Biogeosciences Discuss., 10, C1629–C1648, 2013
www.biogeosciences-discuss.net/10/C1629/2013/

Biogeosciences Discussions

Interactive comment on "Impact of physical processes on the phytoplankton blooms in the South China Sea: an eddy-resolving physical-biological model study" *by* Y. Sasai et al.

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Received and published: 7 May 2013

We thank two anonymous reviewers for valuable comments. Major revised points are addition of statistical analysis between observation and model, explanation of model, and revision of results (addition of two new figures). We also added revised manuscript (see supplement pdf file), new figures of eddy activity in the model (Fig. 7, new) and the effect of Kuroshio intrusion (Fig. 10, new), and revised figures (Figs. 2, 3, 4, 5, and 6). Revised figures are satellite SSHA map in Fig.2, statistical analysis in surface chlorophyll concentrations between SeaWiFS and model in Figs. 3 and 4, addition of

two lines (nutricline and thermocline depths) in Figs 5a and 6a. Page and line numbers in our comments are presented in revised manuscript (supplement file). We describe major and miscellaneous comments for each reviewer below:

Reply to Reviewer #1

1. The manuscript "Impact of physical processes on the phytoplankton blooms in the south China Sea: an eddy-resolving physical-biological model study" by Sasai et al. mainly examines the mechanism that control distributions of chlorophyll concentration in two monsoon-driven upwelling regions, Vietnam coast and west of Luzon in the South China Sea. Although it appears a sound analysis, I do not find it sufficient for publication in Biogeosciences. The results presented in this paper, such as monsoon induced coastal upwelling associated eddy advection and upwelling, Kuroshio intrusion, Mekong river plumes, etc. have been either discussed or published in old publications. To those people who have been working on the SCS biogeochemistry for many years, the understanding to the generation mechanisms of the phytoplankton blooms in those two regions is pretty clear now. I really appreciate the work of this paper in terms of methods, analysis and conclusions, but it is just that I do not see anything new from it for publication in BG, as BG holds such a high standard for selecting papers. I do suggest maybe submit to another journal.

(Our reply)

Advantage of using a model is to examine the detail mechanism of biogeochemical processes forced by the different scales of physical processes (gyre circulation, eddy, mixing, and upwelling etc.). The ship observation is limited temporal and spatial scale. We think the model could support the generation mechanism of phytoplankton blooms presented in situ observation in two upwelling regions. In this study, our model can reproduce nitrate dynamics by physical transports and response of phytoplankton bloom with nitrate supply. In both regions, the model reproduces the seasonal variability of surface chlorophyll is consistent with the variability of subsurface nitrate concentration.

The peak of surface chlorophyll concentration does not match the peak of shallowest nutricline depth (subsurface high nitrate concentration), but the winter mixing (Luzon) and upwelling forced by the summer monsoon (Vietnam) are able to explain the peak of surface chlorophyll. Additionally, in the northwestern Luzon, the temporal variations in nitrate distributions are induced by the anticyclonic eddy and the Kuroshio intrusion, and the variations connect to the winter phytoplankton bloom.

2. The validation of model results is only surface chlorophyll. We added AVISO SSHA map in Figure 2. We also added the description in Sections 3.1 and 3.2. (p6, Lines 11-16) “The variability of simulated SSHA is also consistent with the satellite data, and the gyre circulation pattern in the SCS (e.g., Hu et al., 2000) is well reproduced. The basin scale pattern of nitrate distribution in summer and winter is similar to the hydrographic data (Ning et al., 2004). The high nitrate off the east coast of Vietnam in summer and the high nitrate band in the SCS basin in winter are reproduced. The simulated nitrate distribution reflects the basin-scale circulation and mesoscale eddies (Fig. 2).”

(p8, Line 14-17) “The simulated vertical chlorophyll distribution is consistent with the hydrographic surveys (Chen et al., 2006). The simulated subsurface maximum in chlorophyll is at 50 – 80 m depth which is very similar to that observed.”

3. Why do you choose 73 m depth layer to analyze data, and also in figures 7, and 9, you use 78 m depth to look at vertical velocity? We chose the bottom of subsurface maximum depth in chlorophyll in the model. The difference between tracer field depth and vertical velocity field depth is due to the defined model grid. We also added in Section 3.1. (p5, Lines 10-11) “The 73 m depth is close to the subsurface chlorophyll maximum depth in the model.”

