Variation of seawater temperature and chlorophyll-a prior to and during upwelling event in Bali Strait, Indonesia: from observation and model

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Abstract. Coastal upwelling event can be observed clearly from drastic changes of seawater temperature and chlorophyll-a before and during the event. From observation and model output, time-series data of these variables provide important datasets to be used for further analysis, such as developing gaussian empirical model of net marine primary productivity (NPP). Here, the objectives of this study are to analysis variation of temperature and chlorophyll-a (chl-a) from both observation and model output datasets, and to evaluate model temperature and chl-a for estimating the NPP prior to and during the upwelling event in Bali Strait. The archive CTD collected in April, June and August 2013 and model output datasets were used in this study. It is shown that during peak of upwelling event in August 2013, observed temperature is minimum and chl-a is maximum in the upper 50 m depth. It is found surfacing isotherm of 25-26°C from sub-surface to sea surface. Furthermore, model output of temperature was in good agreement with observed data, complementing the evolution of upwelling for entire year. Estimated NPP from empirical model suggested that a high NPP distribution occurred in the eastern part of Bali Strait during peak of upwelling event.

1. Introduction
Seawater temperature and chlorophyll-a (chl-a) are the main parameters for indicating upwelling event in Bali Strait. Time-series data of these parameters obtained from observation and complemented by numerical models provide important datasets for studying upwelling. Previous studies, based on satellite data and field observation, showed that upwelling event impacted on high marine primary productivity in south of Java and Bali the Indian Ocean [1][2]. This also triggered indirectly on upwelling intensity in Bali Strait [3]. High primary productivity is closely related to the abundance of lemuru fishes (as a plankton feeder) (Sardinella longiceps) in Bali Strait that occur during the transition monsoon. Swimming layer of of lemuru fishes can extend down to 30 m depth [4]. Seasonal upwelling event in Bali Strait is associated with high plankton concentration and high density of lemuru fishes [5]. Deep colder water but rich-nutrients are drawn to the sea surface during upwelling process. In surface area physical characteristics of upwelling is indicated by colder and higher salinity compared to the surrounding waters. Upwelling event is also associated with high concentration of nutrients, such as phosphates and nitrates and followed by by high concentration of plankton or chlorophyll-a after certain time. The higher concentration of chlorophyll-a is equally with high phytoplankton abundance [6].

The concentration of chlorophyll-a in Bali Strait was also affected by the inflow and outflow of water mass from the northern strait entrance, where inflow of low nutrient water may prevent nutrients...
availability from deeper water column [please put references]. Upwelling onset appears during the southeast monsoon period (May to September), which was characterized by the cold sea surface temperatures along the southern Java and Bali waters [7][8]. Observation study in 2012 showed that during the southeast monsoon period, the highest chlorophyll-a concentration in the upper 23 m depth with a minimum of temperature and maximum of salinity were found in Bali Strait [9].

This study aims to investigate variation of seawater temperature and chlorophyll-a prior to and during the upwelling event in Bali Strait, and to evaluate a empirical Gaussian model of vertical distribution of chlorophyll-a estimate from observed chlorophyll-a datasets in 2012. The data sets were obtained both from observation and model output of ocean general circulation model of hydrodynamic model Hamburg Shelf Ocean Model (HAMSOM).

2. Method

The study area is in Bali Strait Indonesia, constrained to geographical boundary of 08.10°S – 08.90°S and 114.25°E - 115.25° E (Figure 1). Seawater temperature and chlorophyll-a derived-fluo datasets were obtained from CTD (Conductivity Temperature Depth) measurement, carried out in April, June and August 2013. Total of 45 CTD casts have been collected during the cruise. However, in this study, we only used three cross-sections for further analysis.

![Figure 1](image_url)

Figure 1. Study area in Bali Strait Indonesia. Red dots are CTD stations. Black rectangles are sampling boxes for model validation.

