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Currents Simulation in the Malacca Straits by Using Three-Dimensional Numerical Model

(Simulasi Arus di Selat Melaka Menggunakan Model Berangka Tiga Dimensi)

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ABSTRACT

The Malacca Straits is located between Peninsula Malaysia and Sumatra Island. This investigation used equation of motion (Navier-Stokes equation) with the following driving forces: tides, wind of National Centers for Environmental Prediction (NCEP) for year of 2007, salinity and temperature. The equation of motion was solved by means of Hamburg Shelf Ocean Model (HAMSOM). The results for both southwest and northeast monsoon were explained and discussed. The simulation results both for February and August 2007 were relatively similar. Current surface simulation in the Malacca Straits agrees well with the current pattern of previous works. The magnitude of current was between 10-70 cm/s to the northwest. While at the layer 30-50 m in the Malacca Straits, the currents have the magnitude of 10-30 cm/s towards northwest. For the bottom current, the current speed was 0-20 cm/s towards northwest. For the surface and 30-50 m layer, generally the current magnitudes were greater in February compared to those in August. While for the bottom layer, the current magnitudes between February and August were relatively the same.

Keywords: Baroclinic current; Malacca Straits; northeast monsoon; southwest monsoon

ABSTRAK

Selat Melaka terletak di antara Semenanjung Malaysia dan Pulau Sumatera. Kajian ini menggunakan persamaan gerakan (Navier-Stokes) bersama daya pemacu berikut: air pasang-surut, data angin dari Pusat Kebangsaan Ramalan Sekitaran bagi tahun 2007, saliniti dan suhu. Persamaan gerakan diselesaikan menggunakan Model Lautan Pelantar Hamburg (HAMSOM). Keputusan bagi monsun barat daya dan timur laut dibincangkan. Keputusan simulasi bagi bulan Februari dan Ogos 2007 adalah hampir sama. Hasil simulasi arus permukaan di Selat Melaka adalah berpadanan dengan corak arus yang dilaporkan sebelum ini. Magnitud arus adalah antara 10-70 cm/s ke arah barat laut. Pada lapisan 30 hingga 50 m, magnitud arus adalah 10-30 cm/s ke arah barat laut. Pada bahagian dasar, kelajuan arus ialah 0-20 cm/s ke arah barat laut. Arus pada bahagian permukaan dan lapisan adalah 30-50 cm/s, secara umumnya adalah lebih tinggi pada bulan Februari berbanding pada bulan Ogos. Bagi lapisan bawah pula, magnitud arus antara bulan Februari dan Ogos adalah hampir sama.

Kata kunci: Arus baroclinic; monsun barat daya; monsun timur laut; Selat Melaka

INTRODUCTION

The Malacca Straits is located between Peninsular Malaysia and Sumatra Island. In terms of economic and strategic, the Malacca Straits is one of the most important shipping routes in the world, like Suez or Panama Canal. Malacca Straits is a canal shipping route between the Indian and Pacific Ocean that connects three different countries with the largest number of people in the world: India, Indonesia and China. Thus, the circulation flow through the Malacca Straits is very important to be investigated.

In this investigation, the three-dimensional numerical model developed at the University of Hamburg, Germany was used. This model is called as HAMSOM model (Hamburg Shelf Ocean Model). This model has been successfully applied in the Bohai Sea, North Sea and some cases of open sea in different domains in various countries (Backhaus 1983; Huang et al. 1999; Pohlmann 1996)

This model was developed in the form of discrete solutions of Navier-Stokes equation with the finite-difference semi-implicit method. The primitive equation model with a free surface utilises two time-levels, and is defined in Z co-ordinates on the Arakawa C-grid. Stability constraints for surface gravity waves and the heat conduction equation were avoided by the implementation of implicit schemes. With a user defined weighting between future and presence time levels a hierarchy of implicit schemes is provided to solve for the free surface problem, and for the vertical transfer of momentum and water mass properties.

In the time domain a scheme for the Coriolis rotation was incorporated which has second order accuracy. At the seabed a non-linear (implicit) friction law as well as the full kinematic boundary condition is applied. Seabed cells may deviate from an undisturbed cell height to allow for a better resolution of the topography. The HAMSOM coding excludes any time-splitting, i.e. free surface and internal baroclinic modes are always directly coupled. Simple upstream and more sophisticated advection schemes for both momentum and matter may be run according to directives from the user.

The objective of this work was to simulate the Malacca Straits in order to find the patterns of the current both for the northeast monsoon and southwest monsoon.

