Comparison of volume transport in the Halmahera Sea between La Nina 2011 and El Nino 2015 events based on numerical model

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Abstract. Variations of volume transport in the Halmahera Sea are strongly influenced by the El Nino Southern Oscillation (ENSO). Based on the Southern Oscillation Index (SOI), in 2011 La Nina event took place with a strength of 3.02, while in 2015 El Nino occurred with a strength of -2.6. This paper discusses the variation of transport volume caused by the ENSO phenomenon based on the results of the Regional Ocean Model System (ROMS). On the Halmahera Sea at a latitude of 0.3ºS with a width of 67 km and a depth of down to 200 m, net volume transport always moves southward. The largest volume transport in La Nina 2011 occurred in September-October, which was -8.9 Sv. Meanwhile, in El Nino 2015 the largest volume transport occurred in July-August, which was equal to -4.9 Sv. The cross correlation coefficient between volume transport and SOI in 2011 and 2015 was r = 0.55 and r = 0.61 respectively, where these results indicate a strong relationship.

Keywords: transport volume variation, Halmahera Sea, ENSO, numerical model, ROMS

1. Introduction

Indonesia, which is adjacent to two large seas namely the Pacific Ocean in the north and northeast and the Indian Ocean in the south and southwest, Indonesia is the connecting link of the two Oceans known as the Indonesian throughflow (ITF). Water mass flow that occurs as a result of the difference in pressure between the two oceans. The water sources carried by the ITF come from the northern and southern of the Pacific Ocean. The waters of the Makassar and Flores Sea Strait are more influenced by the mass of the North Pacific sea, while the Seram Sea and Halmahera Sea are more influenced by the mass of water from the South Pacific [1]. According to the theory of Clarke and Liu [2], the volume transport of throughflow is expected to vary during the El Nino Southern Oscillation (ENSO) cycle, with larger than normal transport during the La Nina (cold) phase, when strong easterlies along the equatorial Pacific build up high sea level in the western Pacific. The pressure difference from the Pacific to the Indian Ocean is the driving force for throughflow [1], so it seems intuitively reasonable to expect a larger transport at this time. In the theory, the Pacific sea level is transmitted to the north-western coast of Australia and influences throughflow by geostrophy.
However, it is not yet possible to estimate the amount of water mass carried through this eastern path due to other water mass inputs on the eastern path, through the Halmahera Sea. Apart from the measurement results, the estimated transport passing through the Halmahera Sea from the modelling analysis is also done by Morey et al. using ROMS (Regional Ocean Modelling System) transport volume within the thermocline and the intermediate layer in 2011 (La Nina Event) occurred in September-October -8.9 Sv. While in 2015 (El Nino event) the largest transport volume occurred in July-August -4.9 Sv.

The Halmahera Sea is the first route from the ITF before entering the Seram Sea and Maluku Sea, so the value of volume transport in the Halmahera Sea affects the total volume transport of the mass water through Indonesian waters. Therefore in this study, the influence of ENSO on the variability of volume transport in the Halmahera Sea will be assessed using the ROMS model. The purpose of this study is to see the direct effect of ENSO on changes in transport volume within the thermocline and the intermediate layer that occur in the Halmahera Sea.

![Figure 1. Study area of ROMS Model, Halmahera Sea.](image)

Figure 1. The red line shows the crossection taken to calculate the transport volume in the Halmahera Sea.

2. Data

2.1 Tides

Forcing from tides is put to ROMS, and represented with eight tidal constituents of the M2, S2, N2, K2, K1, O1, P1, and Q1. They were imposed on the lateral open boundaries with constituents obtained from global model of ocean tides TPXO8-atlas TOPEX/Poseidon. TPXO8-atlas is current version of tides model with complex amplitudes harmonic constituents of earth relative sea-surface elevation with ¼ degree resolution global grid and used a least-squares sense, the Laplace Tidal Equations and along track averaged data from TOPEX/Poseidon and Jason (on TOPEX/Poseidon tracks since 2002) [4, 5]. As a model verification, we used sea surface elevation, field observation data from Compact TD instrument, and compared to model result of 2017. We verified model elevation at latitude of 00°13’ 26,8”S and longitude of 117° 25’ 11,2”E with date of verification is from January 29th to February 19th, 2017.
2.2 Temperature, Salinity, and Current
Global reanalysis assimilation data sets from Hybrid Coordinate Ocean Model (HYCOM) and Navy Coupled Ocean Data Assimilation (NCODA Global 1/12\(°\)), e.g, sea water salinity, sea water potential temperature, sea water velocity (u and v), and sea surface elevation, used as initial condition to the model (http://hycom.coaps.fsu.edu/thredds/catalog.html). During the simulation, the interior temperature and salinity were nudged to the tracer fields from HYCOM with a time scale of 1 day for each year simulation.

