Upwelling Dynamic Based on Satellite and INDESO Data in the Flores Sea

Reski Kurniawan, D. A. Suriyamihardja, Alimuddin Hamzah Assegaf

Study Program in Geophysics, Faculty of Mathematics and Natural Sciences, Hasanuddin University
E-mail: reskur.r@gmail.com

Abstract. Upwelling phenomenon is crucial to be forecasted, mainly concerning the information of potential fishery areas. Utilization of calibrated model for recorded upwelling such as INDESO gives benefit for historical result up to the present time. The aim of this study is to estimate areas and seasons of upwelling occurrences in the Flores Sea using data assimilation of satellite and modeling result. This study uses sea surface temperature, chlorophyll-a data from level 3 of MODIS image and sea surface height from satellite Jason-2 monthly for three years (2014-2016) and INDESO model data for sea surface temperature, sea surface height, and chlorophyll-a daily for three years (2014-2016). The upwelling is indicated by declining of sea surface temperature, sea surface height and increasing of chlorophyll-a. Verification is conducted by comparing the model result with recorded MODIS satellite image. The result shows that the area of southern Makassar Strait having occurrences of upwelling phenomenon every year starting in June, extended to July and August. The strongest upwelling occurred in 2015 covering more or less the area of 23,000 km². The relation of monthly data of satellite has significantly correlated with daily data of INDESO model.

1. Introduction
Oceanographic characteristics are determined by various oceanographic parameters, namely temperature, chlorophyll-a, and sea surface height. Temperature and chlorophyll-a are crucial resources for life of fish, and sea surface height is important to predict upwelling area [1]. Temperature is environmental parameter which is most often measured at sea because of its usefulness in studying physics, chemistry, and biology processes that happened at the sea. The distribution pattern of sea surface temperature can be used for identification other oceanographic parameters such as current, upwelling, and front [2]. Some of the parameters for describing oceanographic characteristic at the sea can be measured in two ways. The first way is direct measured oceanographic parameter at sea for example ship survey or by placing measuring instrument on research location (mooring, tide gauge, etc). The second way is using satellite technology [3].

Provision of oceanographic data through direct measurements are relatively involved large operating costs. Information data obtained from the satellite could estimate chlorophyll-a distribution, sea surface temperature, and the pattern of sea waves. Assimilation data from satellite and modeling data could interpret ocean phenomenon especially for the potential presence of schooling fishes which is associated with the upwelling phenomenon [4]. Some researchers have investigated for reviewing upwelling areas at the Flores Sea, predicted the areas of upwelling phenomena just using satellite data and have not yet compared with the modeling data.

An accurate monitoring and forecasting system for the ocean is certainly vital to managing Indonesia waters and its resources. To meet these challenging objectives the INDESO (Infrastructure Development of Space Oceanography) project was developed for the Government of Indonesia [5]. The Operational INDESO physical Ocean forecast system, at 1/12° horizontal resolution, provides 10 days of 3D ocean forecast and is updated weekly. The output of the INDESO model covers daily mean fields of atmospheric fluxes, physical parameters (temperature, salinity, currents, sea level), hourly surface
variables such as Sea Surface Temperature (SST), Sea Surface Height (SSH), and currents, as well as hourly values of all fields related to selected mooring sites and validation metrics [6].

The main objective of this study aims to obtain proper areas and significant months providing potential fishing grounds, based on SST, SSH, and chlorophyll-a maps using the assimilation of MODIS satellite images with INDESO model. Therefore, it is necessary to examine the correlation between satellite data and model data to construct reasonable judgment.

2. Methodology
The study area covers the Flores Sea as the whole depicted in figure 1 with southern latitude between 5°50'22.69'' S and 8°30'32.43'' S, and with longitude 119°18'56.20'' E - 125°10'2.61'' E. Soft-ware used in this study for processing data are Ferret NOAA, SeaDAS 7.4, and Ocean Data View. Data to be analysed are (1) SST, chlorophyll-a from level 3 of MODIS image (obtained from www.oceancolor.gsfc.nasa.gov); (2) SSH from satellite Jason-2 (obtained from www.podaatools.jpl.nasa.gov) monthly for three years (2014-2016); and (3) INDESO model data for SST, SSH, and chlorophyll-a daily for three years (2014-2016) (obtained from www.indeso.web.id).