MATERIALS AND METHOD

Data used in the current model consists of:

1. Bathymetry data 10′×10′ from year 2002 (Figure 1).
2. Tidal assimilated data from the harmonic component (Zahel et al. 2000)
3. Temperature and salinity data (Levitus & Boyer 1994a, b)
4. 4-times daily Secondary data of meteorology for the year of 2007 from the National Centers for Environmental Prediction (NCEP), namely:
   a. U-wind speed at 10 m (m/s).
   b. V-wind speed at 10 m (m/s).
   c. Air temperature at 2 m (K).
   d. Downward longwave radiation flux (W/m^2).
   e. Downward solar radiation flux (W/m^2).
   f. Precipitation rate (kg/m^2/s).
   g. Specific humidity at 2 m (kg/kg).
   h. Sea level pressure (Pa).
   i. Total cloud cover (%).
   j. Upward longwave radiation flux (W/m^2).
   k. Upward solar radiation fluks (W/m^2).

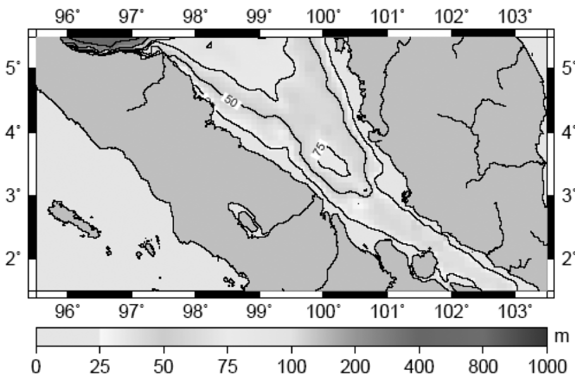

FIGURE 1. Bathymetry of Malacca Straits. Contour labels are in meters

Wind circulation patterns in the Malacca in February 2007 (northeast monsoon) and August 2007 (southwest monsoon) can be seen in Figures 2 and 3. Wind in February 2007 flows from northeast to southwest. While in the southwest monsoon for August 2007, the wind flows from southwest to northeast and from the north to south.

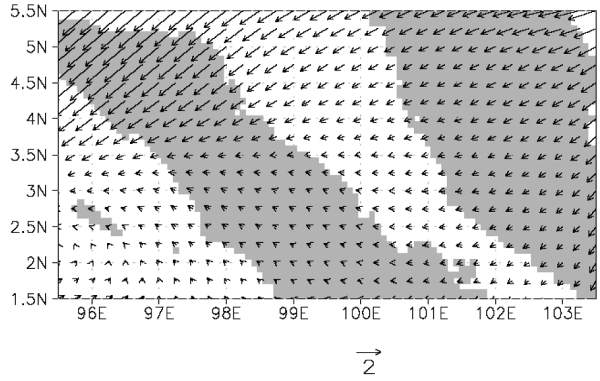

FIGURE 2. Wind pattern for February 2007 (m/s)

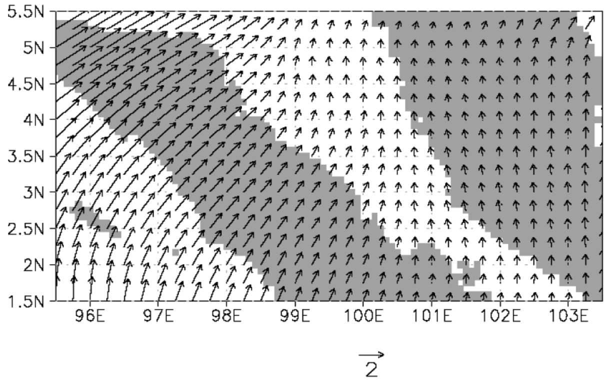

FIGURE 3. Wind pattern for August 2007 (m/s)

Basic equations used in this research are the Navier-Stokes equations in the direction x and y (Backhaus 1985; Huang et al. 1999; Pond & Pickard 1983; Rizal 2000; Rizal & Sündermann 1994):

$$\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}+w\frac{\partial u}{\partial z}-fv=-\frac{1}{\rho}\frac{\partial p}{\partial x}$$
$$+\frac{\partial}{\partial x}\left(A_H\frac{\partial u}{\partial x}\right)+\frac{\partial}{\partial y}\left(A_H\frac{\partial u}{\partial y}\right)+\frac{\partial}{\partial z}\left(A_v\frac{\partial u}{\partial z}\right). \tag{1}$$

$$\frac{\partial v}{\partial t}+u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}+w\frac{\partial v}{\partial z}+fu=-\frac{1}{\rho}\frac{\partial p}{\partial y}$$
$$+\frac{\partial}{\partial x}\left(A_H\frac{\partial v}{\partial x}\right)+\frac{\partial}{\partial y}\left(A_H\frac{\partial v}{\partial y}\right)+\frac{\partial}{\partial z}\left(A_v\frac{\partial v}{\partial z}\right). \tag{2}$$

