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Maritime Circulation of the South China Sea: A Numerical Study

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ABSTRAK

Sebuah model numerik telah dibentuk menggunakan persamaan klasikal hidrodinamik pemuliharaan jisim dan integrasi momentum menegak. Model ini menyelesaikan mod luaran atau barotropik. Mod komputer telah disingkirkan dengan menggunakan skema terbalik Euler bagi setiap aras masa N (ganjil). Model yang serupa dengan yang ini telah digunakan sebagai pemberitahuan amaran banjir akibat dari ribut taufan dan ribut tropika. Tambahan lagi, model jenis ini telah digunakan dalam berbagai masalah, antaranya simulasi tumpuhan minyak, pusuan ombak, kejadian tsunami dan simulasi pasang-surut. Tujuan kajian ini adalah untuk mendapatkan beberapa maklumat dan pemahaman mengenai kitaran arus Laut China Selatan semasa musim monsun Timur Laut (Tenggara) dan Barat Daya. Dengan ini peredaran Zon Eksklusif Ekonomi (ZEE) Malaysia telah dapat disimulasikan. Keputusan yang diperolehi tidak banyak berbeza dengan pemerhatian yang dijalankan oleh Wyrtki (1961).

ABSTRACT

A numerical model employing the classic hydrodynamic equations of conservation of mass and momentum, vertically integrated, has been developed. The model solves the external, or barotropic, mode. The computational mode is eliminated by employing a Euler backward scheme at every N (odd) time level. A similar model is used for issuing flood warnings of hurricanes and extratropical storms. This type of model is also used in a variety of situations such as oil spill simulations, storm surges, tsunamis, and tidal simulations. The aim of this investigation is to gain some insight into the circulation of the South China Sea during the NE and SW monsoon seasons. Thus the circulation of the Malaysian EEZ has been simulated. Our results compare well with Wyrtki's (1961) observations.

Keywords: circulation, Malaysian EEZ, numerical simulation, barotropic mode

INTRODUCTION

Coastal oceanography is a continually expanding field. Continuous demands of economic development necessitate the investigation of the physical principles involved in coastal circulation. Knowledge of coastal oceanography is also extremely useful for the planning of fisheries activities (Liew *et al.* 1987).

Coastal projects can severely modify the existing hydro-dynamic pattern. It is advisable to understand the ways in which the environment is affected by the execution of such projects so the necessary steps to preserve the ecosystem can be undertaken.

Due to increased activity on the South China Sea and the Malacca Straits over the past few years and the danger of major oil spills, Malaysian research into various aspects of containment of oil spills under adverse weather conditions, mainly due to the NE and SW monsoons, must experience a rapid growth in the near future.

The main purpose of this investigation is to accurately simulate wind-driven coastal circulation of the South China Sea (*Fig. 1*). For this purpose, a hydrodynamic numerical model was constructed. Problems such as oil spill simulations, circulation (due to winds and tides), tidal simulations,

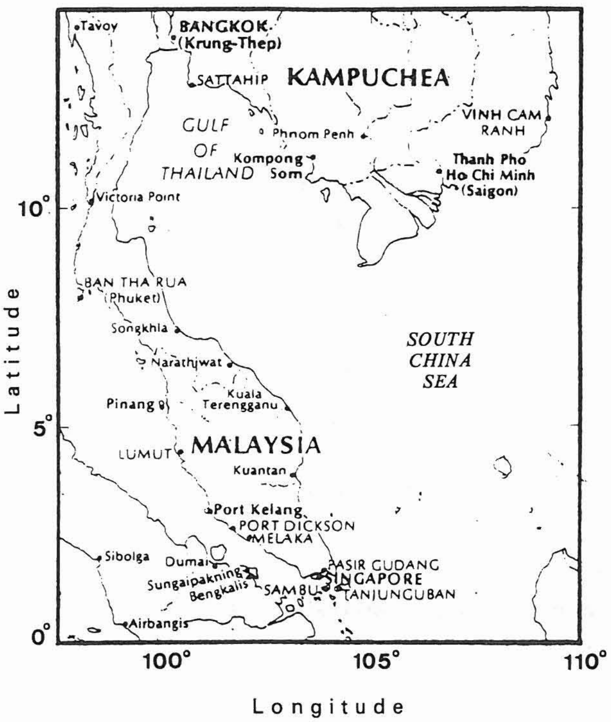

Fig. 1. Study area

volume transports, flood warning systems, nonlinear tidal interactions, energy calculations, storm surges, tsunamis, barotropic residual circulation could be readily addressed with this model.