The CTD datasets were processed and visualized in a vertical sectional by using Ocean Data View software version 3.2.0. From the vertical section the CTD data then were analyzed cross sectional from Java to the Bali (west to east) to see temperature variability, chlorophyll-a distribution, and Net Primary Productivity (NPP) distribution. Monthly average temperatures data were obtained from the reanalysis output HAMSOM) which was an average of 20 years data that were represented in January, April, June, September 2012. HAMSOM was one of the ocean models that had been widely used and applied in the world [10][1]. HAMSOM was built as a 3D hydrodynamic model and a baroclinic model [10] where the density changes and atmospheric forcing were considered in this simulation. The main equations that were used in this model were the equation of momentum, vertical hydrostatic equation, the continuity equation, and the continuity equations for temperature and salinity. This model had also been applied to the Indonesia waters and had been undergoing the validation process for the Indonesia waters, particularly the western part of Indonesia [11]. The bathymetry data was obtained from the Geomap which represented a resolution of 200 meters latitude x 200 meters longitude. The bathymetry data was
used as a barrier of euphotic layer and controller of chlorophyll and NPP calculation. Temperature data had a horizontal resolution of 5 minutes x 5 minutes (9 km x 9 km) which had 30 m of depth layers from 3 meters up to 10.455 meters, so re-gridding and kriging in the x and y axis to 200 m x 200 m were required. Data at the first layer that was considered as surface layer was used in the calculation of primary productivity. Then other temperature layer data will be used as supporting data to analyse the condition of NPP.

Chlorophyll-a vertical data were obtained from field measurement in June and September 2012, while surface data were acquired in January and April from Moderate Resolution Imaging Spectroradiometer (MODIS) satellite images were accessed in http: www.science.oregonstate.edu/ocean. productivity/. Field measurement data were used to get five parameter coefficients that form Gauss model in June and September. Furthermore, each of Gauss models were used to calculate vertical chlorophyll-a spatially in Bali Strait in January, April, June and September with reference of surface chlorophyll-a satellite data. MODIS surface chlorophyll-a data represented the monthly average with resolution of 9 km x 9 km, so the re-gridding and kriging on the x and y axis to 200 m x 200 m were conducted in accordance with the bathymetry resolution. Then the vertical chlorophyll-a as the result of Gauss model calculation was compared against the observation data in 2012 and 2013 for data test. The points of vertical test as shown in Figure 1 (black rectangles at station 1, 13, 25, and 35). The calculation process of chlorophyll-a and NPP. Vertical chlorophyll-a was calculated by using Gauss equation as in [12] and can be seen in equation (1) below:

\[
Chl(z) = B_0 + S \times z + \frac{h}{\sigma \sqrt{2\pi}} \exp \left(-\frac{(z-z_{\text{max}})^2}{2\sigma^2}\right)
\]

where:
- \(Chl\) : chlorophyll-a concentration (mg/m³).
- \(B_0\) : chlorophyll-a concentration background in the surface (mg/m³).
- \(S\) : gradient of slope (mg/m³/m).
- \(h\) : biomass total above the background (mg/m²).
- \(z\) : the depth of estimated chlorophyll-a (m).
- \(z_{\text{max}}\) : the depth of maximum chlorophyll-a (m).
- \(\sigma\) : standard deviation of Gauss distribution that controlled the thickness of chlorophyll-a maximum layer (m).

Values of \(B_0, h, \sigma, S,\) and \(z_{\text{max}}\) were obtained from vertical profile of chlorophyll-a in observation station in Bali Strait that was shown in Figure 2 (a). Value of these five parameters were required to obtain value of \(Chl(z)\) based on its relation to \(Chl(0)\) in the form of regression equation that the scheme can be seen in Figure 2 (b). \(B_0\) and \(z_0\) value were obtained directly from the regression as a function of surface chlorophyll-a, while \(Chl_{\text{max}}\) was used to find the \(h\) value. Then, the \(S\) value was obtained from the regression as a function of \(B_0\). After five parameters above were obtained, the standard deviation can be calculated by using equation (2) below [12]:

\[
\sigma = \frac{h}{\sqrt{2\pi}} \left(Chl_{\text{max}} - B_0 - S \times z_{\text{max}}\right)
\]

Primary productivity measurements which were conducted by [13] in the Sargassum Sea North Atlantic, the Southern Ocean and the Arabian Sea showed that the level of NPP based on [13] was higher in the Indian Ocean if compared with the [14], particularly in Southeast Asia, therefore, Marra were considered can be used for the calculation of primary productivity in the Indian Ocean, including the Bali Strait. Marra was based on the equation that was first used by [13]. Daily primary productivity at the depth \(z\) can be written as an equation (3) below:

\[
P(z) = \Phi \times \max_x \left(\frac{E_k}{E_k + Epar(z)} \right) \times \Phi \times Chl(z) \times Epar(z) \times dz
\]
Primary productivity in the depth of \( z \) (mol C/m\(^2\)/day).