In the direction z, hydrostatic equation is written in the form of:

$$\frac{\partial p}{\partial z}=-\rho g. \tag{3}$$

Sea water state equation is given as:

$$\rho=\rho\left(S,T,p\right)=\rho_o+\rho'. \tag{4}$$

The heat transport equation is given as:

$$\frac{\partial T}{\partial t}+u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}+w\frac{\partial T}{\partial z}=K_H\nabla^2 T+\frac{\partial}{\partial z}\left(K_V\frac{\partial T}{\partial z}\right)+S_T. \quad (5)$$

The salt transport equation is given as:

$$\frac{\partial S}{\partial t}+u\frac{\partial S}{\partial x}+v\frac{\partial S}{\partial y}+w\frac{\partial S}{\partial z}=K_H\nabla^2 S$$
$$+\frac{\partial}{\partial z}\left(K_v\frac{\partial S}{\partial z}\right)+S_s. \quad (6)$$

The continuity equation is given as:

$$\frac{\partial \zeta}{\partial t}+\frac{\partial}{\partial x}\int_{-h}^{\zeta}u\,dz+\frac{\partial}{\partial y}\int_{-h}^{\zeta}v\,dz=0, \quad (7)$$

where $u\,(x, y, z, t)$, $v\,(x, y, z, t)$ and $w\,(x, y, z, t)$ is the current in the direction x, y and z. $f = 2\omega \sin \varphi$ is the Coriolis parameter, ω is the earth's rotation angle speed and φ is geographic latitude, $\zeta(x,y,t)$ is the elevation surface water that is measured from the surface of rest water, $h(x,y)$ is the water depth also measured from the surface of rest water, g is the constant acceleration of gravity, H_{xk} and H_{yk} at the same time is the layer thickness in the direction of u and v in the k-th layer, ∇_H and is the horizontal gradient operator. A_H is the exchange coefficient of horizontal turbulence A_V and is the viscosity coefficient of vertical eddy. K_H and K_V are horizontal and vertical eddy diffusivities. S_T and S_S are source term of temperature and salinity. Hydrostatic pressure p (by ignoring the terms of $g\rho_0 z$ and p_a, since they do not have a contribution to the horizontal pressure gradient) in the z direction, is written in the form of:

$$p=g\rho_1\zeta+p'(\zeta)+g\int_z^0\rho'\,dz\equiv g\rho_1\zeta+I \quad (8)$$

Since the requirements related to stability in the time step that must be fulfilled by the numerical simulation, pressure in (8) is separated into two terms, namely: barotropic component ($g\rho_1\zeta$) and baroclinic component (I).

Model surface currents, sea bottom current and currents in a certain depth in the Malacca Straits due to the tidal, wind, meteorology parameters and density difference for February and August 2007 were simulated. The domain of simulated areas were between 5°30′ N - 1°30′ N and 95°30v E - 103°30′ E (Figure 1) with a horizontal grid width ∂_x = 10′, ∂_y = 10′ and at the direction of depth (z), it is discreted for 17 layers, namely 0-10,10-20, 20-30, 30-50, 50-75, 75-100, 100-125, 125-150, 150-200, 200-250, 250-300, 300-400, 400-500, 500-600, 600-700, 700-800 dan 800-900 m. Time step Δt = 600 s, horizontal eddy coefficient A_H = 500 m^2/s, vertical eddy coefficient A_V = 0.01 m^2/s and bottom friction factor C_f = 0.0025. Amplitudes and phases for tides are given at the open boundaries based on the assimilated data of harmonic components (Zahel et al. 2000) with 10′ interpolation.

In this paper, the analysis was done for surface layer (0-10 m), (30-50 m) and bottom layer both for Northeast monsoon, represented by February 2007 and the Southwest monsoon represented by August 2007.

RESULTS AND DISCUSSION

Circulation of surface current both for February 2007 and August 2007 through the Malacca Straits due to tidal, wind pattern (Figures 2 and 3) and the density difference is shown in Figures 4 and 5. It indicates that current flows towards the northwest with the speed range between 10 and 70 cm/s. This is consistent with the work of Wyrtki (1961) as shown in Figures 6 and 7.

