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Validation of INDO12 Ocean Model at Makassar Strait

Bayu Priyono[1] *, Mukti Trenggono[2,3], Teguh Agustiadi[1]

[1]Institute for Marine Research and Observation, Ministry of Marine Affairs and Fisheries, Jl. Baru Perancak, Jembrana, Bali, 82251, Indonesia
[2]Fisheries and Marine Science Faculty, Jenderal Soedirman University, Jl. Dr. Suparno, Karangwangkal, Purwokerto 53123, Indonesia
[3]Centre for Maritime Bioscience, Institute for Research and Community Services JenderalSoedirman University, Jl. Dr. Suparno, Karangwangkal, Purwokerto 53123, Indonesia

**Corresponding author: bayu.priyono@kkp.go.id*

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ABSTRACT

INDO12, a 1/12 regional configuration of the NEMO3.1 physical ocean model covering the whole Indonesian EEZ has been developed and was running with 3D daily and 2D surface hourly outputs in the framework of the INDESO project. Validate the model results highly required for any downstream applications (services or scientific studies). In order to enhance confidence in using the INDO12 model outputs in Makassar Strait, qualitative comparisons with observed variables is performed. The datasets were used in this study provided by the INSTANT and MITF programs. Validation of model outputs was performed by compare the value of variables from simulation with observation results. The method of comparisons was conducted as follows: current velocities, temperature, and salinity, volume transport. The volume transports differences especially occurred below the thermocline layer. The model was colder and fresher in the thermocline layer, whereas deeper the model was warmer and saltier. The differences of the volume transport and temperature distribution affected the transport-weighted temperature and 16 °C isotherm depth. The model produced warmer transport-weighted temperature and deeper 16 °C isotherm depth compared to the observations. It is concluded from the validation results that the model give a fairly good comparison with the in-situ data, especially for seasonally signals.

Keywords: Validation, INDO12, Ocean Model, Makassar Strait, INSTANT and MITF Programe

ABSTRAK

INDO12, sebuah konfigurasi model fisik lautan NEMO3.1 skala regional 1/12 yang mencakup seluruh ZEE Indonesia telah dikembangkan dan dijalankan dengan keluaran harian 3D dan permukaan 2D per jam dalam kerangka proyek INDESO. Validasi hasil model sangat diperlukan untuk semua aplikasi hilir termasuk di dalamnya layanan pemakai maupun studi ilmiah. Untuk meningkatkan kepercayaan dalam menggunakan keluaran model INDO12 di Selat Makassar, dilakukan perbandingan kualitatif terhadap variabel yang diamati. Data yang digunakan dalam penelitian ini disediakan oleh program INSTANT dan MITF. Validasi keluaran model dilakukan dengan membandingkan nilai variabel dari simulasi dengan hasil observasi. Metode perbandingan dilakukan terhadap data kecepatan arus, temperatur dan salinitas, serta volume transpor. Perbedaan volume transpor terutama terjadi di bawah lapisan termoklin. Model menunjukkan massa air lebih dingin dan lebih segar di lapisan termoklin, sedangkan lapisan lebih hangat dan asin. Perbedaan volume transpor dan distribusi suhu mempengaruhi suhu bobot pengangkutan dan kedalaman isoterm 16 °C. Model tersebut menghasilkan temperatur transportasi yang lebih hangat dan kedalaman isoterm 16 °C yang lebih dalam dibandingkan dengan pengamatan. Dari hasil validasi dapat disimpulkan bahwa model memberikan perbandingan yang cukup baik dengan data in-situ terutama untuk sinyal musiman.

Kata kunci: Validasi, INDO12, Model lautan, Selat Makassar, Program INSTANT dan MITF

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1. Introduction

The framework of the Infrastructure DEvelopment of Space Oceanography (INDESO) project, which is operated by Institute for Marine Research and Observation, Ministry of Marine Affairs and Fisheries has provided INDO12 model. It is a 1/12 regional configuration of the NEMO3.1 physical ocean model covering the whole Indonesian Exclusive Economic Zone (EEZ) and has temporal spatial from hourly to daily. The regionalization configuration of the code deals with the addition of high-frequency processes such as tide and the atmospheric pressure forcing. Specific numerical schemes such as time-splitting, non-linear free surface (Levier et al., 2007) and open boundary algorithms have been implemented or improved. Specific physical parameterizations for regional modeling have been added such as generic length scale turbulence model including wave impact, logarithmic bottom friction, etc. In addition, the vertical mixing induced by internal tides is taken into account using the parameterization of Koch-Larrouy et al. (2007) by artificially enhancing vertical viscosity and diffusion coefficients (Tranchant et al., 2015).

