Ocean numerical model experiment on estimating the variation of volume and heat transport in Karimata strait

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Abstract. Volume and heat transport variations through Karimata Strait during 2010-2014 were studied using three-dimensional numerical model of Hamburg Shelf Ocean Model (HAMSOM). Simulated area is located in 1°0'0" N - 4°30'0" N and 104°0'15"E - 110°30'0"E with a horizontal resolution 0.5' (approximately 0.94 km). The average of root mean square error of current velocity between model and observation are 0.17 for zonal (v) and 0.20 for meridional (v) components. The results of signal analysis showed that the volume and heat transport is strongly influenced by the seasonal period. There was also weak and medium phase of El Niño and La Niña during 2010 - 2014 that affected volume transport. The average volume (heat) transport during 2010-2014 through Karimata Strait is -2.75 Sv (-0.031 PW), meanwhile the average volume (heat) transport during boreal winter and boreal summer are -0.66 Sv (-0.06 PW) and -0.38 Sv (-0.03 PW), respectively (1 Sv = 10⁶ m³/s; 1 PW=10¹³ W). Southward total transport indicates that there are parts of South Chinese Sea-Indonesia seas flow through Karimata Strait.

1. Introduction

Indonesian Throughflow (ITF) is the flow of water from the Pacific Ocean to the Indian Ocean through Indonesian waters. The ITF's main line is the Makassar Strait [1]. Thus, that statement makes the other line of ITF not getting more attention, for example is the current in the Karimata Strait. According to previous study, Karimata Strait throughflow is part of the Indonesian Throughflow [2]. The waters flow from the Pacific through the Luzon Strait into the South China Sea (SCS) and flowing into the Karimata Strait and Indonesian waters. The transport variation in the Luzon Strait is influenced by ENSO, strengthened to the west and cools during El Niño. Transport in the Luzon Strait ranges from almost zero to 6 Sv with an average of 4.5 Sv [3]. Meanwhile, It show the transport average is 2.9 Sv. The transport of the Luzon Strait is a source of water mass for the South China Sea [3].

The number of rivers that contribute fresh water into the South China Sea, Natuna Sea, and Karimata Strait to the Java Sea causes the water mass through the Karimata Strait as main line of ITF to have a
relatively low density. The results is Karimata Throughflow disrupts the surface flow in the southern part of the Strait of Makassar in the northwest monsoon [3]. Based on the estimation results from observation data when peak of northwest monsoon the transport volume reach -3.6 ± 0.8 Sv and the heat transport is -0.36 ± 0.08 PW [4]. Meanwhile other research calculated volume and heat transport in the Karimata Strait (without Gaspar Strait) recorded the maximum value of -2.565 Sv and -0.258 PW in the west season and 1.233 Sv and 0.131 PW in the southeast monsoon [5]. However, the measurements were discontinues.

Due to lack of data measurements, many researchers conducted the numerical simulation to estimate volume transport. So, this research used HAMburg Shelf Ocean Model (HAMSOM) to simulate water dynamics in Indonesian seas. The results from hydrodynamics model such as current velocity and water temperature used to calculate volume and heat transport.

2. Method
2.1. Numerical and verification experiments
HAMburg Shelf Ocean Model (HAMSOM) was built by Backhaus on 1984 [6]. This model applied Arakawa-C for horizontal grid and $z$-level types for depth. HAMSOM has been used several times to conduct studies in Indonesian waters [7]. HAMSOM is used to study the volume transport in Karimata Strait with nesting techniques. The main model derived from Mayer [6] has a horizontal resolution of 6' and a depth of 39 levels. The large model area is 11°N-12°S and 92°E-132°E. Then Putri performs a higher resolution model for the area 1°0'0"S-3°0'0"S and 104°0'15"E-110°30'0"E. It has horizontal resolution of 0.5' and a depth of 23 levels (3 m for each level) [6]. Higher resolution model add input of tidal and river flow from southeast Sumatra and western Kalimantan. It used a nested technique and runs from 2009 to 2014 [6].

The current velocity obtained from model is verified with data from South Chinese Sea Indonesian Sea Transportation/Exchange (SITE) project (26 June 2012-10 October 2012) [5]. The average of root mean square error of current velocity between model and observation are 0.17 for zonal (v) and 0.20 for meridional (v) components (Figure 1). Thus, the model results can be used to estimate transport in the Karimata Strait with continuous data.