\( \phi_{\text{max}} \) : Maximum value of quantum efficiency (mol C/mol photons).

\( E_k \) : Irradiance where \( \phi \) reach the half of its maximum value (mol photons/m\(^2\)/day).

\( E_{\text{par}}(z) \) : Radiation of Photosynthetic Active (mol photons/m\(^2\)/day).

\( a^*_{\text{ph}} \) : Coefficient of phytoplankton absorption (m\(^2\)/mg).

\( Chl_a \) : Chlorophyll-a number (mg/m\(^3\)).

\( dz \) : Thickness of depth layer (m)

Before the calculation of NPP were conducted, the euphotic depth \( z_{eu} \) was calculated based on the percentage of light intensity in the surface layer. Euphotic depth was the depth which light intensity only stayed 1% of surface light intensity: 

\[
EE = \frac{E_{\text{par}}(z)}{E_{\text{par}}(0)}, \quad z_{eu} = EE < 0.01
\]

The euphotic depth \( z_{eu} \) was used as integration boundary of net primary productivity as shown in equation (4).

\[
NPP = \int_0^{z_{eu}} P(z)dz
\]

Primary productivity calculation was conducted until the depth of 115 meters with 1 meter intervals so that primary productivity in the euphotic layer can be described well. Then the primary productivity was described horizontally and vertically in June to July, August to September, October to November.

**Figure 2.** (a) Gauss distribution that showed parameters of \( B_0 \), h, \( \sigma \), S, \( z_{\text{max}} \). Value of \( B_0 \), h, \( \sigma \), S, and \( z_{\text{max}} \) will be used to describe vertical profile of chlorophyll-a, (b) Procedure to calculate Gauss parameter value. Where: *1 regression as function of Chl\(_{0}\); *2 regression as function of \( B_0 \); *3 regression as function of Chl\(_{\text{max}}\); *4 calculate based on equation.

### 3. Result and discussion

#### 3.1. Observed seawater temperature

A cross-section of seawater temperature from CTD datasets in April, June and September 2013 revealed large spatial and temporal variations in Bali Strait (Figure 3). In April, temperature ranged from 26.5 to 29.5°C. Temperature in east side was 29.5°C which was warmer than that observed in west side (26.5°C). The minimum temperature was found at the depth of 55-60 m at 26°C. Temperature in June 2013 was relatively similar to those observed in April, which ranged from 29.5 to 30°C. In April and June, SST in the east side relatively warmer than the west side. The minimum temperature was found at a depth of 90-100 m ranged from 26 to 26.5°C. Temperature in August 2013 were coldest among temperature in April and June, as well as the temperature at the depth of 55-60 m colder which were ranged from 20-22°C and will decrease with the increased of depth, such as at the depth of 90-100 m where the minimum temperature reached 17.5-20°C.
Figure 3. Vertical distribution of temperature in April, June and August 2013.

At the same depth level in August, temperature was relatively colder than in April (26°C) and June 2013 (26-26.5°C). This is because August is peak of the southeast monsoon, in which the SST in the south Java, Bali, Nusa Tenggara waters is minimum, including in Bali Strait that was affected by the monsoon winds [15]. During the southeast monsoon (June-August) temperature is minimum and chlorophyll-a concentration maximum. In contrast, from December to February, during the northwest monsoon, warmer temperature and low chlorophyll-a are found. This minimum of temperature and maximum of chlorophyll-a indicate the upwelling phenomenon, which was characterized by cold water mass that moved from the deep layer to the surface that cause the decreased of SST and the increased of chlorophyll-a concentration.

3.2. Model monthly seawater temperature
The SST datasets from the HAMSOM model output were used for the analysis in January (the northwest monsoon), April (monsoon break I), June (the southeast monsoon) and September (monsoon break II) (Figure 4). In January, the SST ranged from 27.1 to 28.9 °C, which is much higher than that in the beginning of April that ranged from 26.5 to 27.1 °C. When entering the southeast monsoon in July, the SST ranged from 25.3 to 26.1°C, and decreased until the beginning of September that ranged between 24.3 and 25.1°C. [16] stated that in the northwest monsoon from January to March, SST of Indian Ocean
in south of Java ranged from 28-29°C and decreased in April-May that ranged from 28-27°C, and decreased to 25°C when entered the southeast monsoon in June to September. In addition, [17] reported that based on the monthly average of MODIS Aqua satellite image in 2012, SST in the southeast monsoon indicated a range of temperatures between 22 and 28°C, which is minimum compared to temperature in the northwest monsoon that ranged from 27 to 30 °C.

