A THREE-DIMENSIONAL NUMERICAL MODEL FOR BAROCLINIC DYNAMIC IN THE MALACCA STRAIT

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Abstract

The circulation in the Malacca Strait is simulated using a three-dimensional baroclinic numerical model. The circulation model is derived from the combined effects of tides, wind, meteorological forcings, temperature and salinity. The computational results produced pattern of general circulation and also sea surface temperature and salinity. In the present study, the pattern of current circulation in the Malacca Strait coincided with the work [17].

Keywords: Three-dimensional numerical model; Baroclinic circulation; Sea surface temperature and salinity; Malacca Strait

1. Introduction

The Malacca Strait is being an important international shipping route in the Southeast Asian region. The strait has 890 meters in length and situated in the narrow passage linked eastcoast of Sumatra in the western and westcoast of Malayan Peninsula in the eastern (Fig. 1). The Malacca strait is the shallow waters. The form of bottom topography is slope slightly in the southeastern and has 40-100 meters in depth and changing rapidly with the depth of 400-1000 meters through the southwestern.

Geographicaly, the Malacca strait connected the South China Sea in the southeastern and the Andaman Sea in the northwestern. The Malacca Strait, as any other tropical region, has a tropical climate with warm surface temperature at the entire region. The water mass movement is influenced by the Indian Ocean monsoon, thus this region have two principal monsoon seasons, i.e, northeast and southwest monsoon. The salinity is influenced by high rainfall in the land. The big river runoff charge from both Sumatera Island and Malay Peninsula also affect for lowering surface salinity in each seasons. In the other side, the annual variations of salinity is also influenced by the monsoon.

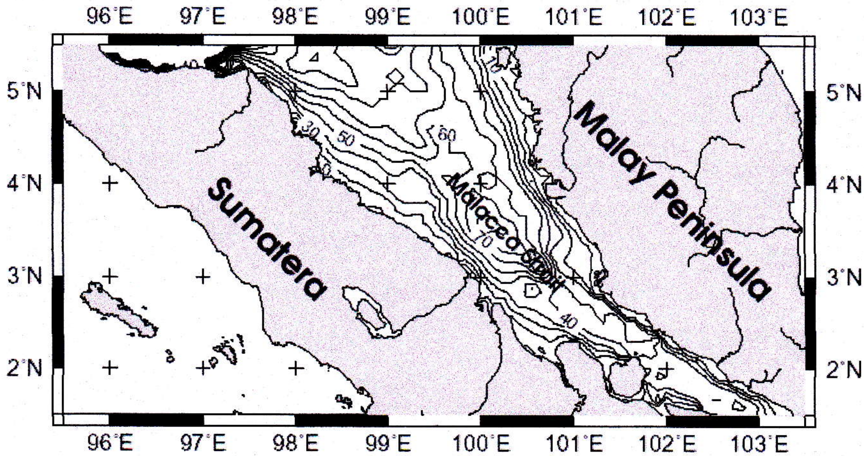


Fig. 1. *Bottom Topography of the Malacca Strait (m).*

2. HAMSOM Model

HAMSOM is a three-dimensional baroclinic primitive equation model. The underlying differential equations are as follows :

x-component momentum equation :

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

y-component momentum equation :

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

The variables are the three components of the velocity u, v, and w, the pressure p, the density ρ, the three space variables, i.e. x (positive in the east direction), y (positive in the north direction), z (positive upwards) and of the time t, the Coriolis acceleration f. The variables A_H and A_V are the horizontal and vertical coeffcients of turbulent viscosity, F_x and F_y are the components of the horizontal exterior forces.

Continuity equation :

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}+\frac{\partial w}{\partial z}=0 \quad (3)$$

Hydrostatic equation :

$$\frac{\partial p}{\partial z} = -\rho g \tag{4}$$

where g is the acceleration due to gravity.