The ocean physical model named INDO12 used for the INDESO project is a regional configuration of the NEMO-OPA primitive equation OGCM (Madec et al., 1998; Madec, 2008). This model is forced at the surface using 3-hourly ECWMF atmospheric analysis and forecast fields and at the lateral open boundaries using Mercator Ocean global operational analysis and forecast fields. This regional ocean physical model provides physical fields for the past two weeks (forced by a global 2-weeks analysis) and ocean forecasts (forced by a global 10-day forecast) for the next 10 days. The regional INDESO physical ocean model is implemented with a horizontal resolution of 1/12° and 50 vertical layers with increased resolution near the surface. The horizontal grid is defined on a curvilinear ORCA grid but outputs are provided on a regular 1/12° grid. The regional INDESO physical ocean model has the following additional characteristics that is partial step representation of the bathymetry, explicit resolution of the tides, non-linear free surface to allow a good representation of tidal waves in coastal regions where their amplitude is large compared to the local depth (Levier et al., 2007), parameterization of internal tidal mixing as developed by Kock-Larrouy et al. (2007) for the Indonesian sea [6].

Processing data of SST and chlorophyll-a from Aqua-MODIS image is done by downloading the data in Hierarchical Data Format (HDF). The downloaded data is cropped according to the study area using software SeaDAS 7.4. The cropping result is then converted into * txt format in order to be able to export to Ocean Data View that serves as a data filter (quality control) to eliminate extreme high data and low extreme data that is not supposed to be the value of the parameters being searched. Quality control is used for SST in the ranges of 25°C < SST ≤ 32°C and for chlorophyll-a in the ranges of 0 mg/m³ <chlorophyll-a ≤ 1.0 mg/m³. The result of this data processing will be in a two-dimensional spatial distribution profile of SST and chlorophyll-a concentration in the * tif format.

Data processing for INDESO model data using Ferret application from NOAA, this application run under Ubuntu Linux operating system. The SST and chlorophyll-a data are processed to produce spatial profiles for two seasons to analyze upwelling phenomena, then SST and SSH data are created in order to be able to overlay through the obtained graphs in time series to examine the relationship between the two parameters to upwelling phenomena.
3. Results

3.1. Verification Data

Figure 2 depicts the data from satellite and INDES0 model that shows a similar pattern of SST and chlorophyll-a. Root Mean Square Error (RMSE) value between the two data origins is about 0.5 for SST and 0.57 for chlorophyll-a concentrations. Those results informed that the model has a good level of trust. The two data origins show strong correlation value, as for SST is about 0.91 and as for chlorophyll-a concentrations is about 0.94.
3.2. Distribution Sea Surface Temperature (SST) and Sea Surface Height (SSH)

The result of monthly satellite image from level 3 and INDES model at the Flores Sea showed homogeneous distribution pattern of SST. The more homogeneous distribution pattern of SST at the Flores Sea is found in the west monsoon (December-February). To be the relatively high temperature in the range of 28-31°C. The east monsoon begins in June characterized by decreasing temperature at southern Makassar Strait as depicted in Figure 3 and figure 4.

![Figure 3. INDES model results in distribution pattern of SST on east monsoon (June-August).](image)

The more visible decreasing temperature in the area is found in July and August, it is supposed to indicate upwelling phenomena. The low value of SST indicates upwelling phenomenon reached its culmination in the first week on July with water mass temperature is about 23°C-24°C and continued until the fourth week on August, then weakened until disappear in the fifth week on September which is in agreement with the results of Bidawi (2010) [7].
Figure 4. Satellite results in distribution pattern of SST on east monsoon (June-August).

