	200

1): Experiments listed in Table 1 use 20 m/day.

Secondly, fresh water from rivers also induces horizontal river plumes with anticyclonic gyres due to geostrophic adjustment (*e.g.*, Isobe, 2005). There are previous studies related to the physics of the anticyclonic gyre enlarging with the bottom topography, for example, the horizontal gyre tends to be strongly trapped on the shelf and be suppressed toward the offshore direction in areas with a gently sloping bottom topography (Fig. S1; Tanaka et al., 2009).

In this study, we applied an OGCM with an ecosystem model to clarify how the bottom slope angle controls the NPP in phytoplankton blooms. Model case studies varying the bottom slope angle show how physical processes of vertical circulation and horizontal gyre control various nutrient supplies from the river,

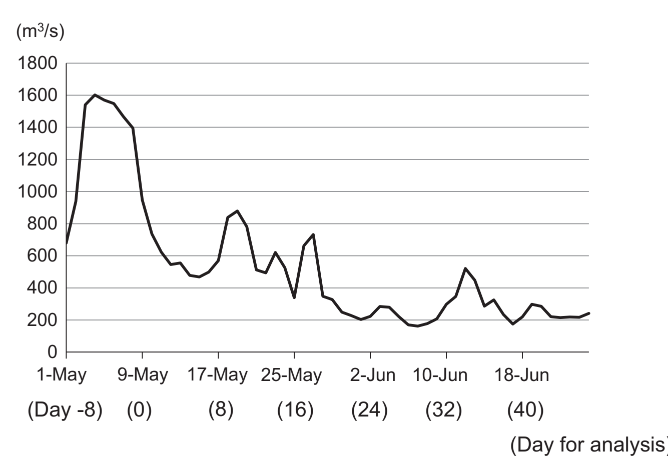

Fig. 2. River discharge observed at Ishikari Ohashi located 22.6 km from the river mouth of Ishikari River in Hokkaido, Japan in May to June, 2007 (Ministry of Land, Infrastructure, Transport and Tourism, Japan: http://www1.river.go.jp/). Days in parentheses show the day number in the simulation analysis in this study.