The model used in this study is similar to the one used is the storm tide warning system for the North Sea. It operates, on a routine basis, at the Weather Service at Bracknell, UK. An identical model (the SLOSH model), warning of hurricanes for the east coast of the US, is operated by the National Weather Service.

Wyrtki (1961) made field observations of the South China Sea. As pointed out by Pohlmann (1987), no significant improvement has been achieved in the understanding of the dynamics of the South China Sea since then. Understandably, our results are compared with Wyrtki's (1961). A numerical simulation of this area was undertaken by Azmy *et al.* (1991). They considered the wind data of Kuala Terengganu as representative of the whole eastern coast of the Malay Peninsula. Pohlmann (1987) used a 12-layer model to simulate the circulation of the South China Sea due to the mean winter and mean summer monsoons. His numerical results compare relatively well with Wyrtki's (1961) observations.

THE MODEL

The model equations are the classic hydrodynamic equations of conservation of mass and momentum, vertically integrated. The model solves the external, barotropic mode. The Boussinesq approximation and the hydrostatic pressure in the vertical are assumed.

The equations for the external mode are:

$$\partial V/\partial t + V \cdot \nabla V + fkxV = -g\nabla\eta + (\Gamma_W - T_B)/(\rho(H+\eta)) + A\Delta V$$
$$(\partial\eta/\partial t + \nabla \cdot (V(H+\eta)) = 0$$

where V represents the Eulerian velocity vector. Its east-west and north-south velocity components, u and v, correspond to the horizontal co-ordinates x and y (positive in the east and north direction, respectively); ∇ is the horizontal gradient; Δ the Laplacian operator; η, the free surface elevation; H, the mean depth; $f(=\beta y)$, the Rosby parameter; g, the gravity's acçeleration; Γ_W, the wind stress;. T_B, the bottom friction; K the vertical normal vector; ρ, the water density and A, the horizontal coefficient of eddy diffusion.

The terms on the left-hand side of the momentum equations represent the local time derivative, the nonlinear (advective) term, and the Coriolis deflection term. The terms on the right-hand side are, respectively, the pressure gradient due to the slope of the sea surface, tangential wind stress on the sea surface, linear bottom friction, and the horizontal momentum diffusion modelled empirically by the horizontal Laplacian operator.

The bottom friction is represented by:

$$(T_B^X,\ T_B^Y) = R(u, v)$$

where R represents friction coefficient. A linear bottom friction is implemented.

We assume a constant density $\rho = 1020$ kg m^{-3}. The other constants are the Coriolis parameter $\beta = 2.10$ m^{-1} s^{-1}; the acceleration of gravity, $g = 9.8$ m^2 s^{-1}; the horizontal diffusion coefficient, $A = 100$ m^2 s^{-1}; and the bottom friction coefficient, $R = 0.002$.

A is kept very small, in such a way that it will not affect the interior solutions. Thus, the order of magnitude of the Laplacian (lateral viscous terms) will be five orders of magnitude fewer than the leading terms of the momentum equations. The wind stress forcing used for this study is that of Hellerman and Rosenstein (1983).

The model extends from 99° 10'E - 109° 30'E longitude and 13° 45'N - 0° 30'S latitude. Therefore, 32 grid points are used in the east-west direction, and 29 in the north-south direction. The Cartesian grid spacing has