Current simulations at layer of 30-50 meters for the month of February and August 2007 are shown in Figures 8 and 9. The current speed at layer of 30-50 meters is 0-30 cm/s towards the northwest. While at the bottom layer, current speed is between 0 and 20 cm/s (Figures 10 and 11) towards the northwest.

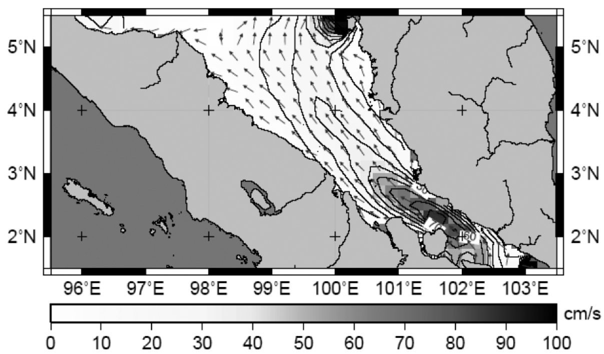

FIGURE 4. Surface current in February 2007 in Malacca Straits

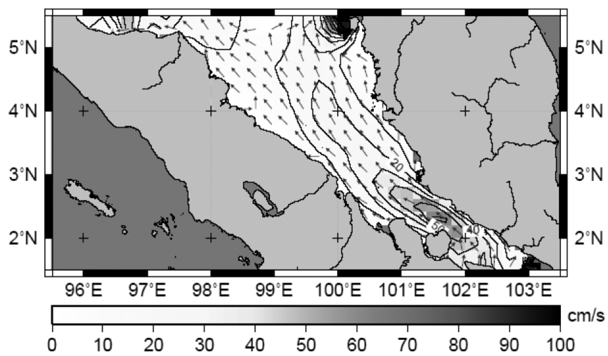

FIGURE 5. Surface current in August 2007 in Malacca Straits

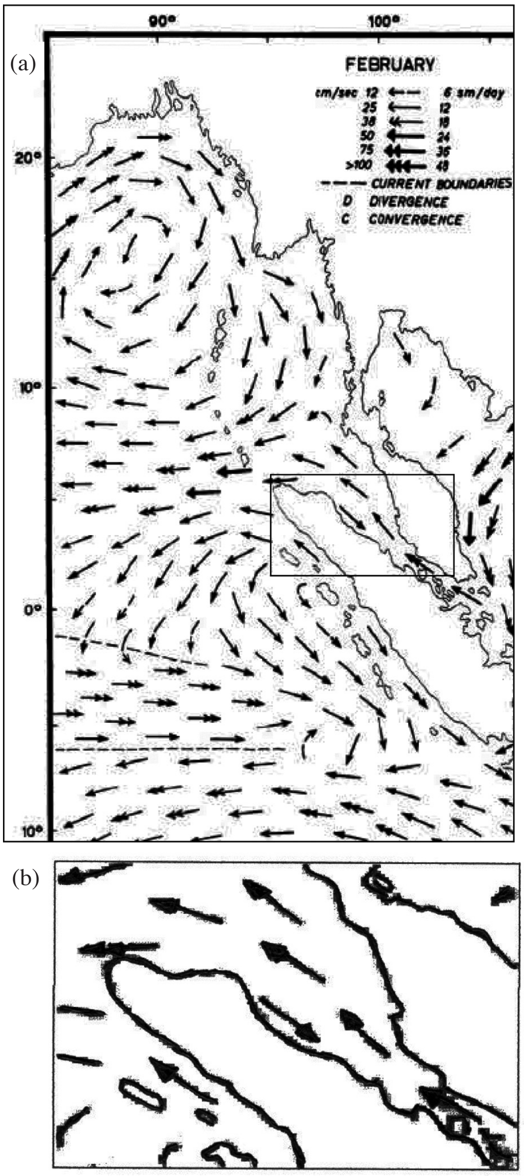

FIGURE 6. Surface current in February (Wyrtki 1961) in a) Malacca Straits, Andaman Sea and Indian Ocean, b) Malacca Straits

