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To cite this article: Siswanto *et al* 2019 *IOP Conf. Ser.: Earth Environ. Sci.* **303** 012005

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Estimated transport of Equatorial Undercurrent observed at 90°E during the Indonesia Prima 2017 campaign

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Abstract. Equatorial Undercurrent (EUC) plays an important role in the dynamic of the eastern Indian Ocean. EUC supplies water masses with high salinity into Indonesian waters. This article examines the EUC transport volume at 90°E across 2°S - 2°N observed on 1st – 3rd March 2017 during the Initiative on Maritime Observation and Analysis Expedition (Indonesian Prima 2017). The analysis of temperature and salinity obtained from conductivity, temperature and depth (CTD) instruments at five stations (CTD11 - CTD14) and current profiles of Shipboard Acoustic Doppler Current Profiles (SADCP) indicate the presence of high speed water column flowing the Arabian Sea High Salinity Water (ASHSW) as characterised by maximum salinity (35.15 - 35.2 PSU) in the temperature range of 18°C - 23°C. ASHSW carried by EUC from the western Indian Ocean at the upper thermocline layer had a tendency to be asymmetrically stronger to the north of the equator. The analysis shows a maximum EUC current speed of 94 cm/sec. Estimated EUC transport water masses based on the curvature area of salinity contour 35.15 and 35.2 PSU respectively result a ~3.4 Sv and a ~1.4 Sv, while at curvature area of salinity 35.00 - 35.10 PSU gave about ~8.7 Sv. The total estimated EUC mass eastward transport calculated in this study is ~13.5 Sv.

Keywords: equatorial undercurrent, Indian Ocean, SADCP.

1. Introduction

Equatorial Undercurrent (EUC) is the flow of water mass eastward that is strong in the subsurface layer in the equatorial region that occurs in the Atlantic, Indian and Pacific Oceans. There have been known two main EUC drivers namely the southeasterly trade wind which blows above the equatorial zone and the convergence of the east equatorial nonlinear currents. The convergence of east nonlinear currents toward the equator, in which caused by changes in the coriolis effects between the northern and southern hemispheres, lead to a strong subsurface current around the equator [1].

The maximum speed of EUC differs depending on the oceanic region. The maximum speed of EUC in the Pacific Ocean (often called Cromwell current) is more than 150 cm per second [2], in the Atlantic Ocean (often called Lomonosov current) with a velocity more or less similar to the Cromwell current. In the Indian Ocean, EUC is often called a strong subsurface equator jet and does not exist throughout the year. This phenomenon occurs in the winter when the northeast monsoon develops, and disappears in the summer when the southwest monsoon occurs [1], with currents between 50-100 cm/sec [6].



EUC in the Indian Ocean is already known to be a seasonal phenomenon [3]. This current has a relatively stronger magnitude in the eastern Indian Ocean [4] flows eastward and can be found in a strong thermocline layer (pycnocline) beneath the top layer (top layer mixing).

Rao et al. [5] stated the EUC presence at depths between 50 m and 150 m at the equator at a latitude range of 2°S from 61°E - 63°E during January - February 1963.

EUC is often referred to as a subsurface jet that occurs in the winter when the northeast monsoon develops, and disappears in summer during the southwest monsoon, with a current velocity of 50-100 cm/sec [6].

1.1. Observed zonal equatorial current

Observed zonal equatorial current from RAMA/ATLAS mooring buoy at 0° 90°E during 2000 - 2014 (Fig.1) shows a variation of a strong eastward current which mainly has two maximum axis speeds (>50 cm/s) namely at ~50 and ~100 m depth. The deeper presence earlier mainly during the late boreal winter, while the shallower appears later during springtime, although variation in the strength of current speed and time appearance is also observed.

