MAIN REASONS OF ERRORS IN SATELLITE DERIVED PRIMARY PRODUCTION MODELS: CASE STUDY OF THE WESTERN PART OF THE JAPAN/EAST SEA

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Abstract

Application of satellite derived models of primary production using ocean colour remote sensing data opens new possibilities of estimation of its time and spatial variability at different scales. However, it is always necessary to take into account that errors of model retrieval can affect wrong interpretation of this variability. In the study we analyzed errors of satellite derived primary production models and explain main reasons of its appearance for a case study of the western part of the Japan/East Sea (35-44 N, 130-137 E). As satellite derived primary production we used data of Vertical Generalized Production Model (VGPM) from Ocean Productivity database. Due to insufficient amount of in situ primary production data in the western part of the Japan/East Sea, satellite derived primary production was compared with modeled assessments, which were got using ship data of model input parameters (chlorophyll-a at different depths, assimilation number, euphotic depth etc). Applied analysis showed three reasons of errors of satellite derived primary production models: (1) accuracy of remote sensing chlorophyll-a, (2) oceanographic conditions - water stratification and (3) accuracy of assimilation number determination.

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1. Introduction

Due to different natural factors, the Japan/East Sea has high biological and fishery productivity, complete understanding of which is not possible without estimation of primary productivity link – the phytoplankton and organic matter produced by them during photosynthesis involving green pigment chlorophyll *a* (Chl *a*). This primary production (PP) causes production and functioning of the next trophic levels of the marine ecosystem.

PP may be measured manual (from water samples) or retrieved using models, which are based on the dependence of photosynthetic rate on the parameters of the medium. Since light is a main energetic force for synthesis of organic matter, in the vast majority of models photosynthesis is represented as one-substrate process. In this case, a substratum is underwater illumination (Zvalinski, 2006). There is lack of *in situ* data of PP in the Japan/East Sea (Yamada et al., 2005, Lee et al., 2017), so its retrieval using models is of a big interest.

There is an internet database of PP for the World Ocean - Ocean Productivity database (OP) (www.science.oregonstate.edu/ocean.productivity), which includes PP retrieved using satellite data of model parameters. The main parameters are: (1) biomass index, which reflects amount of biomass involved into photosynthesis (Chl *a*, carbon concentration, etc.); (2) rate of photosynthesis normalized to the biomass index (P^B_{opt}), which in turn is retrieved as a function of sea surface temperature; and (3) surface photosynthetically active radiation (PAR). This database is in demand, however standard remote sensing algorithms of Chl *a* and P^B_{opt} not always provide their accurate assessments. This, in turn may cause wrong assessment of PP. In this study, we compared modeled satellite and field assessments of PP and identify possible reasons of errors in satellite derived primary production algorithms.

2. Data and Methods

For this study we used *in situ* data provided by V.I. Ilyichov Pacific Oceanological Institute (POI): Chl *a* [mg m^{-3}], nutrients (N, P, Si) [μmol m^{-3}], P^B_{opt} [mg C mg Chl^{-1}h^{-1}], and water temperature [^{0}C]. These data are from three marine cruises held in spring of 2004 (May) and in autumn of 2005 and 2011 (October-November) in the western part of the Japan/East Sea (35-44^0 N, 130-137^0 E) (Figure 1). Assuming bimodal feature of phytoplankton blooming allowed us to use one value of P^B_{opt} for all cruises. Using *in situ* data we calculated following parameters: the euphotic depth (z_{eu}) [m], the downwelling defuse attenuation coefficient (k_d) [m^{-1}], the first optical depth (z_{90}) [m], Chl *a* concentration in the layer of z_{90} (Chl_{90}) [mg m^{-3}] and daily water column PP (PP_{eu}) [mg C m^{-2} day^{-1}]. Since 90% of coming solar radiation reflects from the layer of z_{90} and satellite sensors get information only from it, we averaged *in situ* Chl *a* in this layer to validate satellite assessments. We analyzed 131 stations, and 120 of them were used for validation of satellite derived data of PP_{eu} and 61 – for Chl_{90}.