The horizontal grid is an extraction of the global ORCA grid at 1/12° developed at Mercator Ocean. It is a quasi-regular grid on the Indonesian area and with a mesh approximately equal to 9 km. In the vertical direction, the model uses a partial step z coordinate (Barnier et al., 2006). The vertical grid is spread over 50 levels and a depth-dependent resolution (1 m at surface to 450 m at the bottom). In the first 10 m, the layer thickness is less than 2 m, then rise to about 10m at 50 m deep.

Atmospheric forcing fields come from the European center (ECMWF) and have a high frequency (3 h). “Bulk” formulae from CORE are used to model the atmosphere-ocean interface (Large and Yeager, 2004). INDO12 has geopotential tidal forcing for M2, S2, N2, and K2 (the four largest semidiurnal constituents) and for K1, O1, P1, and Q1 (the four largest diurnal constituents). As in Maraldi et al. (2013), two long period tides Mf and Mm and one non-linear constituent (compound tides) M4 are also added. These 11 tidal constituents coming from the astronomical forcing TPX0.7 (Egbert and Erofeeva, 2002) are used to force open boundaries.

A monthly runoff climatology is built with data on coastal runoffs and 99 major rivers from Dai and Trenberth (2002) and prescribed with a flux formulation into the model. In addition, two important missing rivers (Mahakam and Kapuas on Borneo Island) with large enough rates (class 3) were added to this database.

The INDO12 simulation starts on the 3 January 2007 with conditions given by the Mercator-Ocean Global Ocean Forecasting System at 1/4° (PSY3V3R3) (Lellouche et al., 2013) started three months before from a Levitus climatology. These conditions include temperature, salinity, currents and sea surface height. Open boundary conditions (OBCs) are located on a relaxation band of 10 grid points (~1°) and come from daily output of the Mercator-Ocean Global Ocean Forecasting System at 1/4°.

Since mid-2014, the production of the regional model is operational and a weekly monitoring of the results quality is done through different metrics of validation. Validate the model results remains highly required for any downstream applications (services or scientific studies). In order to enhance confidence in using the INDO12 model outputs in Makassar Strait, qualitative comparisons with observed variables is performed.

2. Materials and Methods

To improve the model quality knowledge, we have decided to focus on the Makassar Strait, by comparing the model data to in-situ observations. The dataset used to validate the INDESO model in Makassar Strait comes from different sources. Since this strait is the main channel of the Indonesian Throughflow (ITF), that is the Pacific-to-Indian Ocean through flow, several oceanographic measurement programs have been conducted there. In this study we use datasets provided by the International Nusantara Stratification ANd Transport (INSTANT), and Monitoring Indonesian ThroughFlow (MITF) programs. The INSTANT data were obtained from http://www.marine.csiro.au/~cow074/index.htm and MITF data were obtained from the 2015-2019 scientific cruises. Description and in part of MITF cruises data is provided at http://ocp.ldeo.columbia.edu/res/div/ocp/projects/MITF/Makassar_Strait_Mooring.html

Validation of model outputs are performed by compare the value of variables from simulation with observed data. Direct methods, that is one-to-one comparisons data sets, is used as a comparison method in this study. Direct comparison methods compare state variables from two data sets at specific times and locations. Ocean current, temperature, salinity, and transport at specific area are the variables used in the comparison. The ocean models ability to locate oceanographic phenomena such as transport-weighted temperature allows to be known by this method.

Root mean square error (RMSE) and relative root mean square error (RRMSE) is used as qualitative number of comparison. The lower of RMSE value then represent better ability of a model prediction in terms of its absolute deviation (Willmott and Matsuura, 2005). RRMSE is calculated by dividing the RMSE by the average value of the measured data. The accuracy of the model is considered very good when RRMSE < 10%, good if 10% < RRMSE < 20%, reasonable if 20% < RRMSE < 30%, and poor if RRMSE > 30% (Li et al, 2013 and Despotovic et al, 2005). RRMSE equation is symbolized as follows:

$$RRMSE = \sqrt{\frac{\frac{1}{n}\sum_{i=1}^{n}\left(y_i - \hat{f}(x_i)\right)^2}{\sum_{i=1}^{n} y_i}} \times 100$$

where y_i is observed value, $\hat{f}(x_i)$ is modelled value, i is sequence of data, and n is total amount of data.