4. In figures 3 and 4, where comparison between model and SeaWiFS is performed, statistical quantities (bias, correlation, RMS, etc.) are needed. Explanation about the bad performance in Box-V are also needed. We added the statistical analysis (correlation and mean with SD) in sections 3.1 and 3.2 and figures 3 and 4. (p.7, Line 5-7)”

(Correlation coefficients are 0.90 in box-L and 0.50 in box-V, respectively). In Box L, the mean surface chlorophyll concentrations of SeaWiFS and OFES are 0.16±0.07 mg m-3 and 0.22±0.10 mg m-3, respectively.”

(p.7, Lines 15-17)” In Box V, the mean surface chlorophyll concentrations of SeaWiFS and OFES are 0.16±0.04 mg m-3 and 0.21±0.02 mg m-3, respectively.”

(p.8, Lines 5-7) “The correlation coefficient between SeaWiFS and OFES is 0.82, and the average of surface chlorophyll concentration is 0.16±0.07 mg m-3 in SeaWiFS and 0.20±0.11 mg m-3 in OFES, respectively.”

(p8, Lines 28-27)” The correlation coefficient (0.28) of interannual variability is weaker than the climatological monthly mean (Fig 3). The average of surface chlorophyll concentration is 0.16±0.07 mg m-3 in SeaWiFS and 0.21±0.03 mg m-3 in OFES, respectively.”

Reply to Reviewer #2

Major revised points:

1. The comparison of model and observations needs to be improved before we can trust that the model is a valid tool to study the issue addressed by this paper. We added more description and discussion to reviewer major comments.

1a. . . . To give the readers more confidence that the model is suitable for this study, the author should provide some evidence that nitrate field from the simulation is comparable to observations. . . . We added the description of comparison between model and observation. (p6, Lines 11-16) “The variability of simulated SSHA is also consistent with the satellite data, and the gyre circulation pattern in the SCS (e.g., Hu et al., 2000) is well reproduced. The basin scale pattern of nitrate distribution in summer and winter is similar to the hydrographic data (Ning et al., 2004). The high nitrate off the east coast of Vietnam in summer and the high nitrate band in the SCS basin in winter are reproduced. The simulated nitrate distribution reflects the basin-scale circulation and mesoscale eddies (Fig. 2)."

(p8, Lines 14-17) "The simulated vertical chlorophyll distribution is consistent with the hydrographic surveys (Chen et al., 2006). The simulated subsurface maximum in chlorophyll is at 50 – 80 m depth which is very similar to that observed."

1b. Even for the surface chlorophyll comparison, the OFES simulations (Figure 1b) is unlike the SeaWiFS observations (Figure 1a). ... Why not first include the river for model-observation comparison, and then perform a scenario experiment by turning the river discharge off to examine the upwelled nitrate influence? We used the outputs data of a near global domain ocean model to investigate the influence of mesosclae physical processes (eddy, Kuroshio and upwelling) for ecosystem in the basin size scale ocean. We would like to know how performance of global scale model for the marginal sea. Global ocean model lacks the coastal dynamics, but we can examine the effects of mesoscale eddies, Kuroshio inflow, and monsoonal circulation on marine ecosystem. Next step, we should consider the coastal system.

We added the description of comparison between the SeaWiFS and OFES in section 3.1. (p6, Lines 20-27) "This is because the coupled physical-biological model does not include nitrate input with river runoff and benthic nitrate fluxes due to the sedimentary remineralization (Liu et al., 2007). Additionally, since the parameter values for phytoplankton growth based on open ocean values, they may not be suitable for the coastal environment (e.g., Liu et al., 2002; Liu and Chai, 2009). On the other hand, the high value of SeaWiFS data might be unreliable owing to the high levels of suspended sediments and colored dissolved organic matter (Liu et al., 2002)."

1c. ... It is best if the author can show the model-observation comparison results using some type of quantitative analysis, ... We added the statistical analysis (correlation and mean with SD) in sections 3.1 and 3.2 and figures 3 and 4. (p.7, Lines 5-7)" (Correlation coefficients are 0.90 in box-L and 0.50 in box-V, respectively). In Box L, the mean surface chlorophyll concentrations of SeaWiFS and OFES are 0.16±0.07 mg

m-3 and 0.22±0.10 mg m-3, respectively."