![Figure 4](image_url)

**Figure 4.** Monthly surface temperature (°C) from model simulation result for (a) January (the northwest monsoon), (b) April, (c) June (the southeast monsoon), (d) September.

Comparison of SST value in the northwest and southeast monsoon from previous studies is presented in Table 1. Previous study by [9] using CTD, showed that the maximum of chlorophyll-a concentration was occurred during September in the southeast monsoon at surface until 23 m depth. This indicated that temperature in the southeast monsoon in Bali Strait had been influenced by upwelling from waters in south of Java, Bali, Nusa Tenggara that were physically characterized by the upwelled colder water mass to the surface. So that, the surface temperature becomes colder and increased salinity in the surrounding waters. Previous study by [7] through the analysis of SST in the southeast monsoon in November 1981 - July 1999, reported that upwelling in the south Java and West Sumatra were closely related with the cycle of the southeast monsoon. The south-easterly monsoonal winds over south coast of Java flow along south coast of Java and Sumatra towards the equator. From that analysis showed that upwelling occurred in the south of East Java in June and it was seen maximum in August, moved toward to the equator along the west coast of Sumatera, and was seen maximum in October.
Table 1. SST in Indian Ocean in Bali Strait and South of Bali.

| No | Study                                | Northwest Monsoon | Southeast Monsoon |
|----|--------------------------------------|-------------------|-------------------|
| 1  | IMRO Observation (2012-2013)         | 27.1-28.9         | 24.3-25.1         |
| 2  | Sachoemar. I. S dan Yanagi. T (2000) | 28-29             | 25-27             |
| 3  | Ridha dan Hartoko (2012)              | 27 - 30           | 22 - 28           |

Upwelling phenomenon was clearly visible from the vertical distribution of the monthly average temperature (Figure 5) that cross from west to east (from Java Island to Bali Island). In the northwest monsoon, warm water mass with a temperature of 25.5-27.5°C was distributed until the depth of 60 m.

Figure 5. Simulated vertical temperature distribution (°C) in (a) January (Northwest monsoon), (b) April, (c) June (Southeast monsoon) and (d) September.

In April, cold water mass moved to the surface until the depth of 50 m and will continue to move to the surface when entering the southeast monsoon (July) at the depth of 40 m and the temperature decrease to 25-26 °C. In September temperature continues to decrease until reaching 25 °C at 23 m depth. This indicated that in the southeast monsoon around July to September in Bali Strait, colder water was lifted from deeper layer to surface which was physically characterized with the colder surface temperature and higher surface salinity. In July-September the surface temperature was lower based on the vertical distribution of cold water mass in the depth of 23-30 m and in January-April cold water mass moved to the bottom until the depth of 50-60 m. Based on the model output result, cold water mass was
lifted from the bottom to the surface when entered the southeast monsoon (July-September) and cold-water-mass will move down when entered the northwest monsoon until the end of April.

3.3. Model and data comparison of seawater temperature
Comparison of temperature profiles from model and observation showed a good agreement, especially in the CTD station closed to the ocean in St.25 and St.35 (see Figure1 for distribution of CTD stations), while the stations in the narrow strait waters closed to the mainland (St. 1 and St. 13) showed large discrepancies since the HAMSOM model is more suitable in the open ocean than in the narrow waters. Temperature in the narrow waters (St.1) from the model output was lower than observation result, while in the more open water (St.13) the result was better than in the St.1, where the surface temperature until the depth of 7 m from the model output was higher than the observation data. Temperature result from model output and observation had similar value at the depth of 10-20 m. At the depth more than 30 m, the model output had a higher value than the observation result. For the station near the ocean (St.25 & St.35) showed the best result than two previous verifications station (St.1 & St.13) where the range of temperature from the surface to the depth of 120 m were relative similar between model output with observation result. Result of vertical validation from model and observation were shown in the Figure 6.

![Temperature distribution](image)

**Figure 6.** Comparison of temperature profiles between model and data in St.1, St.13, St.25, St.35. Source: Result of model validation with CTD data.