Temperature transport equation :

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

and Salinity transport equation :

$$\frac{\partial S}{\partial t} + u\frac{\partial S}{\partial x} + v\frac{\partial S}{\partial y} + w\frac{\partial S}{\partial z} = K_H \nabla^2 S + \frac{\partial}{\partial z}\left(K_V \frac{\partial S}{\partial z} \right) + S_S \tag{6}$$

where K_H and K_V are the horizontal and vertical coeffcients of turbulent diffusion and S_T and S_S are sources of heat and salinity.

At the surface the kinematic boundary condition is used:

$$\frac{\partial \varsigma}{\partial t} = w \tag{7}$$

where ς is the water level height.

The differential equations are integrated over the vertical distance of a model layer to arrive at differential equations for the layer-averaged fields of transports (U, V), temperature T and salinity S. The deduction of the layer averaged equations of motion can be found in [11]. These latter equations are transformed into finite-difference repesentations on the staggered Arakawa C-grid [1].

For the discretization of the time domain a two-time level scheme is introduced. The prognostic variables ς, U, V, T, S which enter the implicit algorithm, are defined at staggered time-levels. In order to eliminate the stability limitation imposed by the CFL criterion in the hydrodynamic equations, semi-implicit algorithms for the surface height in horizontal direction and vertical shear stress in vertical direction are applied.

In the equations of motion, a stable second-order approximation is introduced to the Coriolis terms, in order to avoid the linear numerical instability arising from forward-in-time approximation [2].

3. Model arrangement for the Malacca Strait

The model region covers 95.5 E to 103.5E and 1.5 N to 5.5 N (Fig. 1). In this study, the Malacca Strait is discretized with a horizontal mesh size of Δ x = Δ y = 5 angular minutes. In vertical direction, the model has 17 layers.

The time-step is Δ t = 300 s. At the open boundaries, amplitudes and phases of the five major tidal constituents (M_2; S_2; N_2; K_1; O_1) are prescribed from a global tidal model (see. [18]) and T and S from climatological data of [10]. The atmospheric forcing, i.e. winds and surface heat uxes are derived from the NCEP/NCAR reanalysis data [see. 8].

4. Results and Discussion

The surface current circulation is presented in Figs. 2 and 3. The model is derived from the combine effect of tides, wind, heatflux which obtained from NCEP/NCAR reanalysis data.

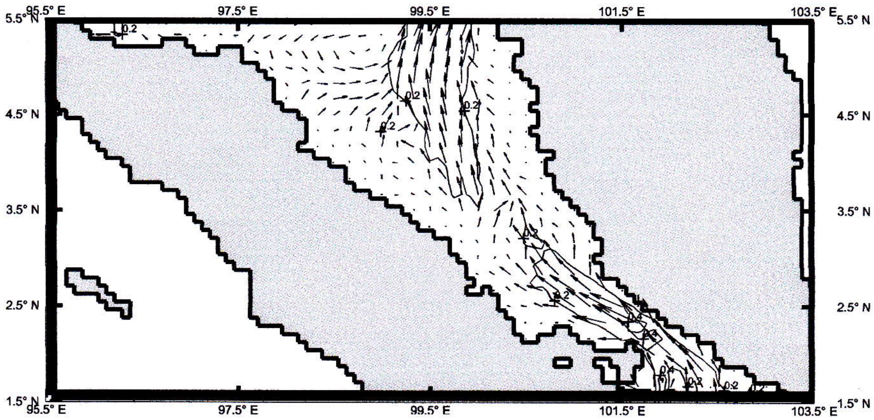


Fig. 2. *The surface currents derived by by tides, wind and heatflux during Northeast Monsoon based on HAMSOM. Contour values mean magnitude of velocity in m/s.*

The circulation in the Malacca Strait has an impact to the water mass exchange between South China Sea and Indian Ocean. Generally, the water movements are in general directed towards the Indian Ocean and are strongly related to the surface gradient of the sea level through this strait. In the Malacca Strait, the period of strongest flow is from January to April, during norheast monsoon, however it is chiefly caused by the low sea level in the Andaman Sea in this season.