(p.7, Lines 15-17)" In Box V, the mean surface chlorophyll concentrations of SeaWiFS and OFES are 0.16±0.04 mg m-3 and 0.21±0.02 mg m-3, respectively."

(p.8, Lines 5-7) "The correlation coefficient between SeaWiFS and OFES is 0.82, and the average of surface chlorophyll concentration is 0.16±0.07 mg m-3 in SeaWiFS and 0.20±0.11 mg m-3 in OFES, respectively."

(p8, Lines 28-30)" The correlation coefficient (0.28) of interannual variability is weaker than the climatological monthly mean (Fig 3). The average of surface chlorophyll concentration is 0.16±0.07 mg m-3 in SeaWiFS and 0.21±0.03 mg m-3 in OFES, respectively."

1d. Since the paper has two sections to discuss how the biological filed altered by the eddy and declared this is an "eddy-resolving" physical-biological model. We added the description of simulated eddy activity (Section 3.3, new) and new figure 7. (p9, Lines 19 - 31)" Mesoscale eddy activity is an important factor in biological production in the upper layer of SCS. In the SCS numerous mesoscale eddies are found in a line stretching in a northeast-southwest direction and southwest of Luzon Strait (Wang et al., 2003; Liu et al., 2008; Chen et al., 2011). In the west of Luzon Strait, eddies are formed by wind stress curl variation and the Kuroshio intrusion (e.g., Wang et al., 2000; Yang and Liu, 2003), and propagate southwestward along the continental slope. The east coast of Vietnam also shows high mesoscale eddy activity. The variability of western boundary current along the coast favors the generation of eddies (e.g., Gan and Qu, 2008; Chen et al, 2010). The distribution of anticyclonic and cyclonic eddies generated by OFES and categorized by the SSHA during 2000-2007, is similar to that observed by satellite altimetry (Chen et al., 2011) (Fig.7). Here we have taken the 20cm and -20cm SSHA contours to denote anticyclonic and cyclonic eddies, respectively. The diameter of both eddies in the OFES is from 50 km to 300 km and the lifetime is from one week to about 7 months."

2. Many interesting outputs from the model need better descriptions and some model results need further analysis before substantial conclusions can be reached.

2a. Why the peak of surface chlorophyll, shallowest thermocline and mean vertical nitrate concentration are not synchronous in Figure 3? Another similar example exists in Figs. 8, 9 and 11, 12 (new). We added the description of this unmatched in sections 3.2 and 4 (Conclusions). (p7, Lines 11-15) "However, the peak of surface chlorophyll concentration and the peak of vertical mean nitrate concentration are not synchronous. The peak of surface nitrate concentration appears in December/January when the MLD is deep and there is a strong vertical nitrate flux, but the peak of subsurface nitrate concentration appears in February when the nutricline depth is shallow."

(p7, Lines 23-24) "The peak of vertical mean nitrate concentration is in October when the nutricline is shallow, and is not at the same time as the peak in surface chlorophyll concentration."

(p13, Lines 15 - 18) "The spatial distribution of surface chlorophyll concentration is consistent with the distribution of the thermocline depth and nutricline depth, implying the surface chlorophyll distribution is mainly controlled by the nitrate supply from the subsurface layer by vertical mixing and upwelling."

2b. On Fig. 4c, the author found that 2004 was the year that chlorophyll from OFES didn't peak and explained this was caused by a modest reduction in the strength of the summer monsoon. However, on Fig.4d, the plot of wind didn't clearly show a reduction in wind stress in 2004. . . . We added the description of wind reduction effect in section 3.2. (p9, Lines 2-7) "The average eastward component of wind stress during summer (June, July, and August) in 2004 is 0.23 N m-3 and this value is 30-60% of other years (0.33 - 0.55 N m-3). The nutricline is deeper (60 m) and the vertical nitrate flux at 73 m depth weaker (0.34 mmol N m-2 d-1) in 2004 compared to other years (when the nutricline depth is 40 – 50 m and nitrate flux is 0.60 – 1.09 mmol N m-2 d-1)."

