Spatial-temporal variation of anomaly chlorophyll-a in Southern Java and Nusa Tenggara using empirical orthogonal function analysis

F Khadami* and T Suprijo
Oceanography Research Group, Faculty of Earth Sciences and Technology, Institut Teknologi Bandung, Bandung, Jawa Barat, Indonesia

*Corresponding Author: fkhadami@oceanography.itb.ac.id

Abstract. Data from Global Ocean Biogeochemistry models were used to study the spatial and temporal variation of sea surface chlorophyll-a in southern Java and Nusa Tenggara. Empirical Orthogonal Function (EOF) analysis was applied to decompose spatial and temporal mode of the anomaly chlorophyll-a. The first mode (58.7%) revealed strong interannual variation that had a significant correlation with the Indian Ocean Dipole (IOD) event. The Second mode (7.2%) of the temporal pattern showed seasonal periods while the spatial pattern showed the opposite phase between southern Java and Nusa Tenggara. The spatial pattern of mode 3 (5.2%) and 4 (2.7%) showed an interesting pattern where it showed strong variance in the exit way of Indonesian Trough Flow. However, it needs more study to conclude the phenomena that were revealed by mode 3 and 4.

1. Introduction
Chlorophyll-a is one of a physical parameter that becomes an indicator of upwelling onset. When upwelling occurs, nutrients from deep layer moves upward to the upper layer which causes increasing of nutrient concentration in the upper layer. Increasing of nutrient induce high biogeochemical cycle that affects on increasing marine productivity.

Southern Java and Nusa Tenggara are one of location in Indonesia that have upwelling system[1,2]. Upwelling in southern Java and Nusa Tenggara occur in every summer monsoon (Juni – August) [2]. Moreover, the variability of upwelling in southern Java and Nusa Tenggara affected by interannual phenomena [3]. IOD positive in the Indian Ocean will affect strong upwelling as well as a high concentration of chlorophyll-a[2].

In this study, we examine chlorophyll-a data from biogeochemical model using Empirical Orthogonal Function (EOF) technique. This technique will be used to decompose spatial and temporal variability. The aim of this study is to describe the spatial-temporal variation of chlorophyll-a in southern Java and Nusa Tenggara.

2. Materials and Methods
The study area was located in along south Java Coast to south Nusa Tenggara Islands. The monthly mean chlorophyll-a from Global Biogeochemical hindcast data with horizontal resolution 0.25 from January 1998 to December 2016 were obtained from Copernicus Marine Environment Monitoring Service. The anomaly of Chlorophyll-a is calculated by subtracting the data with its monthly
climatology data at each grid point. The monthly climatology data is obtained from averaging every data on the month. Dipole Mode Index from National Oceanic and Atmospheric Administration (NOAA) on the same period were used to analyze the result.

EOF technique was used to identifying the spatial and temporal pattern of the anomaly of chlorophyll-a in the study area. EOF analysis decomposes the datasets into modes based on the covariance matrix of the data [4]. The first mode is the most important variance which has the highest variability. The decomposition of the parameters into modes of variability using EOF analysis is expressed as:

\[ X(t) = \sum_{i=1}^{N} [a_i(t)a_i] \]

Where \(X(t)\) is the original time series of chlorophyll-a, \(a_i\) is the temporal pattern of mode-i, and is the spatial eigenfunction mode-I (spatial pattern).

**Figure 1.** Time mean (a) and standard deviation (b) of anomaly chlorophyll-a January 1998 – December 2016.

### 3. Results and Discussion

Figure 1 shows the spatial pattern of time mean and the standard deviation of chlorophyll-a from January 1998 – December 2016. The time-mean chlorophyll-a shows high concentration chlorophyll-a in along southern coast Java, Bali and Lombok (Figure 1a), as well as the standard deviation (Figure 1b), indicates strong variability on along south Java and Nusa Tenggara. It is consistent with the previous study that used satellite data[5].
Figure 2. Monthly climatology of chlorophyll-a from June – November.

The 18 years monthly climatology of chlorophyll-a showed annual variation which high concentration of chlorophyll-a in southeast monsoon. It started in June and maximum August-September and disappear in November. This seasonal pattern is consistent with the previous study that used observed-satellite data [2]. The abundance of chlorophyll-a concentration during southeast monsoon is caused by along-shore southeasterly winds from Australia that drive offshore Ekman transport then result in Ekman pumping [2,5].

