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Aqua MODIS and altimetry satellite data utilization for determining the effective time and area of fishing in South Sulawesi

M F Islami, H A Rejeki and A Fadlan
Indonesian Agency for Meteorology Climatology and Geophysics, School of Meteorology Climatology and Geophysics, Tangerang Selatan, 15221 Indonesia

e-mail: muhammad.fuad@stmkg.ac.id

Abstract. South Sulawesi is one of the provinces in Indonesia which geographically is a marine-based area with huge potential of marine resources. In sea resources exploration activities are often found obstacles caused by the variability of weather and climate that affect the condition of South Sulawesi waters. Limited availability of weather data in the waters of South Sulawesi Province has caused difficulties in analyzing and identifying conditions in these waters. The use of the MODIS Aqua satellite and Altimetry can be used as a solution in the analysis and identification of water conditions. Aqua MODIS satellite data used in this study is the sea surface temperature (SST) and chlorophyll-a data while the Altimetry satellite data used is significant wave height data. In addition, Niño 3.4 Index are used as supporting data to identify the weather and climate phenomena that occur in the waters of South Sulawesi in this case are El Niño and the Southern Oscillation (ENSO) phenomena. SST and chlorophyll-a data are used as indicators in determining fish catch potential and significant wave height data are used to determine the effective time in fishing activities in the waters of South Sulawesi Province. The results showed that a significant wave peak height in the waters of South Sulawesi occurred in July. The highest chlorophyll-a average occurred in August when the average SST showed the lowest value or when the El Niño event occurred.

1. Introduction
South Sulawesi is one of the provinces in Indonesia which is geographically a very large marine-based area. This is caused by the 24 regencies located in South Sulawesi Province, 2/3 of them are regencies that have coastal and marine areas. The potential of marine resources is certainly a boon for fishermen living in the coastal and marine areas of South Sulawesi province. However, fishermen who live in these places get problems and threats, one of which is about changes or variability in weather and climate that occur in the waters of South Sulawesi Province.

The interaction between the oceans and the atmosphere in the waters of South Sulawesi province in relation to weather and climate variability is very interesting to study. The sea is considered to play a very important role in changing weather and climate. Ocean and atmospheric interactions cause very important phenomena, namely El Niño and La Niña (ENSO). ENSO is a global phenomenon in the Pacific Ocean region, namely heating up or cooling the sea water temperature far above or below its normal conditions. Whereas generally the ENSO phenomenon affects the fertility of waters in the Indonesian region [1].
Several oceanographic parameters that are quite widely studied are related to the physical dynamics that occur in a water area, namely sea surface temperature (SST), water fertility, and wave height. Temperature is an important factor for the life of organisms in the sea and becomes an indicator of the phenomenon of climate change [2]. Chlorophyll-a is the most common chlorophyll type of plant. In the inventory and mapping of coastal and marine natural resources, chlorophyll-a is used to determine the presence of phytoplankton in water. Indicators of fertility and aquatic productivity can be measured from chlorophyll-a content [3][4]. The highest value of chlorophyll-a concentration generally moves according to the lowest SST development [5]. Utilization of satellite-based oceanographic oceanography data and fish catch data can be used to indicate the relationship between SST and chlorophyll-a to potential fishing zones for skipjack fish. This shows that the main oceanographic indications of SST and chlorophyll-a provide a good indicator to predict the potential of skipjack fishing in Bone Bay - Flores Sea during the Northwest Monsoon [6]. Ocean waves are natural phenomena that affect efficiency and safety for marine activities, so that information on variations and characteristics of ocean waves is certainly needed by fishermen in catching fish in the ocean [7].