2.3 Atmospheric Forcing
Atmospheric forcing such as surface wind, air pressure, air temperature, air humidity, net fresh water flux, rainfall rate, net long-wave radiation flux, and solar shortwave radiation flux extracted from European Centre for Medium-Range Weather Forecasts (ECMWF) (http://apps.ecmwf.int/datasets/) and applied to model for each scenario. Surface wind is velocity of wind 10 meters above sea surface elevation and used as generating force for surface current circulation. Surface wind was imposed every 3 hours for a-year long simulation. Atmospheric forcing were computed by ROMS using bulk-fluxes formulation internally and turbulent fluxes for wind, heat, and moisture are computed using Monin-Obukhov similarity theory [6]. These atmospheric forcing were imposed to the model every 3 hours time step.

2.4 Bathymetry
Figure 1 showed bathymetry that was used for the model area. It was extracted from global topography data fusion of NASA Shuttle Radar Topography Mission (SRTM) [7] land topography with measured and estimated seafloor topography (SRTM15_PLUS) (ftp://topex.ucsd.edu/pub/srtm15_plus/). This data is corrected by sounding [8] and gravity data [9] and modified from SRTM 30 product distributed by USGS EROS data center. The grid resolution is 30 second which is roughly one kilometer. Land data are based on the 1-km averages of topography derived from the USGS SRTM 30 gridded DEM data product created with data from the NASA Shuttle Radar Topography Mission. The ocean data are the same as SRTM30_PLUS but required more extensive editing to remove the bad points mostly along edges of the swath data. For model, depth minimum settled to -5 m and deepest depth is -2734 m.

3. Methods
As a part of future goal research, in this study we focused to apply ROMS model to determine characteristic transport volume in Halmahera Sea. We forced this model using ECMWF data and HYCOM data as initial condition to the model. To determine ENSO effect in Halmahera Sea, we compiled 2 different scenarios hence represented La Niña 2011 and El Niño 2015 year. The correlation coefficient between the two variables is used as the closeness of the linear relationship between the variables involved, in this study a linear relationship between the two variables in question is a linear relationship between the volume transport in the Halmahera Sea and Southern Oscillation Index (SOI). Correlation coefficient is in the range of -1 <R<1, if R=1, the variables x and y are positively correlated perfectly and all possible x and y lie in a straight line with a positive slope in xy fields, if R=0 then the two variables are said to be uncorrelated, the meanings are not linearly related to each other, and if R=-1, then the two variables are perfectly negatively correlated and the variable values lie in a straight line in the xy plane but with a negative slope [11].

The SOI measures the difference in surface air pressure between Tahiti and Darwin. The index is best represented by monthly (or longer) averages as daily or weekly SOI values can fluctuate markedly due to short-lived, day-to-day weather patterns, particularly if a tropical cyclone is present.

We compared model results from year 2017 model using field observation data and used the setting to be applied to the three scenarios of model. To see the correlation between model and observation data, we used Root Mean Square Error (RMSE) and Mean Absolute Percentage Error (MAPE) formula that shown by equation (1) and (2) [12] below
RMSE = $\sqrt{\frac{1}{n} \sum_{i=1}^{n} (A_i - B_i)^2}$ \hspace{1cm} (1)
MAPE = $\frac{100}{n} \sum_{i=1}^{n} \frac{|A_i - B_i|}{A_i}$ \hspace{1cm} (2)

3.1 Hydrodynamic Model ROMS

The simulation of hydrodynamic process in domain area were conducted by using the numerical model Regional Ocean Modeling System (ROMS). This model was quite popular among modeler, scientist and researcher who wanted to study the coastal application and developed from Princeton Ocean Model (POM). Many literatures described this model capability especially in the regional ocean domain.