We validated satellite derived Chl *a* from Climate Change Initiative Ocean Colour database (CCI OC), version 2 (esa-oceancolour-cci.org) and satellite derived PP_{eu} from OP database retrieved using an empirical model – Vertical Generalized Production Model (VGPM) (Behrenfeld and Falkowski, 1997). PAR data [E m^{-2} day^{-1}] (MODIS Aqua) were taken from NASA Ocean Color database (oceancolor.gsfc.nasa.gov).

To retrieve PP_{eu} from *in situ* data we used two models. One was developed in POI. It is a semi-analytical model, which represents photosynthesis in form of cyclic fraction (Zvalinsky and Tishchenko, 2016). If underwater illumination is the main limiting factor, daily PP at depth z ($PP(z)$) may be presented as follows:

$$PP(z) = Chl(z) \times P_{opt}^{B} \times \left(\frac{1 + Ir(z)}{2 \times \gamma} \times \left[1 - \sqrt{1 - \frac{4 \times \gamma \quad \times Ir(z)}{(1 + Ir(z))^2}} \right] \right) \times DL \qquad (1)$$

Where, $Chl(z)$ is Chl *a* at depth z; $Ir = I/I_K$ is the relative irradiance – deviation of PAR to the light constant (I_K); γ is a parameter of curvature of photosynthesis-irradiance curve ≈0.95 (Zvalinski, 2006) and DL is day length [h]. $Ir(z)$ was calculated using exponential law of light penetration in the medium (Gordon and McCluney, 1975) assuming that $I_K \approx$ 10% of surface PAR (I_0) (Zvalinski, 2006).

$PP(z)$ was calculated for each horizon with a step of half a meter down to a depth of the euphotic zone. PP_{eu} was calculated by summarizing of $PP(z)$ of its half a meter layers. Thus, this model reflects vertical distribution of Chl *a*.

The second model is VGPM. According to this model, PP_{eu} can be presented as follows:

$$PP_{eu} = Chl_{90} \times P_{opt}^{B} \times \left(0.66125 \times \frac{I_0}{I_0 + 4.1} \right) \times DL \times z_{eu} \qquad (2)$$

Retrieving of PP_{eu} was carried out by analogy with the one provided by OP database: we calculated P^{B}_{opt} as a function of Sea Surface Temperature (SST) (Behrenfeld and Falkowski, 1997) and z_{eu} was calculated using Morel and Berthon algorithm as a function of Chl_{90} (Morel and Berthon, 1989).

3. Results

Table 1 presents the correlation coefficients for satellite and *in situ* data.

The best correlation is between field estimates of PP_{eu}, because they were calculated on a base of the same *in situ* data. The correlation between VGPM assessments is moderate and it is higher than one between satellite and field PP_{eu} on a base of POI model. The correlation between Chl_{90} assessments is also moderate.

Figure 2 shows averaged PP_{eu} and its standard deviation for all data. You can see that field assessments on a base of two models differ substantially. The difference between satellite and field PP_{eu} is less but satellite PP_{eu} overestimates field VGPM PP_{eu} and underestimates field POI modeled PP_{eu}.

Comparison of averaged over each cruise PP_{eu} and Chl_{90} showed that in those cruises, when satellite PP_{eu} was higher (or lower) than field VGPM assessments, satellite Chl_{90} was also higher (or lower) than in situ Chl_{90}. It is because that Chl *a* is the main multiplier in VGPM and its values in turn influence model retrieval.

The analysis of two autumn cruises showed that there was an interannual variability (Figure 3). In autumn of 2005, satellite PP_{eu} was a little bit higher than field PP_{eu} retrieved with POI model, while in autumn of 2011 satellite assessments were considerably low.