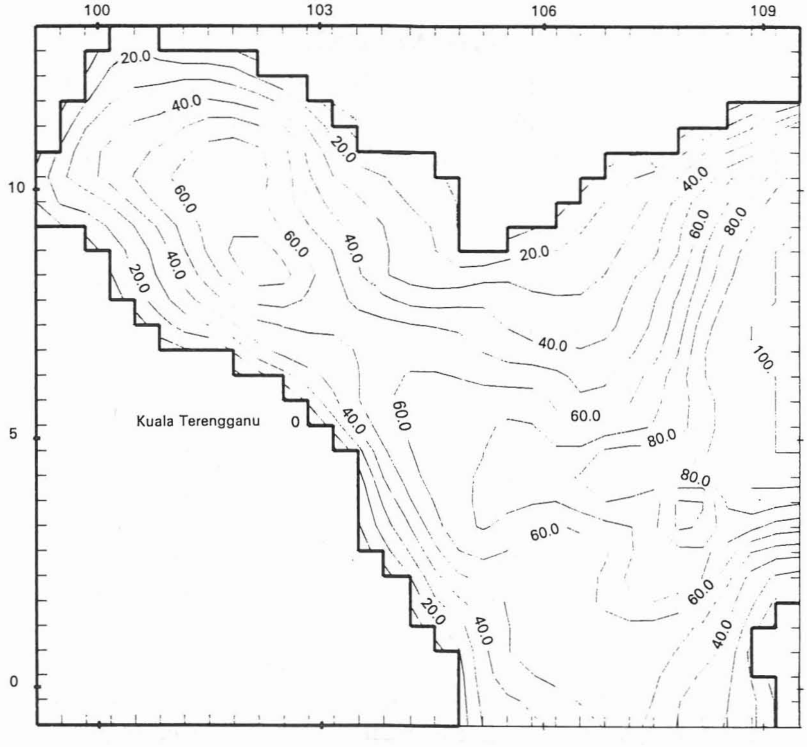

Fig. 2. Bottom topography and domain of integration
Thicker lines represent closed boundaries; thinner lines represent open boundaries
The numbers in the abscissa represent degrees of longitude; the numbers in the ordinate represent degrees of latitude

Dx = 37.5 km and Dy = 55.5 km. This represents a distance of 1162.5 km in the east-west direction and 1554 km in the north-south direction (*Fig. 2*).

Solid walls are implemented at coastal boundaries. At the open boundaries, Camerlengo and O'Brien's (1980) boundary conditions are implemented. A centred in space and time integration (leapfrog) scheme is used; this introduces no computational damping of the physical solutions of the system (Camerlengo and O'Brien 1980). It conserves mass and momentum to second order accuracy. The time step used is 300 seconds. The free surface elevation is calculated at the centre of the grid, while u is calculated at the east and west sides, and v is evaluated at the north and south sides (Arakawa and Lamb 1977).

The model starts from rest, i.e., $u = v = \eta = 0$. At every N (odd) time level an Euler backward (Matsuno 1966) scheme is activated. Therefore, the spurious (computational) mode is eliminated at every N time level. The value of N is set at 9. The x and y coordinates are transformed into a new coordinate system so either a regular or an irregular grid spacing can be used in either direction (Camerlengo 1982).

For the purpose of avoiding the undesirable effects of numerical inertial oscillations, the wind stress forcing is gradually increased via an hyperbolic tangent. The original bathymetry used is based on the values of the nautical chart of the British Admiralty No. 2414 and 2660A. The values taken from these charts represent an average depth for $Dx * Dy$ square centred on the η grid point (*Fig. 1*).

A stationary state is reached within two days in all cases being considered.

DISCUSSION AND CONCLUSIONS

Typical values for the length scale ($L = 10^6$ m), the time scale ($T = 10^6$ sec), and the velocity scale ($U = 0.1$ m sec^{-1}) are used. Upon scaling the momentum equations, and because of the lower latitudes of the region under consideration, it can be shown that the dominant terms are the wind stress, Coriolis parameter and the pressure gradient. The results of our numerical simulations show a clear response of the ocean model to wind stress forcing.

A relatively short period of integration is needed to reach a steady state solution. Following Philander (1990), this short period makes the Coriolis terms play a secondary role. (Furthermore, at these latitudes, the magnitude of f is in the order of 10^{-5} sec^{-1}). This is precisely what happens in our numerical simulations.

The numerical simulation of February, a typical month of the NE monsoon season, is analysed (*Fig. 3*). In accordance with Wyrtki (1961), the numerical model resolves reasonably well the northeasterly jet located along the Vietnamese coast (*Fig. 4*). Pohlmann (1987) located this same jet, further away from the Vietnamese coast.