2c. The author found surface nutrient and chlorophyll was reduced despite the elevated

depth-integrated nitrate, and the model failed to capture the extremely high chlorophyll events at the end of 2005 and 2007; yet, the author didn't provide any analysis or discussion as to why. We added the model failed to capture the extremely high chlorophyll events at the end of 2005 and 2007 in section 3.1. (p9, Lines 12-16) "The SeaWiFS captures the relatively high chlorophyll distribution (> 1 mg m-3) off the east coast of Vietnam in late 2005 and 2007 (not shown). However, the model shows a low chlorophyll concentration in the surface layer because the nitrate supply to the surface layer by the mixing and upwelling is not much different with other years."

2d. Why does OFES overestimate the chlorophyll peak compared to the observation? Because the biological parameters uses the pelagic ocean ecosystem (see Appendix A and Table A). We think the biological parameter of growth rate and grazing rate are not matched to the SCS region.

2e. Why does the subsurface maximum in chlorophyll stay for few months after the surface bloom. The light penetrates to the subsurface layer during spring and summer. After winter bloom finishes in the northwestern Luzon, except for the surface (reduce the nitrate concentration), the good phytoplankton bloom environment is maintained in the subsurface layer.

We added the following sentence in section 3.1. (p8, Lines 17-18) "A subsurface maximum in chlorophyll lingers for a few months after the surface bloom because the shallow nutricline depth is in the euphotic layer during spring and summer."

2f. "The peak in the subsurface maximum occurs slightly later in the year (around September/October) than at the surface". Why is the subsurface later? It looks to me . . . The surface peak is corresponding to upward velocity (Fig. 6d), and the nitrate supply to the surface is larger than the peak of shallow nutricline depth (consistent with subsurface maximum). The peak in the subsurface maximum varies with the varying thermocline and nutricline depths.

2g. The author mentions the intrusion of the Kuroshio impact on the nutrient and chlorophyll field. Although the manner similar to the anticyclonic eddy, it still needs to expand the discussion and include 1 or 2 figures to show it. We added new figure 10 to show the 3 cases (2001-2002, 2005-2006, 2006-2007) of Kuroshio intrusion in winter and discussion in section 3.4. (p11, Lines 29 – 32) “Fig. 10 shows the surface chlorophyll concentration with the horizontal velocity field when the intrusion of Kuroshio occurs in winter. Along the Kuroshio’s southern edge, the phytoplankton bloom is enhanced in all cases. The impact in 2001-2002 was particularly strong (Fig. 4a).”

3. I believe the model has the ability to reproduce the seasonality of the chlorophyll field due to upwelling effects, but it seems to me that the model lacks the ability to reproduce the interannual chlorophyll variability (Fig. 4a and 4c). The discussion of the interannual variability in section 3.2 was not particularly illuminating. The author probably should consider removing this section. However, there are coupled potential interesting points in this section that the author should consider keeping and expanding. We expanded the discussion of the interannual variability in section 3.2 to your major comments 2.

3a. The potential influence of reduced wind stress on nutrient upwelling. Maybe an experiment reducing the wind stress by 20% could be performed? In this study, we used the outputs data of a near global ocean model. If we use a regional ocean model, we might be able to perform your interesting experiment. But we focus on the present condition of nutrient upwelling forcing by the Satellite wind stresses.

3b. The scenario in which an eddy passes by before, in the middle of, and after the phytoplankton bloom (This was actually discussed in 3.3). We added the following description. (p11, Lines 23-26) “In the case when an eddy passes before the phytoplankton bloom, the nutricline depth is deep before northeasterly monsoon winds, and at the edge of eddy, the nitrate supply to the surface is small. In the case when an eddy passes after the phytoplankton bloom, the nutricline depth is deepening. The nitrate supply by the eddy is again small.”