ROMS is a threedimensional, free surface, terrain-following numerical model that solves finite difference approximation of the Reynolds-averaged Navier-Stokes (RANS) equation using the hydrostatic and Boussinesq assumption with a split-explicit time stepping algorithm [13, 14, 15]. It uses a horizontal curvilinear Arakawa “C” grid and vertical stretched terrain-following coordinates [15]. This model also can be configured depending of user application which has several choices for advection schemes, pressure gradient algorithms, turbulent closure, and many types of boundary condition.

The governing equations used in ROMS were presented in flux form on the Cartesian horizontal coordinates and sigma vertical coordinates. For the momentum equations on the x- and y- axis (equation 3 and 4) directions are:

$$\frac{\partial (\mathbf{u} H)}{\partial t} + \frac{\partial (\mathbf{u} \mathbf{u} H)}{\partial x} + \frac{\partial (\mathbf{v} \mathbf{u} H)}{\partial y} + \frac{\partial (\Omega H \mathbf{u} H)}{\partial z} - f H z \mathbf{v} = - \frac{H z}{\rho_0} \frac{\partial p}{\partial x} - H z g \frac{\partial \eta}{\partial x} - \frac{\partial}{\partial s} \left( \mathbf{u}' \mathbf{w}' - \mathbf{v} \frac{\partial \mathbf{u}}{\partial s} \right)$$ \hspace{1cm} (3)

$$\frac{\partial (\mathbf{v} H)}{\partial t} + \frac{\partial (\mathbf{u} \mathbf{v} H)}{\partial x} + \frac{\partial (\mathbf{v} \mathbf{v} H)}{\partial y} + \frac{\partial (\Omega H \mathbf{v} H)}{\partial z} + f H z \mathbf{u} = - \frac{H z}{\rho_0} \frac{\partial p}{\partial y} - H z g \frac{\partial \eta}{\partial y} - \frac{\partial}{\partial s} \left( \mathbf{v}' \mathbf{w}' - \mathbf{v} \frac{\partial \mathbf{v}}{\partial s} \right)$$ \hspace{1cm} (4)

$$0 = - \frac{1}{\rho_0} \frac{\partial \rho}{\partial s} - \frac{\partial}{\partial s} \left( \mathbf{H} \rho \right)$$ \hspace{1cm} (5)

with the continuity equation:

$$\frac{\partial \eta}{\partial t} + \frac{\partial (\mathbf{u} H \eta)}{\partial x} + \frac{\partial (\mathbf{v} H \eta)}{\partial y} + \frac{\partial (\Omega H \eta)}{\partial z} = 0$$ \hspace{1cm} (6)

and scalar transport:

$$\frac{\partial (\mathbf{H} C)}{\partial t} + \frac{\partial (\mathbf{u} H C)}{\partial x} + \frac{\partial (\mathbf{v} H C)}{\partial y} + \frac{\partial (\Omega H C)}{\partial z} = - \frac{\partial}{\partial s} \left( C \mathbf{w}' - \mathbf{v} \frac{\partial C}{\partial s} \right) + C_{source}$$ \hspace{1cm} (7)

These equations are closed by parameterizing the Reynolds stresses and turbulent tracer fluxes as

$$\mathbf{u}' \mathbf{w}' = K_M \frac{\partial u}{\partial x} \quad \mathbf{v}' \mathbf{w}' = K_M \frac{\partial v}{\partial y} \quad \rho' \mathbf{w}' = K_H \frac{\partial \rho}{\partial z}$$ \hspace{1cm} (8)

where KM is the eddy viscosity for momentum and KH is the eddy diffusivity. Eddy viscosities and eddy diffusivities are calculated using one of five options for turbulence-closure models in ROMS: (i) BruntVäisälä frequency mixing in which mixing is based on the stability frequency; (ii) a user-provided analytical expression such as a constant or parabolic shape; (iii) the K-profile parameterization [16], expanded to include both surface and bottom-boundary layers [17]; (iv) Mellor-Yamada level 2.5 (MY2.5) method [18]; and (v) the generic length-scale (GLS) method [19] as implemented in [20] that also includes the option for surface fluxes of turbulent kinetic energy due to wave breaking. and for this study, we applied option (v) to calculated eddy viscosities and eddy diffusivities.