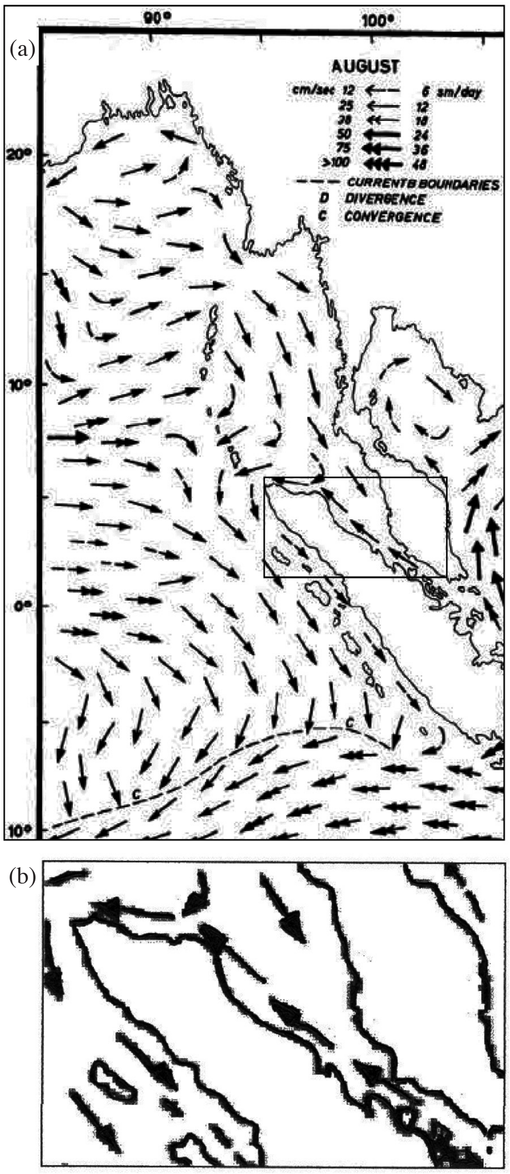

FIGURE 7. Surface current in August (Wyrtki 1961) in a) Malacca Straits, Andaman Sea and Indian Ocean, b) Malacca Straits