Generally, the percentage rate of distribution SST for upwelling phenomena on 2014, 2015, and 2016 begins on July that happened on southern Makassar Strait and reached its culmination on August, which showed the phenomenon of expanding area of low SST value indicated by increasingly expanding of upwelling phenomena. Decreasing SST value is most visible in June and July which indicates the existence of upwelling phenomena. On July-August these phenomena are most visible with the distribution pattern of SST which distributed horizontally on southern Makassar Strait area, this pattern is in agreement with Inaku (2015) [8].
Figure 5. Overlay chart between SST & SSH (left), correlation chart between SST & SSH (right).
Figure 6. Jason-2 satellite results of sea surface height (June-August).
Figure 7. INDESO model distribution pattern of chlorophyll-a concentrations on east monsoon (June-August).
Figure 8. Satellite result distribution pattern of chlorophyll-a concentrations on east monsoon (June-August).
This decreasing temperature followed by low SSH value on southern Makassar Strait during east monsoon, this trend gives a way to overlay between SSH and SST which indicates the upwelling phenomena, this trend can be seen in figure 6. Coefficient correlation between the coordinate of SST and coordinate of SSH has strong value that is 0.8 every year. It means that the troughs and peaks of SST and SSH are relatively coincided.

SSH profile in the ocean is dynamic always changing depending on wind speed blowing over sea surface and strongly influenced by the melting ice in the polar region. The existence of upwelling phenomena also affects the profile of SSH, which causes the value of SSH to be low or even minus. Figure 6 shows areas in southern Makassar Strait has a dynamic SSH and low SSH value which indicates that area is experienced upwelling formation.

3.2. Distribution chlorophyll-a

 Apparently, the level of chlorophyll-a concentrations looks different every season. During west monsoon, the level of chlorophyll-a concentrations on the Flores Sea reaches a low value. However, the level of chlorophyll-a concentrations relatively high encountered in coastal waters instead of offshore areas. This fact is reasonable due to the influence of nutrient input from the land caused by relatively high rainfalls levels in west monsoon.

The spatial distribution of chlorophyll-a concentrations during the east monsoon shows a relatively high increase in June and its culmination occurs in August. The high concentrations of chlorophyll-a in east monsoon previously preceded by low SST that indicates upwelling formation, this is in accordance with Wyrtki explanation (1961) [9] which stated that the upwelling in this area occurs in the east monsoon (June-August). At the beginning of the second transition season in September, the pattern of upwelling is still apparent, estimated in October as the end of the upwelling phenomena, this is seen from the appearance of chlorophyll-a concentrations that begin to decrease again this is shown in figure 7 and figure 8.

![Figure 9. Chlorophyll-a concentrations distribution on southern Makassar Strait.](image)

In July it was seen that the pattern of chlorophyll-a concentrations distribution is relatively high in the surrounding coastal waters especially the southern Makassar Strait, while in July until August distribution pattern began to look widespread to the southwest of Sulawesi Island towards the Flores Sea. Figure 8 depicts the level of chlorophyll-a concentrations in the southern Makassar Strait in 2014, 2015, and 2016 that shows the chlorophyll-a concentrations begins to increase and reaches its culmination in the east monsoon each year, the increased chlorophyll-a concentration is obviously given evidence to the widespread distribution pattern in southern Makassar Strait.
Figure 10. Overlay chart between SST and chlorophyll-a.

3.3. Upwelling Fluctuations
Distribution pattern obtained from the analysed results of SST, SSH, and chlorophyll-a in 2014, 2015, and 2016 indicates that the average SST decrease begins in May or when it enters the east monsoon, which is then followed by decreasing SSH and increasing chlorophyll-a concentrations on southern Makassar Strait which spread to the Flores Sea as depicted in.