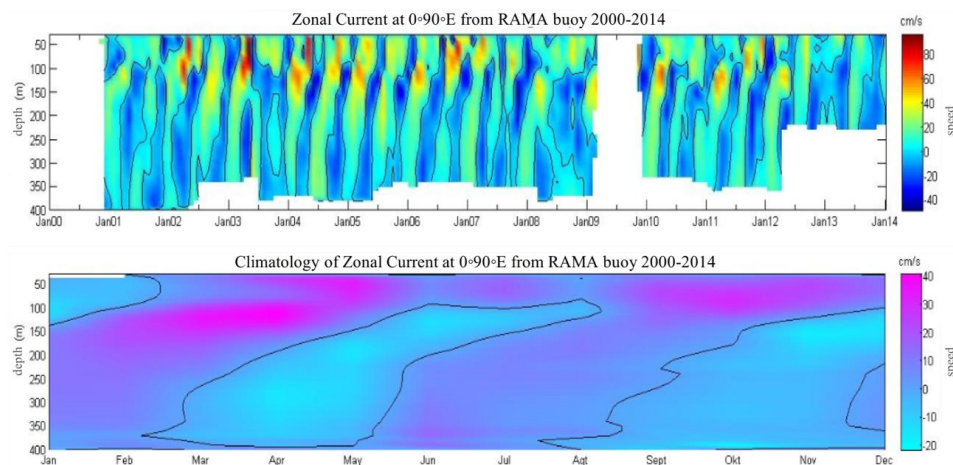


Figure 1. (upper) Observed zonal current variation from the surface to 400m depth obtained from RAMA mooring buoy at 0° - 90°E during 2000 - 2014. (bottom) The climatology means of 14 years of data. Red (blue) indicates an eastward (westward) current.

1.2. Indonesia PRIMA 2017 Field Campaign

The Indonesia PRIMA field campaign is part of a ship time BMKG - NOAA collaboration for maintaining RAMA mooring buoy (ATLAS).

The field campaign includes data survey in the marine meteorology, geophysics, oceanography, and air quality. There were 23 CTD stations and along track SADCP data extracted from the activity. This study takes the advantages of 5 CTD stations and current data represent a latitude range of 2°N - 2°S at 90°E (Fig.2).

The results of this study are expected to provide additional information about the characteristics of the EUC water mass and the volume of instantaneous water mass transport from the western Indian Ocean to the eastern Indian Ocean including Indonesian waters.

2. Objectives

This study aims to determine the characteristics of the eastern Indian Ocean water mass and the EUC current at longitude 90°E and also estimating instantaneous transport of the EUC water masses in the eastern Indian Ocean.

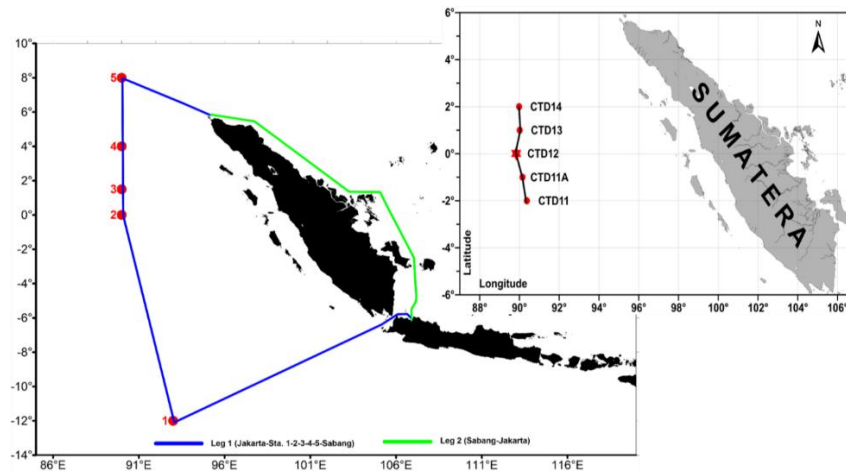


Figure 2. Full ship-track of Indonesia PRIMA 2017, 5 RAMA buoy maintenance sites including mooring buoy at 0° 90°E (red dots) and 5 CTD stations used in this study (insert). The current data was obtained from recorded along track SADC during the field campaign.

3. Data and Methods

We use observational data from CTD11 - 14 and along track SADC obtained from 1 - 3 March 2017 in Indian Ocean at latitude range between 2°S - 2°N along longitude 90°E.

The temperature and salinity parameters are measured continuously up to 1000 m depth using SBE 911 CTD from Seabird Electronic Inc and being smoothed at 1 m resolution

SADC 75 kHz frequency from RD Instrument measures the current parameters from a depth of 12.3 m to 500 m from the surface with a vertical bin every 5 m with 2 seconds intervals at an average 8 knots ship velocity.

The raw data is then being processed to obtain current velocity and direction, zonal current (u) and meridional current (v).