2. Data and method

In this study used a type of approach that is a qualitative approach. The qualitative approach is conducted by explaining the visualization of oceanographic parameter distribution when ENSO phenomena occur in answering the research problem, namely to determine the effect of atmospheric phenomena (ENSO) on the variability of SST, chlorophyll-a and significant wave height in the waters of South Sulawesi Province with coordinates ranging from 116˚ to 126˚ BT and 2˚ to 9˚ LS where the study area is divided into 7 regions, namely the southern Makassar Strait (L.1), the western waters of South Sulawesi (L.2), the waters of the Salabana Islands (L.3), the waters of Selayar Islands (L.4), Bone Bay to the north (L.5), Bone Bay to the south (L.6), and Sea of Flores (L.7) as shown in figure 1.

Figure 1. Research Location at the waters of South Sulawesi Province, Indonesia.
The data used in this study is for 10 years starting from 2006 to 2015, including data on SST and chlorophyll-a, Niño 3.4 index and additional data in the form of sea wave height data. SST and chlorophyll-a data obtained from Aqua MODIS level-3 satellite data that has been corrected geometrically and radiometrically with 4 km spatial resolution. The image used is monthly data for 10 years (2006 – 2015) in the format of HDF (Hierarchical Data Format) which was downloaded from the National Aeronautic Space Agency (NASA) website. SSTs are monitored using canals 20-23 on Aqua MODIS satellites and monitoring chlorophyll-a concentrations using canals 8-16. The ENSO index used is the Niño 3.4 index where this index is a condition of SST anomalies in the Niño region 3.4. Ocean wave height data is obtained from Ina-COAP and altimetry satellites. Wave height derived from Ina-COAP is the result of a numerical calculation of the WW3 model with a spatial resolution of 0.25° x 0.25°. In addition, the significant wave height data used in this study also comes from the results of altimetry satellite observations. This data is in network common data form (NetCDF) with a resolution of 1° x 1° and monthly temporal resolution.

3. Result and discussion

3.1. Verification of significant wave height WW3 and altimetry satellite
The Correlation test results show that the WW3 model output has a very low correlation coefficient of 0.14 but has a positive value which indicates a relationship that is directly proportional between WW3 model output and altimetry satellite. The relationship between WW3 model output and altimetry satellite shows a weak relationship between the two variables [8]. The low correlation coefficient value is thought to be caused by differences in grid resolution between WW3 outputs which have a resolution of 0.125° x 0.125° with altimetry satellite data whose resolution is only 1° x 1°. In addition, the limited availability of altimetry satellite data that only has a 1-day temporal resolution compared to the WW3 model that has a 6-hour temporal resolution results in a lack of comparative data for the WW3 model output so that it cannot show a good correlation.

These results are different from the research conducted by [9] where the correlation value of the WW3 model output is 0.8 (strong relation). While the calculation results from the WW3 model output RMSE obtained a value that is not too large that is 0.67 meters. This indicates that the difference between the WW3 model output value and altimetry satellite data is not too far away so that the WW3 model output can present the value of significant wave height quite well.

3.2. Monthly average of significant wave height
Based on the results of monthly significant wave height data processing for 10 years (2006 - 2015) in the study area, the average significant wave height for January (figure 2) was obtained. These results show that the highest significant wave height in January occurred in the west of South Sulawesi Province, namely the southern Makassar Strait, Salabana archipelagic waters, and Selayar archipelagic waters with a wave height of 1 to 1.25 meters. While the average of the lowest significant wave heights in January occurred in closed water areas such as the Gulf of Bone in the north and south with a significant wave height of 0 - 0.5 meters. At the mean significant wave height in February in general significant wave heights decreased (figure 2). The highest significant wave height still occurs in the southern Makassar Strait, Salabana Islands, and Selayar archipelagic waters with significant wave height of 0.75 - 1 meter and the lowest occurs in the northern Gulf of Bone, southern Bone Bay, and a small portion of Selayar island waters. and the Flores Sea with a significant wave height of 0 - 0.5 meters. The decline in the mean significant wave height was shown in March, where in general the average wave height significantly reached the lowest value of 0 - 0.5 meters in almost all areas of the waters of South Sulawesi Province except in the southern Makassar Strait and partly small waters of the Salabana archipelago (figure 2).
Figure 2. The average of significant wave height in the waters of South Sulawesi Province for 10 years (2006 – 2015).