Details of each data sets that be used in comparison can be explained as follows:

Current velocities

Since the orientation of the Makassar Strait is north-south, the dominant current in this water is meridional (in the north-south direction) current. Comparison of meridional current profile is performed at MITF 2013-2015 program mooring location, that is in the Labani channel. Geographic coordinate of the mooring is 02° 51.785' S and 118° 27.772' E. As a comparison the nearest model grid point from the mooring location is used.

Temperature and salinity

Comparison of temperature and salinity vertical profiles at several points is performed by using Conductivity Temperature Depth (CTD) casting measurements and modelled data on the same date (one day average). The nearest grid point of the model from the CTD casting measurements position is chosen for comparing the two datasets. The observation data from MITF scientific cruise that be held on 14-16 August 2015 is used in this comparison. Figure 1 shows the distribution of the positions of the CTD stations.

Volume transport

Subsurface volume transport comparison is conducted to determine the validity of the INDO12 simulation in Makassar Strait. INSTANT and NOAA OCO programs provide observed separated subsurface volume transports data, i.e. 0-300 m depth and 300-750 m depth, from year 2004 to 2011. The INSTANT and NOAA OCO projects are a cooperative program between the Lamont-Doherty Earth Observatory of Columbia University and the Agency for Marine & Fisheries Research, Ministry of Marine Affairs and Fisheries, Indonesia. However, since the INDO12 simulation outputs are only available since 2008, the comparison has been performed for year 2008 to 2011.

The 16 °C isotherm depth and transport-weighted temperature (TWT)

The observed data obtained from the INSTANT observational period 2004-2006 (Gordon et.al, 2008) is used as a referencein the comparation of 16 °C isotherm depth and transport-weighted temperature of model outputs. The temporal relationship between the temperature and transport profiles can be captured by the transport-weighted temperature. The transport-weighted temperature is therefore the average temperature of the water column,

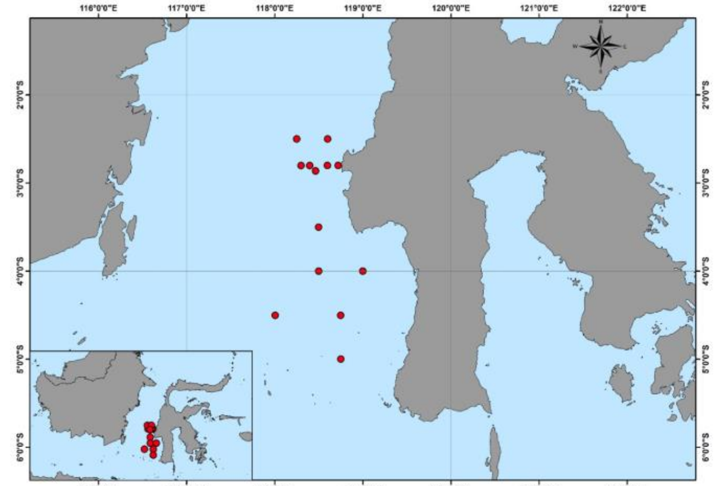

Figure 1. The locations of CTD casting measurement in Makassar Strait conducted during MITF 2015 scientific cruise. Measurement is carried out in the period 14-16 August 2015.

weighted by the transport (Andersson and Stigebrandt, 2005):

$$TWT = \frac{\int QTdz}{\int Qdz}$$

where Q is the transport in Sv and T is the temperature in °C, evaluated from the sea surface to 1200 m, the effective sill depth. In this study Q and T are defined for each of the 5 m layers from surface to 1200 m depth. Since the concept of transport-weighted temperature is only valid for unidirectional flow, northward transport values are set to zero to produce physically meaningful results. Unlike a simple average of temperature, the transport-weighted temperature is the most representative temperature for the whole water column, as the temperature is weighted most heavily at the location of the transport maximum. Changes in the total transport do not directly influence the transport-weighted temperature calculation, but changes in the profile of transport do.

3. Results and Discussions

3.1. Current velocities

Figure 2 shows meridional current profiles at MITF mooring location, both for simulation and observed data. We can see that the simulated and observed meridional current profiles have similar vertical and temporal patterns. There is a thermocline maximum (50-200 m) in the Makassar throughflow for both. The Makassar throughflow is the main part of ITF and a maximum throughflow often occurs within the thermocline, mostly during the times of high throughflow. Both of them also show clear seasonal behavior, reaching a maximum towards the end of the northwest and southeast monsoons, with minimum transport in October-January. The model can also simulate northward surface current during January 2015. However, the northward surface current is not visible in January 2014 simulation, whereas it appears in the observed data. But overall, the model correctly simulates the subsurface meridional velocities patterns.