For quality control process, outlier data is eliminated by criteria of percent good below 50% and correlation coefficient below 0.8 as well as eliminating abnormal data due to a weak global positioning system signal and current velocity more than 250 cm/sec.

3.1. Estimating the equatorial water mass transport

Instantaneous transport estimation Q is calculated based on the mathematical sum of the gridding area of the cross section of the zonal current velocity at the equator ranging from 2°S to 2°N at 90°E longitude following the curvature area of salinity contour using the equation:

$$Q = \sum_{i=1}^{i=100} V_i \cdot A_i \quad (1)$$

where

$$V_i = v_i \cos \theta + u_i \sin \theta \quad (2)$$

V_i is the equatorial current velocity on the i^{th} cell whereas A_i is the cross-sectional area of the i^{th} cell.

4. Results

The T-S diagram shows at least four different water masses (Fig.3A-B). Low-salinity water mass (33.90 - 34.80 PSU) is observed in the surface layer with sea water temperature varying between 28.0°C - 29.0°C. The second layer presents a high salinity water mass with a salinity range of 35.15 - 35.20 PSU

and a temperature range of 18.0 - 23.0°C. The third layer is water mass with salinity 35.00 PSU, temperature 7.0 - 11.0°C.

While the fourth deepest layer is water mass with salinity 34.70 - 34.90 PSU, the temperature range 2.0°C - 6.0°C. The mass of the water downward looks almost homogeneous.

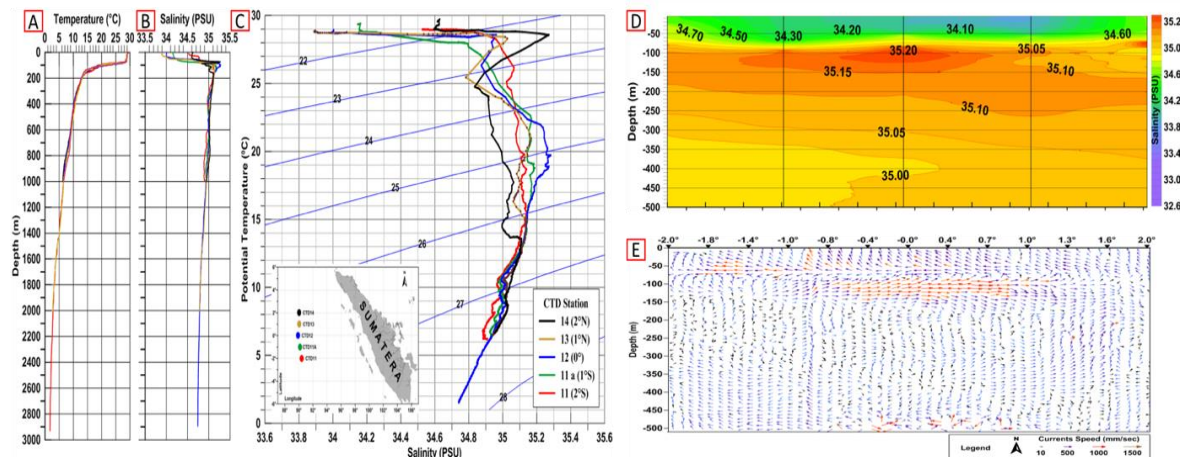


Figure 3. Vertical profile of A) temperature, B) salinity and C) T - S Diagram from CTD11--14 data. Latitudinal cross-section of (C) salinity and (D) current.

At a depth of 80m - 150m from latitude 1.2°S - 1.5°N there is a strong current with highly saline water flowing eastward with a maximum speed of 94 cm.sec⁻¹ (Fig.3C-D and Fig.4). The current is characterized as an EUC current that has a stronger asymmetric tendency toward the north of the equator.