3.4. Observed chlorophyll-a
Upwelling event in Bali Strait can also be seen from the sea surface chlorophyll-a concentration (SSC). Based on chlorophyll-a derived-fluoro sensor attached in CTD unit, spatial distribution of SSC showed temporal variation in April, June and August 2013. In April 2013 it ranged from 0.02 to 0.04 mg/m³ in a cross section from the west (Java) to the east (Bali). Minimum chlorophyll-a in surface layer was seen in the middle of the strait with value of 0.02 mg/m³, while the chlorophyll-a maximum ranged from 0.05 mg/m³ until 0.06 mg/m³ was seen between 20 and 25 m depth closed to Java Island. Concentration of SSC increased to 1-1.5 mg/m³ in June 2012 and minimum chlorophyll-a was still found in the surface layer in the middle of the strait with the concentration increased to 0.5 mg/m³. While the maximum concentrations ranged from 2 to 2.25 mg/m³ in June between 35 and 60 m depth closed to Java Island. Maximum concentration of SSC was found in August at the depth between 35 and 60 m and decreased to 20 m depth until sea surface (Figure 7).
Maximum SSC concentration was found in August (2-6 mg/m$^3$). It is in good agreement with past study, e.g. [2], documenting that upwelling in Bali Strait was influenced from large regional upwelling in South Java-Bali-Nusa Tenggara waters in the southeast monsoon that was characterized by increased of chlorophyll-a concentration. In May to October, southeast monsoon winds over the coastal of south Java – Bali drive westward monsoonal flow and shifts closed to coastal Java. Concentration of chlorophyll-a in southeast monsoon (measurement in June and August) was higher than in the northwest monsoon (measurement in April). This was caused by the water mass increased phenomenon in the south of Java and Bali in southeast monsoon that was occurred more intensive and brought influence in Bali Strait area.

![Figure 7. Vertical distribution of Chlorophyll-a in April, June and August 2013.](image)

Physically, upwelling areas were characterized by colder water mass, and higher salinity than the surrounding area and biologically generally were characterized by a high content of plankton or chlorophyll-a. The higher the concentration of chlorophyll-a in a body of water, the higher the abundance of its phytoplankton [6]. [18] in Bali Strait in the period 1964-1965, indicated that the chlorophyll-a concentration when the southeast monsoon (0.07 to 1.37 mg/m$^3$) was higher than in the northwest monsoon (0.01-.22 mg/m$^3$). In August the maximum chlorophyll-a concentrations that ranged from 4-6 mg/m$^3$ was found at the depth of 20 m in the waters near Bali Island (Figure 7). This was strengthened the results of previous studies by [9], that on the southeast monsoon which was represented by the measurement in July and August 2012 in Bali Strait, the maximum of chlorophyll-a concentration was found at the depth 23-25 meters with ranged from 4.61-6.53 mg/m$^3$. Another study [19] used the Gauss
model showed that maximum vertical distribution of chlorophyll-a in August was found in the depth of 25 m, and in June the maximum chlorophyll-a was found at shallower depths.

3.5. Model chlorophyll-a concentration
The average chlorophyll-a concentration from the model output result from June to July, August to September (southeast monsoon), October to November are shown in Figure 8.

As explained earlier that physically upwelling area was characterized by colder water mass with higher salinity than the surrounding area and biologically was generally characterized by a high content of plankton or chlorophyll-a. The higher the concentration of chlorophyll-a in a body of water, the higher the abundance of its phytoplankton [6]. Upwelling areas provide high nutrient input from the deep layer, the higher the concentration of nutrients, the higher the concentration of chlorophyll-a and followed with the increased of phytoplankton abundance which was the main food for lemuru fishes.

Upwelling phenomenon was clearly visible from the vertical chlorophyll-a distribution from west to the east (Java-Bali) that was represented at latitude 8.7°S (Figure 9). The chlorophyll-a concentration
was seen high in June-July that ranged from 2.3-5 mg/m³ at the depth of 5-23 m and reached a maximum value in August of about 5 mg/m³.

![Image of chlorophyll-a distribution](image)

**Figure 9.** Vertical distribution of chlorophyll-a from simulation result in latitude 8.7°S in (a) June, (b) July, (c) August, (d) September, (e) October and (f) November.