4. The methodology part needs more description to allow the readers to repeat the experiments. We revised “Model description” and added “Ecosystem model” in appendix A. (p3 Line 28 - p5 Line 1)” The physical model is the Ocean general circulation model For the Earth Simulator (OFES) (Masumoto et al., 2004), which is based on the Geophysical Fluid Dynamics Laboratory’s Modular Ocean Model (MOM3) (Pacanowski, and Griffies, 2000). The model domain covers a near global region, except for the Arctic Ocean, extending from 75°S to 75°N. The horizontal resolution is 0.1°. There are 54 vertical levels, with varying thickness between the levels from 5 m at the surface to 330 m at the maximum depth of 6065 m. The model topography is constructed from the 1/30° bathymetry dataset created by the OCCAM Project at the Southampton Oceanography Center. After the physical fields have been spun up for 50 years under the climatological monthly mean data of NCEP/NCAR, the OFES is forced by the daily mean NCEP/NCAR reanalysis data (Kalnay et al., 1996) for 48 years from 1950 to 1998. The last day of 1998 is used for the initial physical fields for this simulation. The marine ecosystem model is a simple nitrogen-based four-compartment, NPZD (Nitrate, Phytoplankton, Zooplankton and Detritus), ecosystem model (Oschlies, 2001). The evolution of the biological tracer concentrations in the OFES is governed by an advection-diffusion equation with source and sink terms. The source and sink terms represent the biological processes (Sasai et al., 2006,2010). The biological processes include phytoplankton growth, zooplankton grazing, mortality, and detritus remineralization. The ecosystem model is described in Appendix A. The initial nitrate field is taken from the climatological dataset (WOA98) and has no supply from the atmosphere and rivers. The initial P and Z concentrations are set to 0.14 mmol m-3 and 0.014 mmol m-3 at the surface, respectively, decreasing exponentially with a scale depth of 100 m (Sarmiento et al. 1993). D is initialized to 10-4 mmol m-3 everywhere. To establish a stable pattern of the biological fields, the biological model is incorporated after the physical field of OFES is spun up for 50 years under the climatological monthly mean data. The biological model coupled with the evolving physical fields is integrated over a 5-year period under the climatological monthly mean data

(Sasai et al., 2006). The variability of biological fields has no feedback on the physical fields. The biological fields at the end of coupled 5-year integration are used as initial conditions for biological fields for this simulation. For the experiment reported here, the coupled physical-biological model (OFES-NPZD) is forced by the daily mean surface wind stress data of Quick Scatterometer (QSCAT) and atmospheric daily mean data (heat and salinity fluxes) of the NCEP/NCAR reanalysis from 1999 to 2007. We use OFES-NPZD outputs for the SCS domain. Results are presented for years 2000 to 2007. The simulated phytoplankton concentration (mmol N m-3) is converted to chlorophyll concentration (mg m-3) using a ratio of 1.59 g chlorophyll per mol nitrogen (Cloern et al., 1995; Oschlies, 2001). To investigate the performance of the coupled physical-biological model, we compare our results with the ocean color satellite image data of the Sea-viewing Wide Field-of-View Sensor (SeaWiFS)."

Appendix is in revised manuscript.

Miscellaneous revised points:

1. In Section 1 (old 3rd paragraph)."Interannual variations of the SCS circulation are related to both the El Nino Southern Oscillation and Indian Ocean Dipole … the upwelling and the phytoplankton bloom of the South Vietnam coast (Liu et al., 2012)" This paragraph talked about the potential ENSO influence on the SCS; however, the ENSO influences is only discussed at the end of the conclusions and is distractive. Please consider removing it. We removed this paragraph and added short description after 2nd paragraph in section 1. (p2, Lines 22-25) "In addition to the seasonal variation, the SCS circulation also shows the interannual variability related to the El Niño Southern Oscillation (e.g., Kuo et al., 2004; Liu et al., 2004; Fang et al., 2006) and Indian Ocean Dipole (IOD) (Saji et al., 1999; Yang et al., 2010) the latter having a considerable impact on the southwest monsoon over the SCS."

2. In Section 2 (2nd paragraph). In the sentence "The source and sink terms represent the biological activity", please be specific about which biological activities are represented and what source and sink terms are included (see specific comments 4b). We revised the ecosystem model description and added appendix A (see major revised point 4).

3. In Section 3.1 (1st paragraph). In the statement "Ocean color satellite images reveal strong seasonality of …", the word "strong seasonality" was not quite appropriate to use here, because the results didn't show the surface chlorophyll distribution in all four seasons or representative months of the four seasons. Please consider revising. We revised this sentence in Section 3.1. (p5, Line 5) "Ocean color satellite images revel two seasons (summer and winter)…".