In northeast monsoon, water mass with high salinity flow from the South China Sea through the Malacca Strait. While in southwest monsoon, the low salinity in the southwestern part of the Malacca Strait is caused by the water mass from the Java Sea.

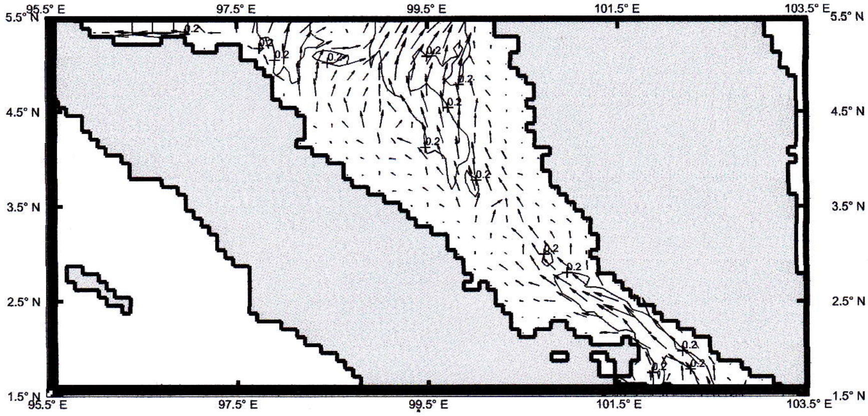
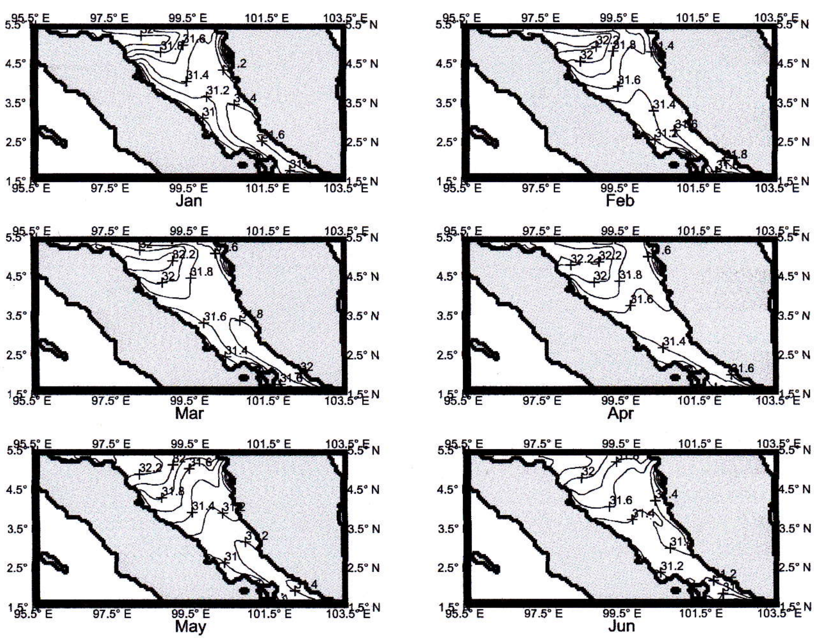


Fig. 3. *The surface currents derived by by tides, wind and heatflux during Southwest Monsoon based on HAMSOM. Contour values mean magnitude of velocity in m/s.*

Sea surface salinity is presented in Fig. 4. During southwest monsoon, surface salinity is lower in the northwest of the Malacca Strait. As has been stated above, strong wind from southwest monsoon leads to maximum rainfall over most parts of the Asian subcontinent from June to September. Freshwater from the rivers is largely responsible for lowering the salinity.