Figure 2 shows that the average significant wave height for April in all areas of the waters of South Sulawesi Province has the lowest significant wave height of 0 - 0.5 meters except in the eastern part of the Flores Sea region which has a monthly significant wave height reaching 0.5 - 0.75 meters. In May the average significant wave height in the study area in general experienced an increase, especially in the eastern part of the Flores Sea which had the highest average significant wave height reaching 1 - 1.25 meters (figure 2). The average of the lowest significant wave height in May still occurs in the western waters of South Sulawesi and most of the Selayar archipelago, Bone Bay in the north and
south with a wave height of 0 - 0.5 meters. The average increase in monthly significant wave height is increasingly shown in June with the highest significant wave height averages occurring in the eastern Flores Sea region reaching 1.25 - 1.5 meters.

In July, the average monthly significant wave height was generally higher compared to other months (figure 2). The highest average significant wave height in the month reached 1.5 - 2 meters in the north-eastern part of the Flores Sea. The lowest mean significant wave height in July occurred in most of the western waters of South Sulawesi, northern Bone Bay, and the southern coastal region of Bone Bay with significant wave height of 0 - 0.5 meters. In August, the average monthly significant wave height in the study area began to show a reduction in height (figure 2). This can be seen from the monthly significant high average in the north-eastern part of the Flores Sea reaching only 1.25 - 1.5 meters or lower than the July average. While the lowest significant mean wave height in August still occurs in most of the western waters of South Sulawesi, the northern Bone Bay, and the southern coast region of Bone Bay with significant wave height of 0 - 0.5 meters. The decrease in the average monthly significant wave height is increasingly shown in September, where the highest mean significant wave height only reaches 1 - 1.25 meters in the northeast part of the Flores Sea and the average lowest significant wave height extends to the island waters Selayar and Flores Sea in the west with significant wave height of 0 - 0.5 meters (figure 2).

Based on the figure 2 it is known that the highest significant wave height in October only occurred in the southern Makassar Strait, the eastern Flores Sea, and a small portion of the Salabana and Selayar islands waters with a significant wave height of 0.5 - 0.75 meters and other regions have the lowest significant wave height of 0 - 0.5 meters. In November the average monthly significant wave height in all areas of the waters of South Sulawesi Province reached the lowest value of 0 - 0.5 meters (figure 2). In December, the average monthly significant wave height was 0 - 0.5 meters in all study areas except in the western region of the southern Makassar Strait where the average height was high.

3.3. Monthly average of sea surface temperature (SST)

Based on the results of monthly sea surface temperature (SST) data processing for 10 years, can be seen in the picture 3 January's highest SST occurred in the northern Gulf of Bone which reached 32.8°C and the lowest occurred in the waters of the Salabana archipelago, the Selayar archipelago and the Flores Sea waters which reached 28°C. The highest average SST in February still occurs in the northern Gulf of Bone, reaching 32.8°C and the lowest occurring in the Salabana Islands waters, the Selayar archipelago and the Flores Sea waters reaching 28°C (figure 3). The highest average SST in March occurred in the northern Gulf of Bone, reaching 32.8°C and the lowest only in the Flores Sea which reached 28°C (figure 3).

In the figure 3 it can be seen that in general the decline in the average monthly SST has expanded in the service area of South Sulawesi Province in July, where the lowest average SST in the month reached 25.6°C which occurred in the waters of the Selayar Islands the highest average SST only reached 30.4°C which occurred in the western waters of South Sulawesi, the northern and southern Bone Bay. The lowest monthly average SST in August was broader compared to the lowest average monthly SST of 25.6°C in the Selayar Islands waters and the highest only reached 30.4°C in the northern and southern Bone Bay (figure 3) The lowest average SST in September reached 26.8°C which occurred in the waters of the Selayar Islands and the waters of the Salabana Islands and the highest reached 31.6°C in the northern Gulf of Bone.
Figure 3. The average of sea surface temperature (SST) in the waters of South Sulawesi Province for 10 years (2006 – 2015).