The decline of SST in 2014 begins in the last week of May then reaches its culmination in the first week of September and ends in the third week of October, followed by increased chlorophyll-a concentration in August and September which then declines again in October. In 2015 the decrease of SST begins in the second week of May then climax in the second week of July and ends in the last week of October, followed by increased chlorophyll-a in August and September which then declines in October. The phenomena that occurred in 2016 were not much different from the previous two years, the decrease in SST starting in the last week of May then climax in the second week of August and ending in the second week of September, as well as the increase in chlorophyll-a concentrations that
occurred in August and decreased at September. In the three years, 2015 was the peak of upwelling with the spreading area of the decreasing SST from the southern part of the Makassar Strait to the southwest Makassar Strait towards the Flores Sea. The time of upwelling phenomena are peaked in all years (2014-2016), but the pattern of upwelling spread clearly pointed towards the southwest of Sulawesi Island. The total upwelling area for 2014 is estimated to be about 15,000 km², then by 2015 to be about 23,000 km², and by 2016 to be about 6,000 km².

4. Conclusion
As mentioned beforehand, this study aims to obtain proper areas and significant months providing fishing ground which give benefit to fishermen. According to the maps of SST and Chlorophyll-a which have been shown in figure 3, 4, 7 and 8 can be concluded that the significant fishing grounds are in the area of offshore waters of Jeneponto and Takalar Regencies covering more or less 23,000 km². According to the data recorded in three years, the most probable season in providing fishing ground is the months of June, July and August which is mainly during east monsoon.

This study involved the two sources of data, the first is obtained from monthly satellite data, and the second is obtained from daily INDESO model. Based on the fact provided by figure 2, the two sources are considered to be significantly related due to the value of correlation is achieving 0.9.

Acknowledgments
We appreciate to Balai Penelitian dan Observasi Laut Jembrana Bali for letting us use INDESO data for three years (2014-2016), and especially for Ms. Desy Berlianty for her introducing and guidance in using the program of INDESO for whom we are indebted.

References
[1] Hakim M R 2011 Karakteristik Oseanografi di Permukaan Perairan Utara Jawa, Selatan Lombok Hingga Sorong, Papua Barat Pada Musim Timur 2010 Skripsi (Bandung: Institut Pertanian Bogor)
[2] Amri K, Asep P and Suprapto 2014 Karakteristik Oceanografi dan Kelimpahan Fitoplanton di Perairan Selat Sunda Pada Musim Timur Jurnal BAWAL 6 (1)
[3] Wilopo M D 2005 Karakter Fisik Oceanografi di Perairan Barat Sumatera dan Selatan Java-Sumbawa Dari Data Satelit Multi Sensor Skripsi (Bandung: Institut Pertanian Bogor)
[4] Sukoraharjo S S, Djsisman Manurung, Indra Jaya, Bonar P. Pasaribu and Jonson L G 2011 Menduga Penaikan Massa Air Dengan Menganalisis Pola Pergerakan Angin di Perairan Selat Makassar Jurnal Kelautan Nasional 6 (3)
[5] Nugroho D, Koch-Larrouy A, Gaspar P, Lyard F, Relfray G and Tranchant B 2016 Modelling Explicit Tides in the Indonesian Seas: An Important Process for Surface Seawater Properties Marine Pollution Bulletin https://doi.org/10.1016/j.marpolbul.2017.06.033
[6] INDESO 2013 A System Implemented by CLS For Balitbang KP all rights reserved
[7] Hasyim B, Sayidah S and Maryani H 2010 Kajian Dinamika Suhu Permukaan Laut Global Menggunakan Data Penginderaan Jauh Majalah Sains dan Teknologi Dirgantara 5 (4) 130-143
[8] Inaku D F 2015 Analisis Pola Sebaran dan Perkembangan Area Upwelling di Bagian Selatan Selat Makassar Torani (Jurnal Ilmu Kelautan dan Perikanan) 25 (2) 67-74
[9] Wyrtki K 1961 Physical Oceanography of the South East Asian Water NAGA Report 2 Scripps Inst.Oceanography La Jolla (California: The University of California)