3.2. Temperature and salinity

Figure 3 shows vertical profiles comparison of temperatures and salinities at Makassar Strait, specifically at points coordinate 118.7196 °E 2.80053 °S, 118.25 °E 2.50 °S, and 118.748 °E 4.50 °S. In general, the temperatures of the model well suit the ones of the CTD measurements for the entire water column. Model and observation show similar temperature decrease to the depth and have the same depth

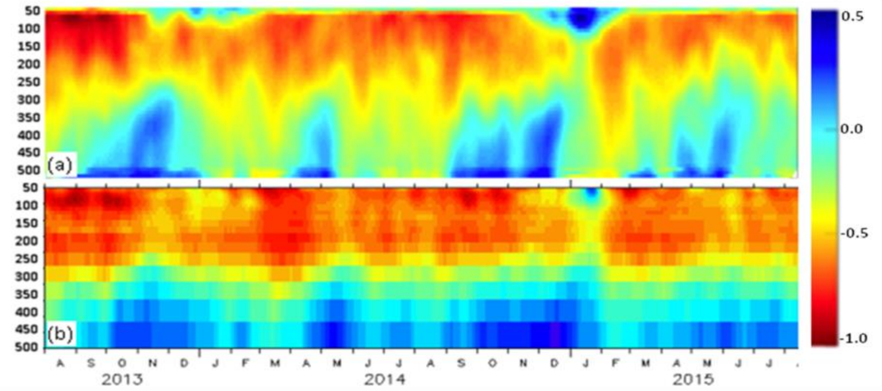

Figure 2. (a) The observed meridional current from MITF mooring (m.s^{-1}). (b) Meridional current profile from INDO12 simulation at MITF mooring location (m.s^{-1}). 15 day running mean is performed for both of data.

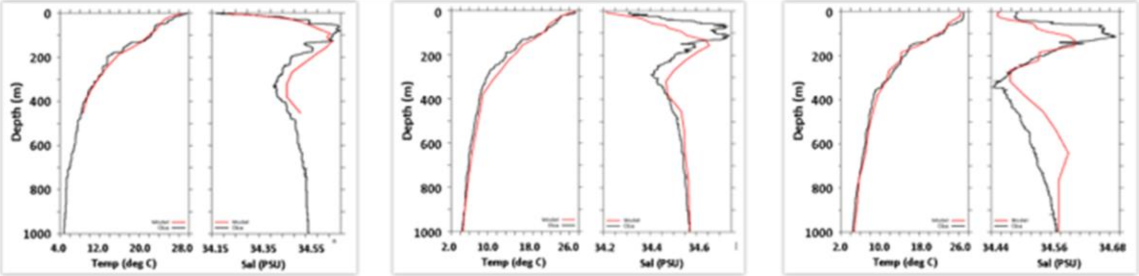

Figure 3. Comparison of temperatures and salinities vertical profiles at points coordinate 118.7196 °E 2.80053 °S, 118.25 °E 2.50 °S, and 118.748 °E 4.50 °S. Red line indicates the model profile whereas black line indicates the observed profile.

for thermocline layers. The model simulates quite well the temperature stratification at depth at Makassar Strait.

The shape of the model salinity vertical profiles is almost similar to the observation. However, most of the profiles shows that the model has deeper maximum salinity in the halocline layer. Halocline is the vertical zone in the oceanic water column in which salinity changes rapidly with depth, located below the well-mixed, uniformly saline surface water layer. Both of model and observation indicate well-mixed layer is vague in Makassar Strait, especially at north part of CTD measurements.

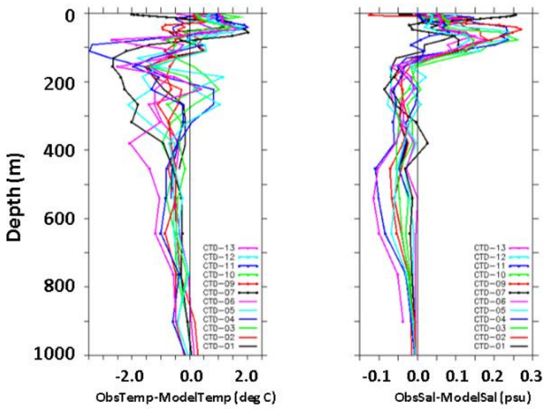

Figure 4. The difference of temperature (left) and salinity (right) vertical profiles between the observation and the model. The difference is obtained from observation minus model.