3.4. Monthly average of chlorophyll-a
Based on the processed data presented in the figure 4, it shows that the average chlorophyll-a distribution in the servant area of the waters of South Sulawesi Province in January-June is always high in the coastal area. In January - April the tendency of chlorophyll-a is more in the western coastal waters of South Sulawesi and Makassar Strait when compared with chlorophyll-a which is found in the eastern region of South Sulawesi Province such as in the Bone Bay and Flores Sea (figure 4). In May and June there was a shift in the chlorophyll-a concentration area in the southern coastal region of the waters of South Sulawesi Province towards the southwest (figure 4).
Figure 4. The monthly average of chlorophyll-a (January – June) in the waters of South Sulawesi Province for 10 years (2006 – 2015).

Figure 5 shows that the average chlorophyll-a concentration in July-December in the waters of South Sulawesi Province is more located around the southern coast of South Sulawesi Province compared to other regions. Chlorophyll-a concentration in the southern coastal area of South Sulawesi Province began to decline from September to December.

Figure 5. The monthly average of chlorophyll-a (July – December) in the waters of South Sulawesi Province for 10 years (2006 – 2015).

Based on the results of processing the chlorophyll-a distribution data in the study area it can be seen that the highest average monthly chlorophyll-a distribution occurs in August (figure 5) and the lowest occurs in November (figure 5). The highest distribution of chlorophyll-a concentration is found in coastal and coastal waters, and the lowest chlorophyll-a concentration is found in offshore waters in the study area [10]. The highest chlorophyll-a distribution occurs in almost all coastal and coastal
areas of South Sulawesi Province with a maximum intensity of 1 mg/m$^3$ throughout the month. While the lowest chlorophyll-a distribution generally occurs in the offshore waters of South Sulawesi and Flores Sea provinces with a minimum intensity of 0.1 mg/m$^3$. These results indicate that the distribution of chlorophyll-a in the study area varies according to geographical location and depth of waters.

3.5. Interaction between ENSO and marine parameters

The ENSO phenomenon which includes El Niño and La Niña is a phenomenon that not only influences climate and weather variability in Indonesian territory but also affects the variability of marine phenomena and parameters in Indonesian waters. This section will discuss the conditions of marine parameters such as SST, chlorophyll-a, and wave height conditions when the ENSO phenomenon occurs in the waters of South Sulawesi Province.

3.5.1. The effect of ENSO on SST. In general, changes in temperature and chlorophyll-a in the sea are influenced by ENSO [11]. The influence of ENSO phenomenon on SST in the waters of South Sulawesi Province can be seen by looking at the SPN Niño 3.4 anomaly temporally from 2006 - 2010 according to the time of the study.

Based on the graph of SST anomalies in the Niño region 3.4 in figure 6 and 7 it is known that the El Niño phenomenon occurred in 2006, 2009/2010 and 2015 because in that year the value of the Niño 3.4 index was above +0.5 if the Niño 3.4 value is above +0.5 then it is an El Niño condition [12]. In 2006 the value of the Niño 3.4 index ranged from +1,06 – +1,18 which occurred from November to December so that it was categorized as El Niño with moderate intensity. In 2009/2010 the Niño 3.4 index value ranged from +1,26 – +1,78 which occurred from November to February so that at that time it was categorized as El Niño with moderate - strong intensity. In 2015 the value of the Niño 3.4 index ranged from +1,04 – +2,8 from May to December, so that at that time it was categorized as El Niño with moderate - strong intensity. While the La Niña phenomenon occurred in 2007/2008, 2010/2011 and the end of 2011 because in that year the Niño 3.4 index value was below -0.5 if the Niño 3.4 index value was below -0,5 then at that time was the condition of La Niña [12]. In 2007/2008 the value of the Niño 3.4 index ranged from (-1,12) – (-1,69) which occurred from September to March so that it was categorized as La Niña with moderate to strong intensity. In 2010/2011 the value of the Niño 3.4 index ranged from (-1,1) – (-1,64) which occurred from August to February so that at that time was a La Niña condition with moderate to strong intensity. At the end of 2011 the Niño 3.4 index value ranged from (-1,01) – (-1,11) which occurred from October to December so that at that time was La Niña condition with moderate intensity.