3.2 Model Design

This model domain have 159 east-west grid cells and 269 north-south grid cells with 2.7 km grid spacing uniformly. This model have 429.3 km wide and 726.3 km long with width area is about 311,800,59 km². We used masking to determine which one is land and which one is ocean using 1 and 0, respectively. This model used sigma vertical coordinate with 30 layers and the shallowest depth is 5 m and deepest...
is 5.829 m. Vertical depth references is mean sea level and no wet and dry scenarios used. We used 4 momentum open boundary with tidal elevation as major forcing input and coupled with atmospherics data from ECMWF as mention in Section 2. No nesting model used and no river discharge in domain model used. Time step was calculated using Courant–Friedrichs–Lewy condition (CFL) [21] and obtained 123.32 second. The result of the model is the velocity of current $u$ and $v$ which is stored every hour for a year of simulation time. Then, we plotted ocean current profiles one-month averages based on SOI (Southern Oscillation Index) for 2 scenarios (El Niño and La Niña).

4. Result and discussion

4.1 Verification of Model

![Figure 2. Model verification between tide observation data and ROMS results, west part of domain model. Observation data showed by red line and model result showed by blue line.](image)

Figure 2 showed a tidal verification between observation data (red line) and ROMS model results (blue line). It showed that model still under-estimated with observation data have higher value than output model. This verification is still good with pattern of tidal is match and RMSE value is about 0.148 m and MAPE is around 12.22 %. The time required for the spin up model is 5 days and due to data limitations, the model results are not verified using velocity data.
4.2 Surface Current Circulation in Halmahera Sea

Figure 3. Monthly averaged ocean current pattern at Halmahera Sea during La Niña (2011); (a) January (b) February (c) March (d) April
Zonal currents reach the minimum velocity in the east direction which occurs in June, and reaching its maximum speed in the west which occurred in November. Whereas the velocity component of the meridional current reaches a minimum to the south in April and reaches a maximum speed to the north in March [28]. The results of the model also show similarities to previous studies where in March the surface zonal currents point north and in April point south. The movement of currents to the north near the bottom of the Halmahera Sea indicates that the mass of water is moving towards the Pacific Ocean, while the movement of currents to the south states that the inflow from the Pacific Ocean via the Halmahera Sea into Indonesian territorial waters [27]. Ocean pattern circulation in Halmahera Sea Figure 3-4 was influenced mostly by wind, tidal forcing, and gradient pressure difference between West Pacific Ocean and East Indian Ocean. The ROMS model results show in January, February, and March in the year of La Nina (2011) Where the SOI values are 2.01, 2.12, and 2.09 respectively, the average
monthly surface flow velocity that enters the ITF is 2.12 m/s, 1.81 m/s, and 1.18 m/s. Whereas in El Nino (2015) in January, February and March, the SOI values were -0.87, -0.04, and -1.4 the average monthly surface flow velocity that entered the ITF lane was 0.772 m/s, 0.343 m/s, and 0.34 m/s. The monthly average surface velocity entering the ITF that occurred in La Nina was greater than the average monthly surface velocity that occurred in El Nino in January the difference was 1,238 m/s, February the difference was 1,467 m/s, and March the difference is 0.84 m/s. The average monthly surface flow velocity indicates that the wind power that drives the water mass is greater in the case of La Nina (2011) than the El Nino event (2015). Comparison of model result and Hycom data (Figure 5) shows the same pattern as RMSE of 0.096 m/s indicating that the model results can be used to see changes in transport volume in Halmahera Sea.