4. The statement "the surface physical fields support the peak conditions of model surface chlorophyll" doesn't explain how they are related in the following sentence. We removed this sentence.

5. In Section 3.1. "The simulated chlorophyll distribution represents same pattern…, but has a relatively low concentration along the coast of southwestern China". The chlorophyll is not just low along the coast of southwestern China but also along the Vietnam coast. We revised this sentence. (p5, Lines 14-16)" The simulated chlorophyll distribution represents same pattern of the SeaWiFS off the east coast of Vietnam, but has a relatively low concentration along the coast of southwestern China and the south coast of Vietnam."

6. In the statement "The strong Kuroshio inflow also effects on the spreading of surface chlorophyll distribution" the words "effect on" should be "affects". Also there is no explanation about how the Kuroshio influences the chlorophyll distribution. Please either expand the sentence with some explanation or remove it. We removed this sentence.

7. In Section 3.2. "The word year boundary" should be changed to "the beginning and the end of the year". We changed.

8. Please plot the thermocline and nutricline depths on top of the chlorophyll concen-

tration to better show that they co-vary. We added two lines (thermocline and nutricline depths) on top of chlorophyll concentration in Figures 5 and 6.

9. In Section 3.4. “During the northwesterly winds . . .” should it be “northeasterly wind”? We changed “northeasterly wind”.

10. In Section 3.4. “The OFES reproduces the number of eddies in the northwestern Luzon during the northeast monsoon (Fig.2)”. Figure 2 doesn’t support this statement. Please consider revising this. We added new figure 7 and description of eddy activities in the model (See major revised point 1d).

11. In Section 3.4 (2nd paragraph last sentence) “There are large upward and downward motions associated with the eddy.” This sentence states a fact that most people know and has loose association with previous sentence. Please consider removing it. We removed this sentence.

Please also note the supplement to this comment:
http://www.biogeosciences-discuss.net/10/C1629/2013/bgd-10-C1629-2013-supplement.pdf

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Interactive comment on Biogeosciences Discuss., 10, 1577, 2013.

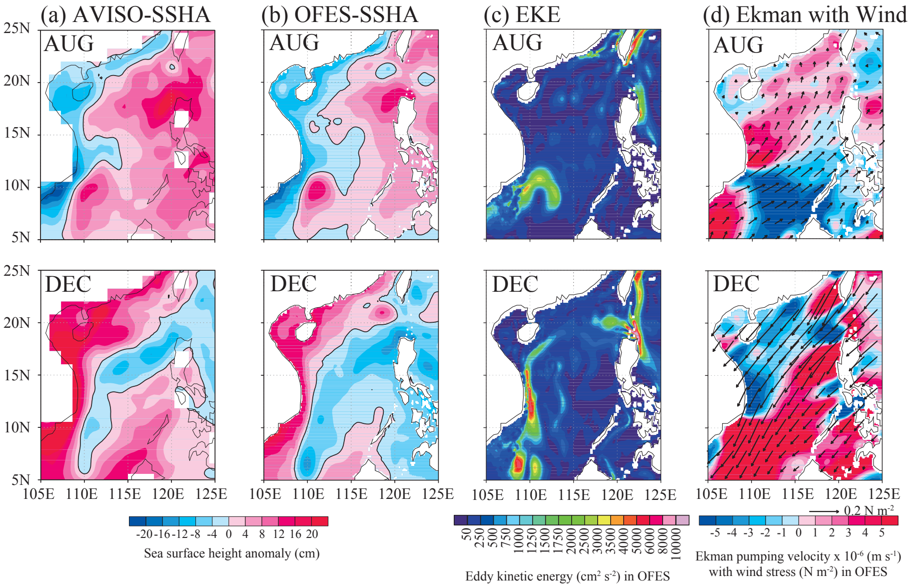


Fig. 2. Climatological monthly mean sea surface height anomaly (cm) during 2000-2007 from (a) AVISO and (b) OFES, (c) eddy kinetic energy ($cm^2 s^{-2}$) in the surface layer, and (d) Ekman pumping (x10^{-6} m s^{-1}) with wind stress (N m^{-2}) in OFES. Contour line in (a) and (b) is 0 cm. AVISO is Archiving, Validation, and Interpretation of Satellite Oceanographic data altimeter products.