![Figure 1. Current speed of model and ADCP data in Karimata Strait](image-url)
The volume and heat transport are calculated using equation (1) and (2) [2][4][5].

\[ F_v = \int_A u dA \]  
\[ F_H = \rho C_p \int_A (T - T_0) u dA \]

With, \( F_v \) is the transport volume (m³/s), \( u \) is the current velocity (m/s), \( dA \) is the cross-sectional area perpendicular to the velocity vector (m²). \( F_H \) is a heat transport (W), \( \rho \) is the density of sea water (kg/m³), \( C_p \) is the heat capacity per unit volume (4,1 × 10⁶ J m⁻³ C⁻¹), \( T \) is temperature (°C), \( T_o \) is the reference temperature (3.72 °C).

3. Results and Discussions

3.1. Volume and Heat Transport

Figure 2. show the variations of volume and heat transport every month during 2010-2014. The time-series data of volume and heat transport are overlaid by NINO 3.4 index to see the correlation with El Nino Southern Oscillation (ENSO) phenomenon. The previous study stated that there is no correlation between ENSO with water transport in Karimata Strait [3]. However in this research ENSO influenced on transportation in the Karimata Strait.

![Figure 2](image)

Figure 2. (a) Volume and heat transport in Karimata Strait (b) Ocean Nino Index at NINO 3.4

The monthly variation of volume and heat transport during 2010-2014 are shown in Figure 2. In the peak of northwest monsoon (January), the transport is always move southward. On the other hand, in the peak of southeast monsoon (July) the transport is move to north. The maximum value of volume transport is found in January (northeast monsoon) 2013 by -1.38 Sv (southward) and 0.47 Sv (northward) in July 2014 (southeast monsoon). Direction of wind and transport show no difference. It is because the average of Karimata Strait depth only 45 m.

Volume and heat transport in the northwest monsoon which occurred with medium phase El Niño in January of 2010 has a value -1.38 Sv and -0.19 PW. While at the time of La Nina phase occurred in July 2011, the volume transport is -1, 35 Sv and - 0.21 PW. In the northwest monsoon, the currents generally move from SCS to Indonesian waters [2][4][5]. However El Nino and La Nina affect the amount of volume transport. At the time of El Nino, volume transport in the Luzon Strait weakened near zero [3]. The water transport in Luzon Strait is a stream from the Pacific to SCS then to the Karimata Strait.

Volume and heat transport variations in southeast monsoon and La Nina occurred in July of 2010 which have a value of 0.21 Sv and 0.02 PW. This is due to the current transports of southeast monsoon in general.
to the north but when it coincides with La Nina the transport strengthens to the south. So when compared with southeast monsoon and La Nina does not occur then the value is greater 0.27 Sv and 0.05 PW.

The volume and heat transport system in the Karimata Strait is closely related to the monsoon and ENSO phenomena. This is because of the Karimata Strait has a shallow water depth (up to 45 m), so that it is strongly influenced by the wind. Furthermore, ENSO affects volumes and heat transport in the Karimata Strait because its water flow comes from SCS originating from the Luzon Strait and is strongly influenced by ENSO [3].

Figure 3. Average current (a) January and (b) July
Average current velocity and water heights in January and July during 2010-2014 indicate conformity with seasonal wind movements (Figure 3). January is the peak of the northwest monsoon, thus the current moves from SCS to the Java Sea, while July is the peak of the southeast monsoon so that the current velocity moves otherwise.

4. Conclusions
The average of root mean square error of current velocity between model and observation are 0.17 for zonal (v) and 0.20 for meridional (v). The maximum volume (Heat) transport during the northwest monsoon is -1.38 Sv (-0.25 PW) and the southeast monsoon is 0.47 Sv (0.08 PW). The mean volume (Heat) transport during the northwest monsoon is -0.66 Sv (-0.06 PW) and the southeast monsoon is 0.36 Sv (0.03 PW). Volume (Heat) transport during the northwest monsoon and El Nino is -1.38 Sv (-0.19 PW) and La Nina is -1.35 Sv (0.21 PW). Volume (heat) transport during southeast and La Nina monsoons is 0.21 Sv (0.02 PW) and normal 0.27 Sv (0.05 PW). For a more comprehensive study of volume and heat transport variations, the research should be conducted with data assimilation approach.

References
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