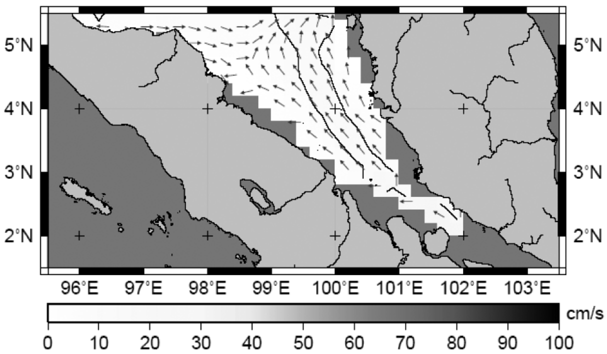

FIGURE 8. Current at the layer 30-50 m in February 2007 in Malacca Straits

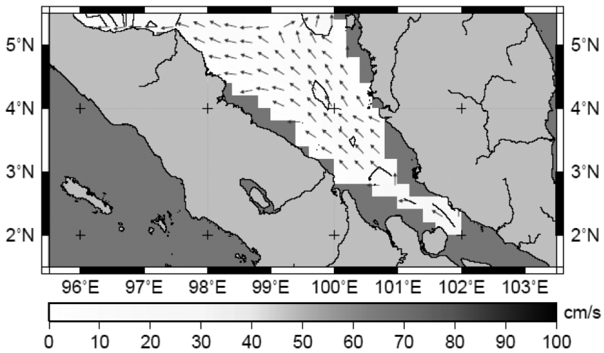

FIGURE 9. Current at the layer 30-50 m in August 2007 in Malacca Straits

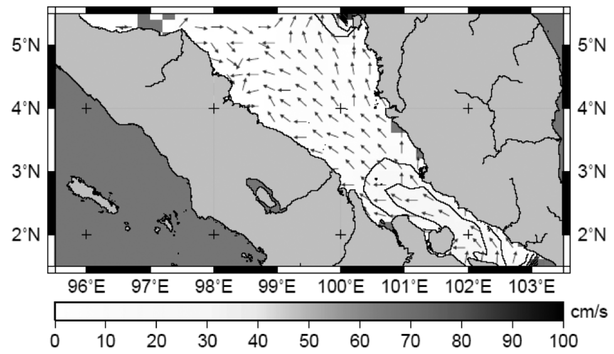

FIGURE 10. Sea bottom current in February 2007 in Malacca Straits

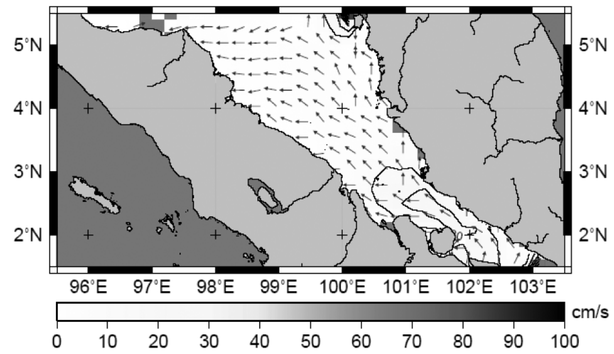

FIGURE 11. Sea bottom current in August 2007 in Malacca Straits

The difference of current magnitudes in February and August 2007 were analyzed with the following equation:

$$\text{abs(currents in February)} - \text{abs(currents in August)} = \text{difference}. \tag{9}$$

Figure 12 shows the difference of current magnitudes in February and August 2007 at the surface. White areas, i.e negative values, mean the current magnitudes in August are greater than those of February. In darker areas, i.e. positive areas, mean the current magnitudes in February are greater than those of August.

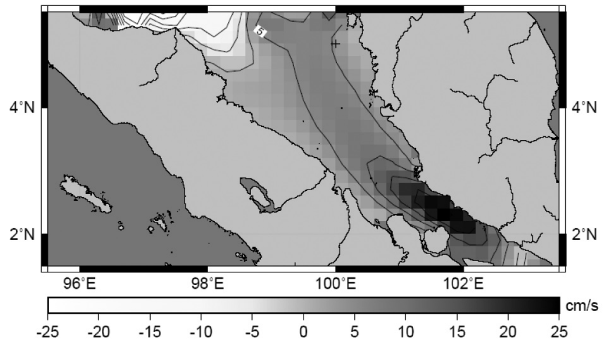

FIGURE 12. Difference of current magnitudes in February and August 2007 at the surface

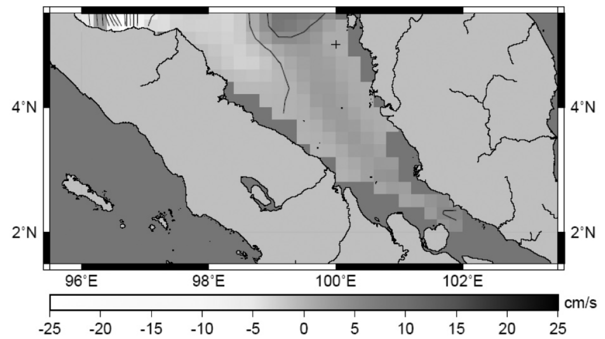

FIGURE 13. Difference of current magnitudes in February and August 2007 at 30-50 m layer

It is shown that in the northwestern part of the Malacca Straits, the current magnitudes are greater in August compared to those of February. However, the rest of areas shown in Figure 12 are dominated by positive values; the current magnitudes are greater in February.

For the 30-50 m layer, the current magnitudes in southeastern part are greater in February than those of August (Figure 13). At the bottom layer the current magnitudes between February and August are relatively the same (Figure 14) because the influence of wind is not significant for the bottom layer.

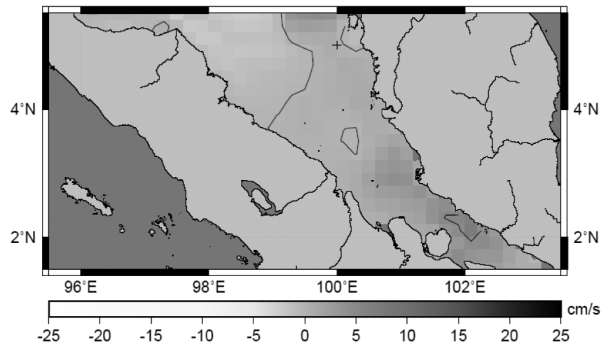

FIGURE 14. Difference of current magnitudes in February and August 2007 at the bottom layer

CONCLUSION

Based on the results of research, it can be concluded that for both February and August 2007, the results of current simulation are relatively similar. Surface current simulation in the Malacca Straits agrees well with the current pattern of the work of Wrytki (1961). The magnitude of current is between 10-70 cm/s to the northwest. Simulation of current at the layer 30-50 m in the Malacca Straits has the magnitude of 10-30 cm/s towards northwest. For the bottom current, the current speed is 0-20 cm/s towards northwest. For the surface and layer 30-50 m, generally the current magnitudes are greater in February. For the bottom layer, the current magnitudes are relatively the same.

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