The surface concentration chlorophyll-a was high when entering the southeast monsoon, where there was a cold-water-mass that moved from the bottom to the surface that carried nutrients with high chlorophyll-a concentrations. This condition was caused by high concentrations of nutrients that was produced through a physical process of water mass, where the water mass brought nutrients from deep layers to the surface layer [20]. The upwelling was occurred in the southeast monsoon and the downwelling was occurred in the northwest monsoon. Upwelling in Bali Strait was occurred in the beginning of southeast monsoon and ended in the end of November. [2] stated that the maximum concentration of chlorophyll-a in the south of Java - Bali was located at the depth of 20 meters in southeast monsoon and 80 meters when the northwest monsoon. Chlorophyll-a concentration in the southeast monsoon was found in shallower depths than in the northwest monsoon, it was related with the lifted of cold-water-mass from the bottom to the surface that brought high nutrient and chlorophyll-a.
3.6. Empirical model of Net Primary Productivity (NPP)

Upwelling phenomenon can be identified from the parameters of temperature, chlorophyll-a and NPP. Parameters NPP was not measured through direct measurement (observation) but using the calculation results of monthly average numerical model output. NPP calculation of numerical model output represented result in June-July, southeast monsoon (August to September) and October to November (Figure 10).

Figure 10. Monthly average of Net Productivity Primary from empirical model in (a) June, (b) July, (c) August, (d) September, (e) October and (f) November.

NPP was the result of a reduction in gross primary productivity value with the energy that was used for respiration. Primary productivity was the formation rate of organic compounds that rich with energy from inorganic compounds. Total number of organic materials (biomass) that was formed in the productivity process was called gross primary productivity, or the total production. Gross and net primary production were generally expressed in the number of grams of carbon (C) which was bound per unit area or volume of sea water per time interval. Thus, production can be reported as the number grams of carbon per m² per day (gC/m²/day), or other units which more appropriate. The standing crop that was applied to phytoplankton was the number of biomass phytoplankton in a certain volume of water at a certain moment. At the sea, especially the open ocean, phytoplankton was the main autotrophic
organism that determined the primary productivity in waters. Net primary productivity in the ocean was greatly affected by physical ocean processes such as upwelling. Figure 10 showed that in June-July NPP was minimum if compared with NPP in southeast monsoon (August to September) and in October to November. Maximum NPP was seen in August - September-October, especially on the east coast of Bali Straits (southwest of Bali Island, southern coast of East Java, and southeast Banyuwangi or Belambangan Peninsula). Based on empirical equations, chlorophyll-a concentration was seen high in August-September, as a consequence, the NPP calculation result was also high. Based on the research results of [21], the average value of NPP and primary productivity in Indonesia water increased in June to September. This was related with the upwelling process in some areas of Indonesia during the southeast monsoon. Then further research by [22] showed that the high primary productivity in the south of Java, Bali, Nusa Tenggara was occurred because the upwelling process on south coast of Java and along the southern coast of Bali to Nusa Tenggara in the southeast monsoon around June to September. The wind from the east caused water mass emptiness along the influence of the duration and intensity of upwelling. The waters were then replaced by a water mass from the deep sea that carried a higher nutrient content, by seeing a decreased of SST and increased of NPP.

4. Conclusion
The result of observation and model output datasets analysis showed that in the southeast monsoon, SST in Bali Strait is minimum and chlorophyll-a concentration and NPP is maximum from surface to 20 m depth, in contrast to that occurred in the northwest monsoon period. This result is in good agreement with previous studies, in which the maximum chlorophyll-a concentration was occurred in southeast monsoon in September from surface to 23 m depth. Furthermore, based on model output and observation datasets it is revealed upwelled cold-water-mass from deeper layer to the sea surface layer that was occurred in July to September or southeast monsoon. It was characterized by decreased of SST and increased of NPP. This study was only reviewed the linkages between temperature, chlorophyll-a and NPP spatially in the certain time (seasonal analysis). In the next study will evaluate temporal variation of parameters by using longer time series datasets covering scale of variability from intra-seasonal to interannual periods. So that upwelling prediction can be made based on the space and time domain. Numerical model approach (parameter: temperature, chlorophyll-a, NPP) and observation (parameter: temperature, chlorophyll-a) have been able to describe a pretty accurate of upwelling phenomenon, although in the next phase NPP observation data are still required for model validation so that the prediction result will have a higher accuracy.

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