Averaged vertical profiles of Chl *a* showed that in autumn of 2011 waters were more stratified (Figure 4). Maximum of Chl *a* was at depth 24-25 m, and averaged z_{90} was about 7 m. Thus, the vast part of Chl *a* in the euphotic zone remained unavailable for satellite spectroradiometers. According to VGPM, Chl *a* does not change with depth and total concentration of Chl *a* is estimated as follows: Chl_{90} is multiplied by z_{eu} (Eq.2). While, POI model considers vertical Chl *a* profile. This can cause lower values of satellite PP_{eu}. Autumn cruise of 2005 was characterized with less stratification and lower Chl *a* values. Gradient in vertical profile was almost absence. In this case, there is no big difference in total Chl *a* concentration of the euphotic zone in two models, and modeled PP assessments may not differ substantially.

However, satellite PP_{eu} in autumn of 2005 was a little bit higher than PP_{eu} retrieved with POI model. Higher satellite assessments in this case may be explained by difference in values of photoadaptive parameters of marine phytoplankton used in the models. Satellite PP_{eu} was retrieved with P^B_{opt} modeled as SST function. Modeled P^B_{opt} for this cruise was maximum for all three cruises and was higher than *in situ* one in POI model (Table 2). This in turn could cause higher assessments of satellite PP_{eu} in comparison with POI model assessments.

4. Conclusion

Results of comparison showed moderate correlation between modeled satellite and field PP_{eu} assessments. Main reasons of difference between two kinds PP_{eu} retrieval using models (on a base of satellite and field data) are (1) differences in satellite and field assessments of Chl_{90}, (2) vertical distribution of Chl *a* determined by water stratification, and (3) values of photoadaptive parameters used in the models (in this case, P^B_{opt}).

Acknowledgements

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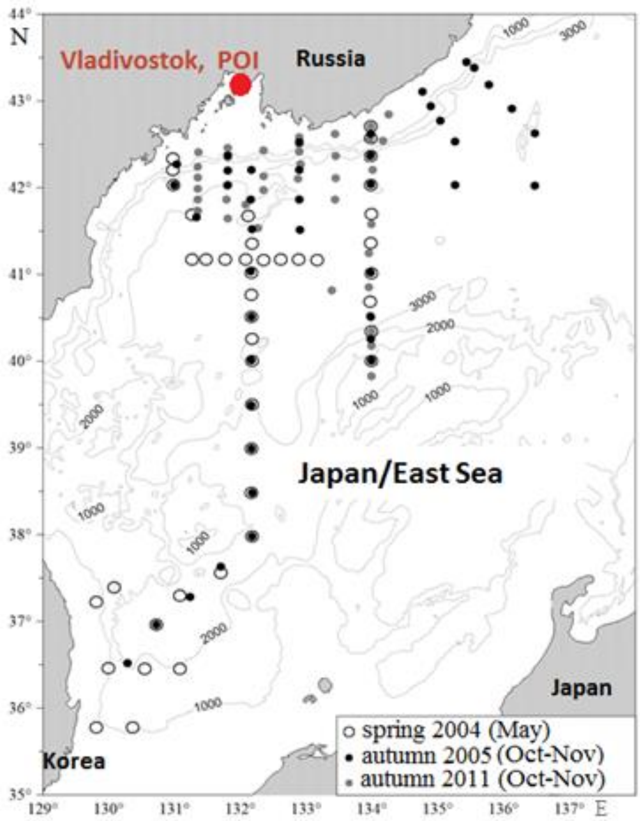