Figure 4 shows the difference of temperature and salinity profiles between the observation and the model. The differences are the observed data minus the model value at the same depth. Can be seen that in average there are three parts in the profile of the differences for temperature and salinity variables. The first part is from the surface to 100 m depth. The model is colder and fresher in this layer with a difference of temperature and salinity approximately being 1 °C and 0.15 psu respectively.

The second part is the layer from 100 m to 150 m depth. The model is about 0.5 °C warmer and 0.15 psu fresher in this layer. The third part is the layer deeper than 150 m depth. In this layer the model is warmer and saltier with temperature and salinity differences of about 0.4 °C and 0.05 psu.

3.3. Volume transport

Figure 5 shows comparison of subsurface volume transport in Makassar Strait. The 0-300 m depth simulated volume transport is close to observed data (Figure 5(a)). Both of them have almost the same phase and the same magnitude of transport. The maximum southward transport appears during southeast monsoon (July-September), whereas the minimum southward transport appears during northwest monsoon (December-February). A significant difference in the magnitude of transport values appears at 300-750 m (Figure 5(b)). Observed data shows larger volume transport and higher variability

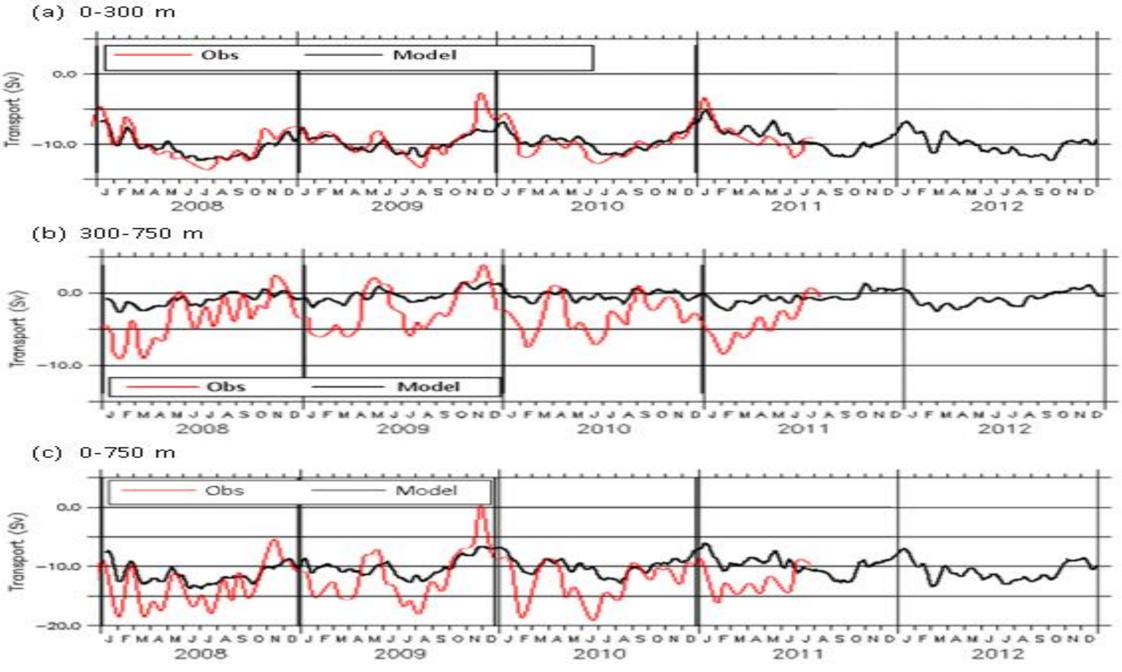

Figure 5. Comparison of subsurface volume transport in Makassar strait. (a) Makassar Strait transport for 0-300 m depth. (b) Makassar Strait transport for 300-750 m depth. (c) Makassar Strait transport for 0-750 m depth.