Fig. 1.

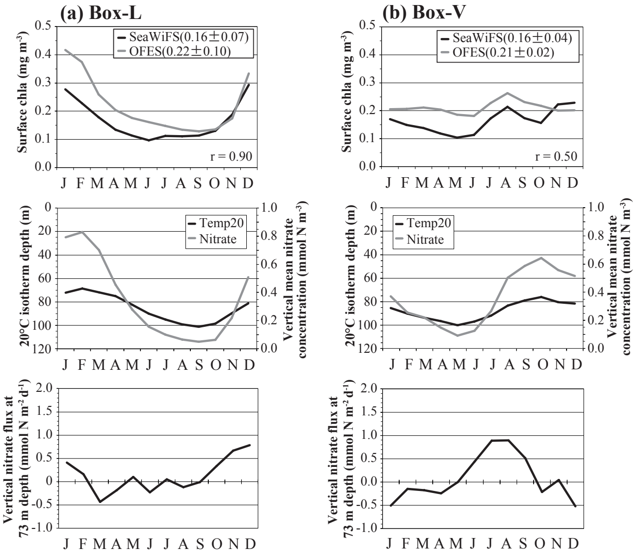


Fig. 3. Time series of climatological monthly mean surface chlorophyll concentrations, thermocline depth, vertical mean nitrate concentration, and vertical nitrate flux at 73 m depth averaged for each upwelling region of Fig. 1: (a) Box-L of northwestern Luzon (16ºN-20ºN, 116ºE-120ºE) and (b) Box-V of southeast Vietnam (11ºN-15ºN, 110ºE-114ºE). Mean surface chlorophyll concentration ± standard deviation, and correlation coefficient (r) are also presented for each box.

Fig. 2.

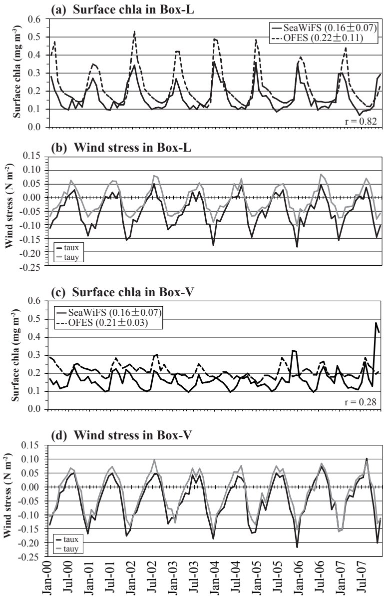


Fig. 4. Time series of monthly mean surface chlorophyll concentrations (mg m^{-3}) and wind stress (N m^{-2}) averaged for each upwelling region of Fig. 1 during 2000-2007 in (a)-(b) Box-L and (c)-(d) Box-V. Mean surface chlorophyll concentration ± standard deviation, and correlation coefficient (r) are also presented for each box.

Fig. 3.

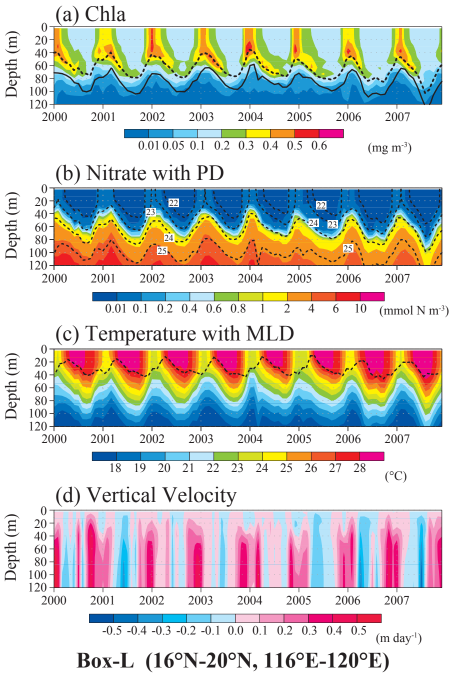


Fig. 5. Time series of simulated vertical distribution of (a) chlorophyll concentration (mg m^{-3}) with nutricline depth (1 mmol N m^{-3}, dashed line) and thermocline depth (20°C, solid line), (b) nitrate concentration (mmol N m^{-3}) with potential density (dashed line), (c) temperature (°C) with mixed layer depth (dashed line), and (d) vertical velocity (m day-1) averaged for Box-L (northwestern Luzon, L in Fig. 1) during 2000-2007.