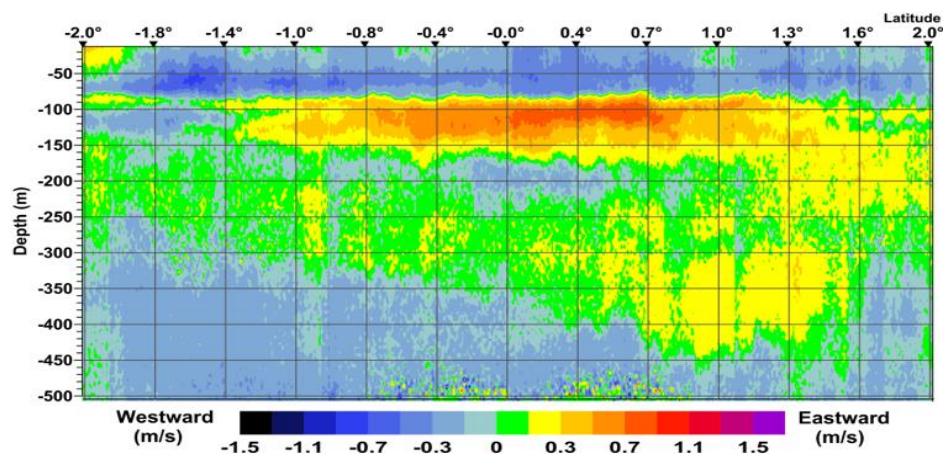


Figure 4. Meridional cross section the EUC zonal current component. Red (blue) indicates an eastward (westward) flow.

The estimated water mass transport is calculated by eastward EUC zonal current overlying the salinity contour (Fig.5A).

The salinity contour is then used to describe water mass columns that have similar characteristics, assuming the dynamics of the water mass follows the physical characteristics of seawater properties as in Fig.3B.

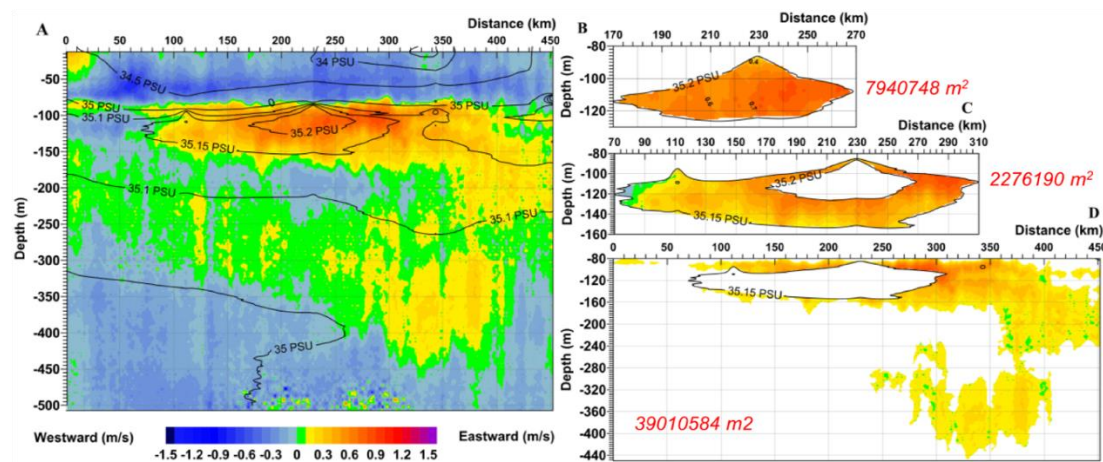


Figure 5. (A) Overlaid zonal current with salinity contour and (B) estimated transport volume based on salinity contour slices at 35.20 PSU, 35.15 PSU, and 35.00 - 35.10 PSU.

The result of estimated volumetric water mass transport based on zonal current velocity of EUC and salinity cross-sectional area defined as in Fig.5B) are 3364682 m³.s⁻¹ (~3.4 Sv), 1377677 m³.s⁻¹ (~1.4 Sv), and 8719226 m³.s⁻¹ (~8.7 Sv), respectively.

Total estimated eastward transport for a high salinity range 35.0 - 35.2 PSU is ~13.5 Sv.

5. Conclusions

A strong EUC current with highly saline water flowing eastward with a maximum speed of 94 cm/sec is observed at depth of 80m - 150m from latitude 1.2S - 1.5N. This current is characterized has a stronger asymmetric tendency toward the north of the equator. The highly saline water is concluded as the Arabian Sea High Salinity Water (ASHSW). The result of estimated eastward transport based on zonal current velocity on EUC and salinity cross-sectional area of 35.0 – 35.2 PSU range is ~13.5 Sv. This result of estimated eastward transport in this study will need to be compared with other studies for forthcoming research.

Acknowledgements

We would like to thanks to BMKG, LIPI, NOAA, and RV Baruna Jaya for their available facilities to conduct this study.

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