Table 1. Makassar Strait Transport, Transport-Weighted Temperature and Depth of the 16°C by Season Derived from INSTANT Program Observation and INDO12 Simulation

Season & data source		Transport	Transp-Weighted Temperature (°C)	16°C Isotherm Depth (m)
JFM	INSTANT	-13.1 ± 2.8 Sv	16.6 ± 3.7	181 ± 10
	INDO12	-9.8 ± 1.5 Sv	18.7 ± 0.5	203 ± 2
AMJ	INSTANT	-11.7 ± 3.1 Sv	16.0 ± 3.9	182 ± 11
	INDO12	-10.3 ± 0.6 Sv	19.5 ± 0.2	203 ± 1.5
JAS	INSTANT	-12.6 ± 2.5 Sv	16.9 ± 2.6	180 ± 10
	INDO12	-11.2 ± 0.3 Sv	19.5 ± 0.4	200 ± 2
OND	INSTANT	-8.8 ± 3.0 Sv	12.7 ± 3.0	178 ± 8
	INDO12	-8.9 ± 0.9 Sv	20.3 ± 0.4	200 ± 2.5

[a]Northwest Monsoon is JFM (January-March); AMJ (April-June). Southeast Monsoon is JAS (July-September); OND (October-December).

than in the model. As in the upper layer, observed transport in 300-750 m still indicates a clear seasonal variation, where these are less obvious in the model. Indeed, transport in the deepest layer is smaller than in the upper layer, but the lack of deep layer transport affects the total transport values (Figure 5(c)).

3.4. Analyzed data

Comparison of the Makassar Strait volume transport magnitude, transport- weighted temperature, and 16 °C isotherm depth in seasonal climatological values is presented in Table 1. As a reference, observed data obtained from the INSTANT observational period 2004-2006 (Gordon et.al, 2008) is used. The 16 °C isotherm depth of model is obtained from native vertical grid to monotonic vertical axis interpolation.

Although calculated at different timescales, 2004-2006 timescales for INSTANT data and 2008-2015 for INDO12 model, seasonal climatological value in Table 1 should not differ too much. Actually, we can see considerable differences for each variable.

For volume transport, the difference ranges from 0.1 to 3.3 Sv, INSTANT data being larger in average. Seasonal phase of transport also shows an aberration. The minimum transport of INSTANT observation occurs in the monsoon transition months, i.e., on October to December (OND; 8.8 Sv). The minimum transport of modelled data also occurs in the October to December (OND; 8.9 Sv). The large difference of transport between model and observation has occurred in JFM period. Another monsoon transition transport of the model (AMJ) is larger than the northwest monsoon months (JFM). We see mainly than the main difference is a too weak transport during the JFM period in the model.

The difference of transport-weighted temperature ranges from 2.1 °C to 7.6 °C in which the model is warmer than observation. The INSTANT data shows that the season of coolest transport-weighted temperature occurs during October-December, the timing of minimum speed. On the contrary, the model shows the warmest transport-weighted temperature in the same time. Perhaps this discrepancy is posed by lower velocities as shown in subsurface volume transport comparison. As one of the main components of water masses in the Indonesian seas this issue may affect the entire model domain.

The depth of the 16 °C isotherm calculated from INDO12 model is deeper than in INSTANT during all seasons. The difference of the 16 °C isotherm depth is ranging from 20 to 22 m. There are possible causes of the discrepancy, such as vertical mixing intensity and temperature distribution processes.

Table 1 also shown that the standard deviation of the model derived variables is smaller than the observed data. It seems that energetic intra-seasonal fluctuations of transport and thermocline depth caught by INSTANT observations are under-represented in the model. This may be due to the lack of energy in simulation that are sourced from the input or unrepresented entirely generate forcing, such as a local phenomenon.

The RRMSE analysis method shown that the models obtained 6.49%, 5.89%, and 12.7% for transport, 16 °C isotherm depth, and transport-weighted temperature comparison respectively. These number means that the modelled data has a good accuracy refers to observed data.

4. CONCLUSIONS

In Makassar Strait, the model correctly reproduces the meridional current features and their seasonal variability. However, considerable differences have been shown in the subsurface waters in volume transports, temperatures, and salinities: The volume transports differences especially occurred below the thermocline layer. The model is colder and fresher in the thermocline layer, whereas deeper the model is warmer and saltier. The differences of the volume transport and temperature distribution affect the transport-weighted temperature and 16 °C isotherm depth. The model produces warmer transport-weighted temperature and deeper 16 °C isotherm depth compared to the observations. It is concluded from the validation results that the model gives a good comparison with the in-situ data that shown by RRMSE analysis, especially for seasonally signals. Perhaps with some improvements driven for instance by sensitivity experiments or/and reach by using a finer model grid, the model will be able to produce more accurate results.

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Authors' contributions

B.P.; conceived and designed of the study, analysed data and co-wrote the paper. M.T.; performed statistical analysis and co-wrote the paper. T.A.; performed data collection and co-wrote the paper. All authors contributed to refinement of the study protocol and approved the final manuscript.

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