EOF technique was applied to Chlorophyll-a anomaly to evaluate the spatial-temporal variation. EOF technique reveals the spatial and temporal variability and also the percentage of the total variance. The spatial variability is presented in figure 2. The first EOF mode of anomaly chlorophyll-a which have 58.7% of total variance show high variability along the south coast of Java – Nusa Tenggara (Figure 2a). The second mode that has 7.2% of total variance reveals opposite phase in south Java and Nusa Tenggara (Figure 2b). The third EOF mode (Figure 2c) is explaining 5.2% of the total variance and it shows minimum variability around south Bali and Lombok. In the other hand, the fourth mode (Figure 2d) which has 2.7% of total variance shows maximum variability around south Lombok. It is interesting finding that mode 3 and 4 show a minimum and maximum variability around south Lombok because Lombok passage is the main exit way of Indonesian Through Flow (ITF). Unfortunately, the effect of ITF toward on chlorophyll-a variability is not discussed further.
Temporal variation of the mode is presented in figure 4. The first mode shows a strong interannual variation. To evaluate the interannual variation, the correlation between the temporal pattern of the first mode and the Dipole Mode Index (DMI) was calculated. The result shows that the first mode and DMI are significantly correlated with $r = 0.58$. The result is consistent with the previous study that the blooming of chlorophyll-$a$ is strongly affected by the Indian Ocean Dipole phenomena [3,6]. The temporal pattern of mode 2, 3 and 4 mostly have strong seasonal variability. This variability is associated with seasonal wind in the study area. The monsoonal change of wind is suggested to be the main driving force of mode 2[2,5]. In other hands, This study suggests that mode 3 and 4 are associated with the seasonal change of ITF. However, it needs more study to explain that.

4. Conclusion
The variability of chlorophyll-$a$ in along south coast Java and Nusa Tenggara is strongly affected by monsoonal wind. The southeasterly wind in June – November derives coastal upwelling that is followed by increasing concentration of chlorophyll-$a$. The first mode of EOF analysis that having 58.7% of total variance reveals the spatial pattern that has high variability of anomaly chlorophyll-$a$ along south coast Java and Nusa Tenggara while the temporal pattern reveals interannual variation associated with Indian Ocean Dipole. The second mode that counting 7.2% of total variance shows opposite phase between along south coast Java and Nusa Tenggara while the third (5.2%) and fourth mode (2.7%) show high variability on around south Bali and Lombok where Lombok is the main exit way of ITF. The temporal pattern of mode 2, 3 and 4 show seasonal variation. Variability of the spatial-temporal pattern of mode 2 suggested the influence of seasonal variation wind while mode 3 and 4 suggested the influence of ITF on chlorophyll-$a$ variability.
Figure 4. Temporal pattern (a,b,c,d) and power spectrum density (f,g,h,i) of principal component of first four EOF mode of anomaly chlorophyll-a and (e) Dipole mode Index.

Acknowledgment

The authors thank Oceanography Research Group, Bandung Institute of Technology for supporting this research through “Program Penelitian dan Pengabdian Masayarakat (P3MI) 2018”

References

[1] Wyrtki K The upwelling in the region between Java and Australia during the south east monsoon 1962 *Aust J. Mar Freshw Res* 17217-225

[2] Ningsih N S, Rakhmaputeri N and Harto A B 2013 Upwelling Variability along the Southern Coast of Bali and in Nusa Tenggara Waters *Ocean Sci* 48(1)49-57
[3] Susanto R D, Gordon A L and Zheng Q 2001 Upwelling along the coasts of Java and Sumatra and its relation to ENSO J. Geophys Res Lett28(8)1599-1602
[4] Emery, W J and Thomson R E 2004 Data Analysis Methods in Physical Oceanography (Amsterdam: Elsevier)
[5] Iskandar I, Sari Q W, Setiabudidaya D, Yustian I and Monger B 2017 The distribution and variability of chlorophyll-a bloom in the southeastern tropical Indian Ocean using Empirical Orthogonal Function analysis Biodeversitas18(4) 1546-1555
[6] Iskandar I, Rao S A and Tozuka T 2009 Chlorophyll-a bloom along the southern coasts of Java and Sumatra during 2006 International Journal of Remote Sensing30 663-671