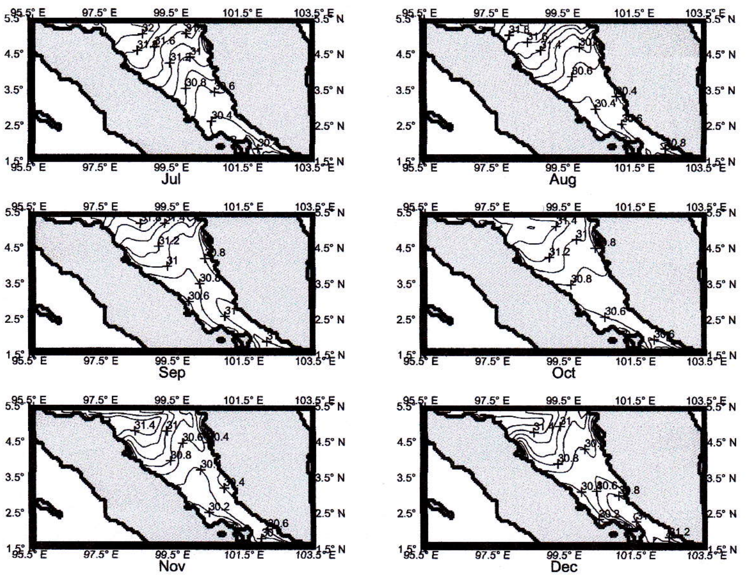
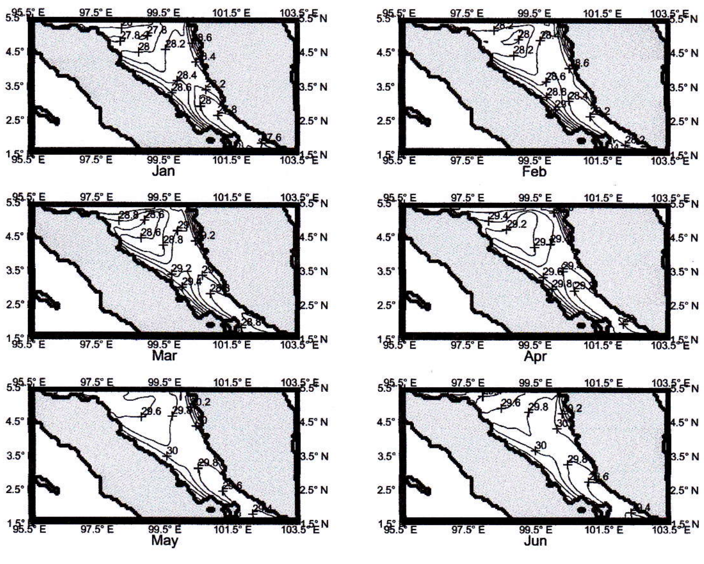


Fig. 4. *Sea surface salinity (January-December), based on HAMSOM Model.*

Sea surface temperature is presented in Fig. 5. Surface water temperature is warm, ranging from 28°C-30°C and 26°C-28°C during southwest and northeast monsoon, respectively.



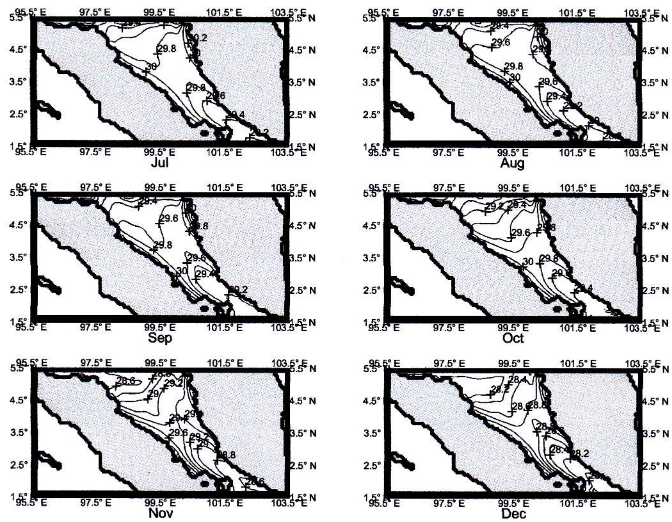


Fig. 5. *Sea surface temperature (January-December), based on HAMSOM Model.*

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