Figure 1. Map of the stations analyzed in the study

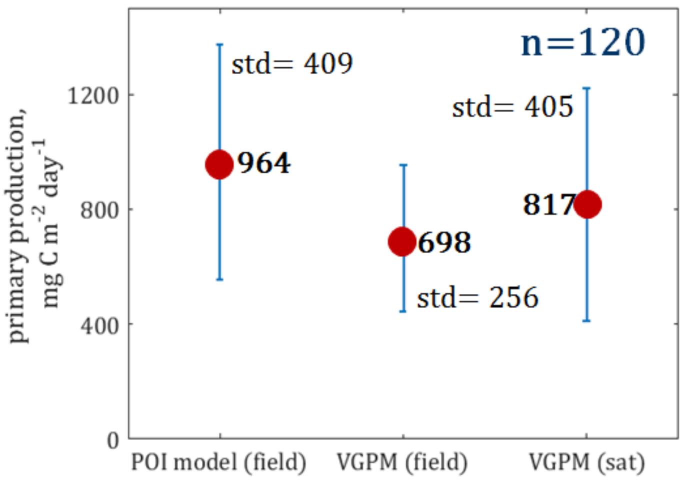

Figure 2. PP_{eu} [mg C m^{-2} day^{-1}] averaged over all stations (n=120), std is standard deviation

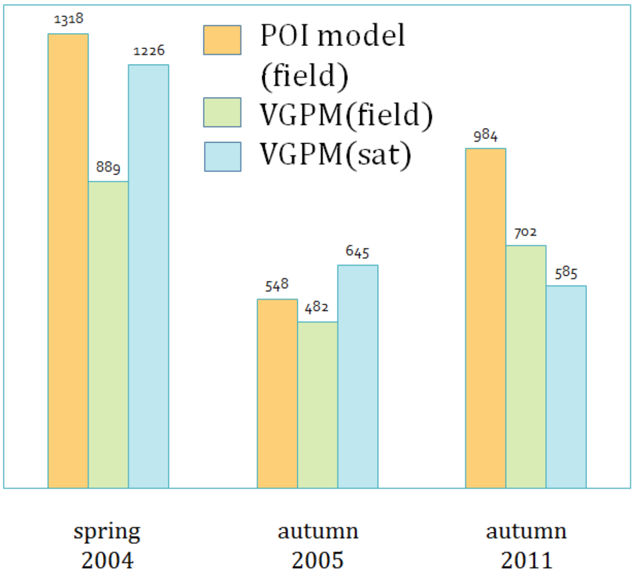

Figure 3. PP_{eu} [mg C m^{-2} day^{-1}] averaged over each cruise

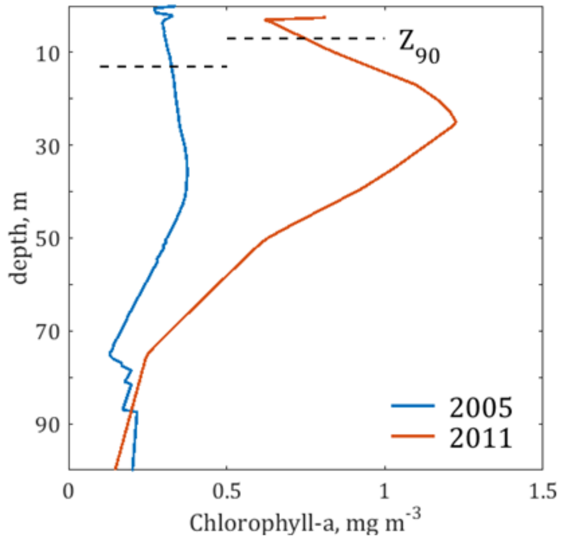

Figure 4. Averaged vertical profiles of Chl *a* [mg m^{-3}] for autumn cruises: blue line - autumn of 2005, red line – autumn of 2011; z_{90} - the first optic depth

Table 1. Correlation coefficients for satellite and field assessments of PP_{eu} and Chl_{90}

Satellite and field PP_{eu} (n=120)		Field PP_{eu} (n=120)	Satellite and field Chl_{90} (n=61)
VGPM	VGPM-POI model	VGPM-POI model	
0.63	0.56	0.71	0.58

Table 2. Modeled and *in situ* P^B_{opt} [mg C mg $Chl^{-1}h^{-1}$] used in the study

Cruises	In situ P^B_{opt}	Modeled P^B_{opt}
Spring 2004	4.46	4.32 (±0.78)
Autumn 2005		**5.69** (±0.79)
Autumn 2011		4.63 (±0.92)
All stations, n=120		4.84 (±1.02)