**Figure 5.** HYCOM data showed by red dot and model result showed by blue dot.
4.3 Volume Transport

Figure 6. Cross Section current velocity monthly average at latitude 0.3°S in 2011 (La Nina)
Figure 7. Cross section current velocity monthly average at latitude 0.3°S in 2011 (La Nina)
Figure 8. Cross section current velocity monthly average at latitude 0.3°S in 2015 (El Nino)
The main driving force of the ITF flow in the upper 200 m layer was the differences in the strong sea level pressure between the Pacific Ocean and Indian Ocean so that the ocean current flows to the south throughout the year [25]. Figure 6-9 is taken from the Cross section in the Halmahera Sea of 0.3°S with a width of 67 km and a depth of surface down to 200 m which then calculates the incoming and outgoing transport volumes of ITF. The main driving force of the ITF flow in the upper 200 m layer is the difference in strong sea level pressure between the Pacific Ocean and Indian Ocean so that ocean currents flow south all year round [25]. Previous studies [27], showed that at 0.283°N and 129.43°E at depths. At 400 m the nontidal current to the south rose 0.25 m/s from October to April and northwest to 0.2 m/s at other times (possibly responses to force months) [27]. Then, the results of the model show 350-1000 m depth of currents in the western part of the cross section (128.8-129.2°E) with a current velocity of 0.1-0.4 m/s moving northward throughout the year. While the movement of the current in the east section (129.2-129.6°E) with a velocity from 0-0.1 m/s moves south. From previous studies show the suitability of the direction with the current model.

From the results of the ROMS model the average volume transport is obtained. monthly, in the year of La Nina (2011) the largest transport volume occurred in September-October worth -8.9 sv, where the maximum monthly average velocity that occurs up to -1.0 m/s from the surface to a depth of 200 m in width 44.4 km. Whereas the largest volume of El Nino transport occurs in July-August at -4.9 sv, where
the maximum monthly average velocity that occurs up to -0.7 m/s from the surface to a depth of 150 m with a width of 33.3 km. the significant difference in transport volume occurred in these two conditions. In La Nina condition, low pressure in the Western Pacific and intense trade wind causing the surface currents strengthen. Therefore, the ITF is increase. Negative indicates southward. On the contrary positive value of transport is northward. In addition to currents that lead to the south, also found currents that lead to the north, the results of the model show currents that lead to a maximum of 0.5 m/s. Previous research conducted in the Halmahera Sea [27], after measuring with the mooring current meter at a depth of 400 m, 700 m and 900 m revealed that currents at each depth have different velocities and directions. However, current changes in the Halmahera Sea were dominantly controlled by NGCC and NGCUC. The NGCC (New Guinea Coastal Current) and NGCUC (New Guinea Under Current) flow along the New Guinea (Papua) coast, and they are part of the South Equatorial Current. NGCC flows northwestward, and NGCUC flows northwestward and then turns eastward to Halmahera Island, joining the Mindanao Current and flows eastward as the North Equatorial Counter Current. The cyclonic ME (Mindanao Eddy) and anticyclonic HE (Halmahera Eddy) were found at the confluence region of Mindanao and NGCUC [26]. NGCC is a surface current caused by seasonal influences [29]. In the boreal summer characterized by the southeasterly monsoon, westward currents of over 60 cm/s were dominant in the surface layer. In the boreal winter, an eastward surface current developed to 100 cm/s extending down to 100 m depth in response to the northwesterly monsoonal winds. During the Southeast Monsoon, NGCUC flows strongly northward [30]. Increased transport volume also occurs along with the changing seasons in that year. Variability also occurs with seasonal changes, where when the January-March (South-West monsoon) in the La Nina (2011) transport volume decreases the number of transports from -6.1 sv to -4.9 sv and when May-September (North-east monsoon) in the La Nina (2011) transport volume has increased the number of transports from -5.3 sv to -8.9 sv. In January-March (South-West monsoon) in the year of El Nino (2011) transport volume also decreased the number of transports from -2.4 sv to -2.1 sv and when May-September (North-east monsoon) in The year of El Nino (2015) transport volume also experienced an increase in the number of transports from -3.5 sv to -4.7 sv (see Table 1). During November to March (South-West monsoon), the equatorial currents in the Indian Ocean flowed strongly and donated water masses to the southwest of Sumatra and south of Java-Sumbawa which were the ITF outflow areas thus increasing sea levels. As a result the gradient the pressure from the Pacific Ocean to the Indian Ocean becomes smaller and ITF transport flow becomes minimum [22]. In contrast, from May-September (North-east monsoon), currents in the Indian Ocean were replaced by southern equatorial currents that spread northwards, pushing water masses away from the eastern Indian Ocean. The low sea level in the region compared to the Pacific Ocean produces the maximum ITF transport flow [22]. Maximum transport volume occurs in La Nina (2011) in September-October when North-east monsoon and the weakest occurred in El Nino (2015) in March when the South-West monsoon.
Table 1. Monthly average transport volume in the Halmahera Sea From Surface to 200 m