![SST Monthly Anomaly Niño 3.4 from 2006 - 2010](image-url)

**Figure 6.** The SST monthly anomaly in the Niño 3.4 area (Pacific Ocean) based on El Niño and La Niña criteria from 2006 – 2010.
El Niño and La Niña phenomena also affect SST in the waters of South Sulawesi Province (figure 8). When the El Niño incident occurred as in November 2015 with strong intensity, in general, the average SST in the study area was lower than the November average SST during normal conditions (figure 3). When the La Niña incident occurred as in January 2008 with strong intensity, in general, the average SST in the study area was higher than the January SST average during normal conditions (figure 3). The study is in accordance with previous research which explains that when the La Niña period occurs, the SST will be higher in the southern waters of Java [13]. This is because during the La Niña period the Trade Wind strengthened so that the hot water pool shrunk and cooled most of the Tropical Pacific Ocean. Atmospheric convection occurs in the most western part of the Pacific Ocean where heavy rain occurs in Indonesian waters. Cold water mass rises more strongly along the waters of western South America and causes the thermocline to be shallower than normal conditions.

3.5.2. The effect of ENSO on chlorophyll-a. Information about the spatial variability of chlorophyll-a at sea level is very important because it can be used to facilitate the management and utilization of fisheries resources [14]. At the time of the El Niño incident in November 2015, there was generally an increase in chlorophyll-a concentration in the waters of the eastern region of South Sulawesi Province and there was a decrease in chlorophyll-a concentration in the water region west of South Sulawesi Province (figure 9) when compared to the average chlorophyll-a in November for 10 years (figure 5).
At the time of the La Niña incident in January 2008, there was generally a decrease in chlorophyll-a concentration in the waters of South Sulawesi Province (figure 9) when compared with the average chlorophyll-a in January for 10 years (figure 4).

3.5.3. The effect of ENSO on significant wave height. Based on the figure 10 it can be seen that when the El Niño phenomenon occurred in November 2015, significant wave heights in the waters of South Sulawesi Province in general were not much different from the average significant wave height in November (figure 2) that is 0 – 0.5 meter. This explains that the El Niño phenomenon has less influence on significant wave heights in the research area. Unlike the case when the La Niña phenomenon occurred in January 2008 (figure 10), significant wave heights in the waters of South Sulawesi Province in general experienced an increase compared to the average significant wave height in January (figure 2) which reached 1.25 – 1.5 meters. This explains that the La Niña phenomenon affects significant wave heights in the study area.

4. Conclusion
The ENSO phenomenon that occurred from 2006 - 2015 affected the fertility variability in the waters of South Sulawesi Province. When the El Niño phenomenon occurred, SST in the study area generally decreased and there was an increase in chlorophyll-a concentration in the L.2, L.5, L.6 and L.7 regions and a decrease in chlorophyll-a concentration in the L.3 region and in that period in general significant wave height equals the monthly average. While at the time the La Niña phenomenon occurred, SST, chlorophyll-a concentrations and significant wave height in the study area generally increased.
Chlorophyll-a distribution in the study area varies according to geographical location and depth of waters. At the time of the ENSO phenomenon it will affect marine parameters such as SST, chlorophyll-a, and significant wave height in the waters of South Sulawesi Province. Effective and efficient time for fishermen in conducting marine activities is during the transitional period (MAM and SON) in coastal and coastal areas of South Sulawesi Province because at that time significant wave heights is poor and high chlorophyll-a concentrations in the region. While in the offshore region of South Sulawesi Province marine activities are effective and efficient when the La Niña phenomenon occurs because this phenomenon will increase the concentration of chlorophyll-a.

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