Fig. 4.

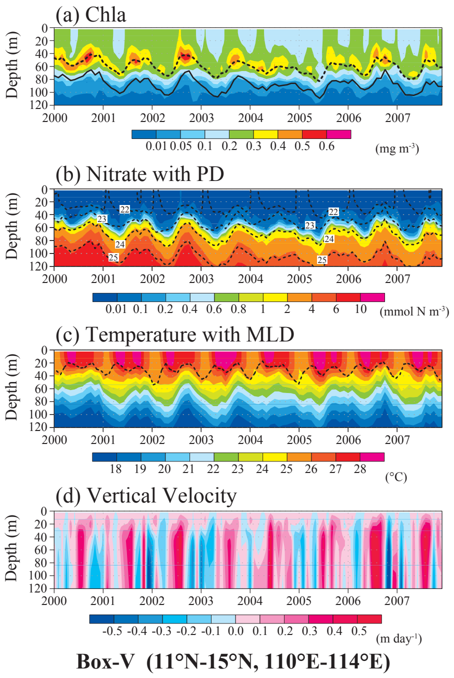
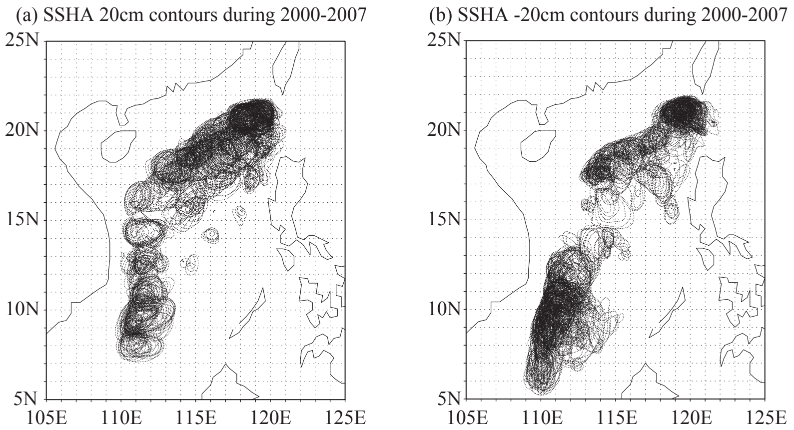


Fig. 6. Same as for Fig. 5, but for Box-V (southeast Vietnam, V in Fig. 1).

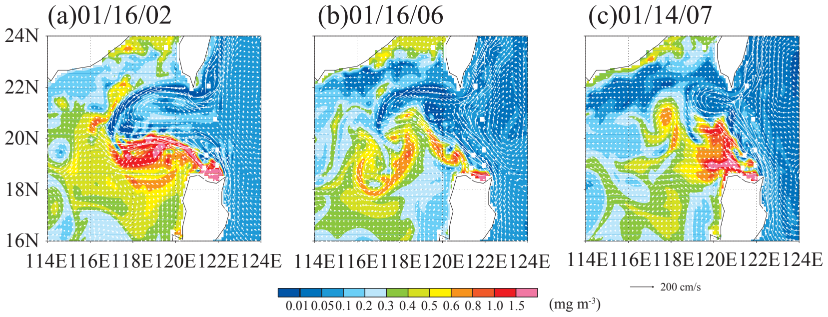
Fig. 5.


(a) SSHA 20cm contours during 2000-2007

(b) SSHA -20cm contours during 2000-2007

Fig. 7. Distribution of sea surface height anomaly (cm) of (a) 20 cm and (b) -20cm during 2000-2007 from OFES. Positive anomaly denotes anticyclonic eddy. Negative anomaly denotes cyclonic eddy.

Fig. 6.


(a)01/16/02

(b)01/16/06

(c)01/14/07

Fig. 10. Snapshots of simulated surface chlorophyll concentration (color, mg m^{-3}) and surface horizontal velocity (vectors, cm s^{-1}) in the northeastern South China Sea: (a) January, 16, 2002, (b) January, 16, 2006, and (c) January, 14, 2007.

Fig. 7.