| Month   | Transport Volume (Sv) 2011 | Transport Volume (Sv) 2015 |
|---------|---------------------------|---------------------------|
| January | -6.1                      | -2.4                      |
| February| -5.8                      | -4.1                      |
| March   | -4.9                      | -2.1                      |
| April   | -2.4                      | -2.3                      |
| May     | -5.3                      | -3.5                      |
| June    | -5.2                      | -3                        |
| July    | -7.2                      | -4.9                      |
| August  | -8.3                      | -4.9                      |
| September| -8.9                     | -4.7                      |
| October | -8.9                      | -4.2                      |
| November| -6.5                      | -4.4                      |
| December| -5.5                      | -1.8                      |

Volume transport cross-correlation and SOI Figure 10 shows a strong relation, where in La Nina the value is 0.5513 and in El Nino the value is 0.6174. This shows the amount of transport volume that enters the ITF waters due to changes in surface height that occur in the Indian Ocean and the Pacific Ocean.

![Cross-correlation between volume transport and SOI in 2011 (Left) and 2015 (right)](image)

The oceanic response to wind forcing is often accomplished through wave processes that propagate along the equatorial and coastal wave guides within the Indonesian Archipelago, and impact the water properties, thermocline and sea level on all timescales. The equatorial winds that produced free equatorial Rossby waves whose signals indicated reached the study region. Equatorial Pacific Rossby waves excited coastally trapped waves off the western tip of New Guinea that propagated poleward along the Arafura Australian shelf break. As well, Pacific energy radiated westward into the southeast Indian Ocean via the Banda Sea [23, 24].

5. Conclusion

The current circulation pattern that occurs in the Halmahera Sea has the similar pattern throughout the year which is towards the south, but the currents will experience strengthening and attenuation along with the strengthening of tidal winds, monsoon, differences in the water level of the Pacific Ocean and
the Indian Ocean, and tidal forcing. The maximum transport volume occurs in La Nina in September-October and the weakest occurs in El Nino in March.
The volume transport correlation and SOI show a strong relation, volume transport maximum 8.9 sv in La Nina and 4.9 sv in El Nino indicating that the transport volume that occurs in the Halmahera Sea is influenced by the difference of gradient pressure between West Pacific Ocean and East Indian Ocean.

References
[1] Wyrtki K 1987 Indonesia through and the associated pressure gradient, Journal of Geophysical Research 92 : 12941-12946.
[2] Clarke A J and X Liu 1993 Observations and dynamics of semiannual and annual sea levels near the eastern equatorial Indian Ocean boundary, J. Phys. Oceanogr., 23, 386-399,
[3] Morey S L, Shriver J F and O'Brien J J 1999 The effects of Halmahera on the Indonesian Throughflow, J. Geophys. Res. 104 23281–96
[4] Egbert G D, Bennett A F and Foreman M G G 1994 TOPEX/Poseidon tides estimated using a global inverse model J. Geophys. Res. 99 24821–52
[5] Egbert G D and Erofeeva S Y 2002 Efficient inverse modeling of barotropic ocean tides J. Atmos. Ocean Technol. 19(2) 183–204
[6] Liu T W, Katsaros K B, and Businger J A 1979 Bulk Parameterization of air-sea exchange of heat and water vapor including the molecular constraints at the interface, J. Atmos. Sci. 36: 1722-1735
[7] Farr T G, Rosen P A, Caro E, Crippen R, Duren R, Hensley S, Kobrick M, Paller M, Rodrigues E, Roth L et al 2007 The shuttle radar topography mission Rev. Geophys 45 (RG2004)
[8] Becker J J, Sandwell D T, Smith W H F, Braud J, Binder B, Depner J, Fabre D, Factor J, Ingalls S, Kim S-H et al 2009 Global bathymetry and elevation data at 30 arc seconds resolution: SRTM30_PLUS Marine Geodesy 32:4 355 — 71
[9] Sandwell D T, Müller R D, Smith W H F, Garcia E and Francis R 2014 New global marine gravity model from CryoSat-2 and Jason-1 reveals buried tectonic structure Science 346 (6205) 65-67 doi:10.1126/science.1258213
[10] Smith W H F and Sandwell D T 1997 Global seafloor topography from satellite altimetry and ship depth soundings Science 277 1957-62
[11] Jumarang I M and Ningisih S N 2013 Transpor Volume Massa Air Di Selat Sunda Akibat Interaksi Enso, Monsun dan Dipole Mode, Prosiding Semirata FMIPA Universitas Lampung, 2013
[12] Abramowitz M and Stegun A 1965 Handbook of Mathematical Function Dover New York
[13] Haidvogel D B, Arango H G, Hedström K S, Beckmann A, Malanotte-Rizaoli P and Shchepetkin A F 2000 Model evaluation experiments in the North Atlantic Basin simulations in nonlinear terrainfollowing coordinates Dynam. Atmos. Ocean. 32 239-281
[14] Shchepetkin A F and McWilliams J C 2005 The regional oceanic modeling system (ROMS) a splitexplicit, free-surface, topography-following-coordinate oceanic modelOcean Model. 9347-404
[15] Warner J C, Sherwood C R, Signell R P, Harris C K and Arango H G 2008 Development of a three-dimensional, regional, coupled wave, current, and sediment-transport model Comput. Geosci. 34 1284-1306
[16] Sprintall J and Revelard A 2014 The Indonesian throughflow response to Indo-Pacific climate variability J. Geophys. Res. Oceans 119 1161–75
[17] Wijffels S and Meyers G 2004 An intersection of oceanic wave guides: variability in the Indonesian throughflow region J. Phys. Oceanogr. 34(5) 1232–53
[18] Large W G, McWilliams J C and Doney S C 1994 A review and model with a nonlocal boundary layer parameterization Rev. Geophys. 32 363-403
[19] Durski S M, Glenn S M and Haidvogel D B 2004 Vertical mixing schemes in the coastal ocean: comparison of the level 2.5 Mellor-Yamada scheme with an enhanced version of the K profile parameterization. Geophys. Res. 109 C01015

[20] Mellor G L and Yamada T 1982 Development of a turbulence closure model for geophysical fluid problems Rev. Geophys. Space. Phys. 20 851-875

[21] Umlauf L and Burchard H 2003 A generic length-scale equation for geophysical turbulence models J. Mar. Res. 61 235-265

[22] Naulita, Y 1998 Karakteristik massa air pada perairan lintasan Arlindo. Tesis Magister Ilmu Kelautan. Institut Pertanian Bogor. 173hlm.

[23] Warner J C, Sherwood C R, Arango H G and Signell R P 2005 Performance of four turbulence closure models implemented using a generic length scale method Ocean Model. 8 81-113

[24] Courant R, Friedrichs K and Lewy H 1928 Math. Ann. 100: 32. https://doi.org/10.1007/BF01448839

[25] Gordon A L, Ffield A and Ilahude A G 1994 Thermocline of the Flores and Banda seas J. Geophys. Res. 18235–42

[26] Kashino Y, Ueki I, Kuroda Y and Purwandani A 2007 Ocean variability north of New Guinea derived from TRITON buoy data J. Oceanogr. 545–559

[27] Cresswell G R and J L Luick 2001 Current measurement in the Halmahera Sea. J. Geophysic Res. 106(C7):13.953-13.958

[28] Wattimena C M, Atmadipoera S A, Purba M, and Larrouy K A 2014 Variabilitas Intra-Musiman Arus Dekat-Dasar Di Laut Halmahera Jurnal Ilmu dan Teknologi Kelautan Tropis, Vol.6, No. 2, Hlm. 267-281

[29] Kuroda Y 2000 Variability of the currents off the north coast of New Guinea. J Oceanogr. 56103–106

[30] Kashino Y, Ueki I, Kuroda Y and Purwandani A 2007 Ocean variability north of New Guinea derived from TRITON buoy data J. Oceanogr. 63 545–559

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