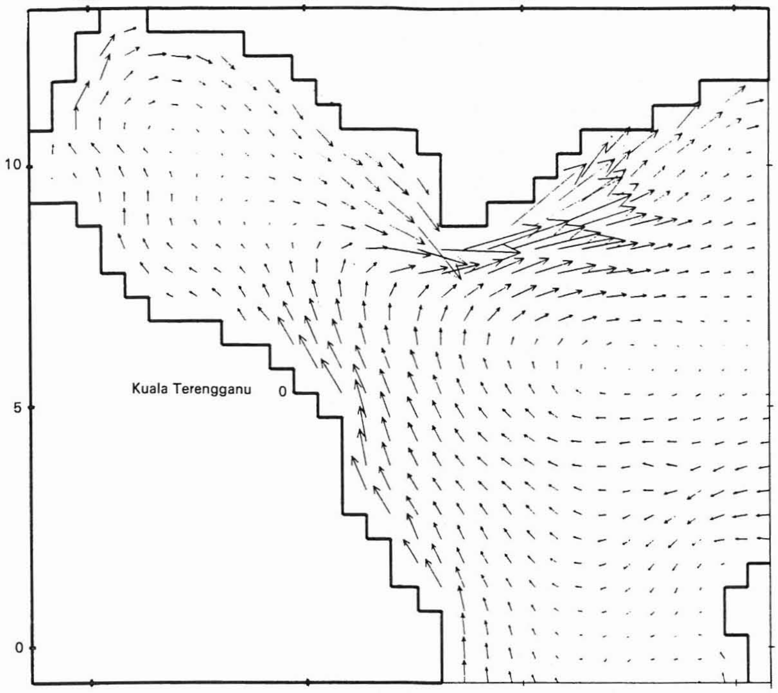

Fig. 3. Model results of the circulation of February.
Thicker lines represent closed boundaries; thinner lines represent open boundaries. Numbers in the abscissa represent degrees of longitude; numbers in the ordinate represent degrees of latitude

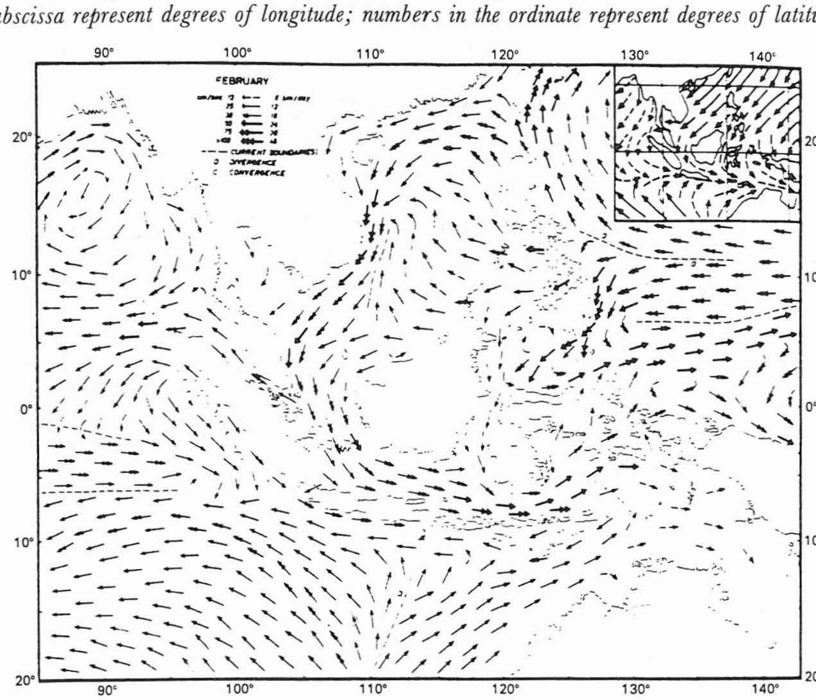

Fig. 4. Surface currents in February, according to Wyrtki (1961)

Saadon and Camerlengo (1995) give the dynamic background for the better understanding of a secondary jet flowing northward along the eastern coast of Peninsular Malaysia. In accordance with Wyrtki (1961), this jet is well resolved in our simulation in February.

In agreement with Pohlmann (1987), a gyre, flowing in a counter-clockwise rotation, located approximately 300 km off the Vietnamese coast, is well resolved in our simulations.

The numerical simulation of July, a typical month of the SW monsoon season, is analysed (*Fig. 5*). A primary jet, flowing in a northeast direction parallel to the Vietnamese coast, is detected. A secondary jet, parallel to the east coast of the Malay Peninsula, makes the water mass flow in a northward direction. Two gyres flowing in a clockwise rotation are well resolved by the model. One is located in the Gulf of Thailand; the other is located approximately 300 km southeast of the Vietnamese coast.

These two jets, as well as the two gyres, were observed by Wyrtki (1961) for the month of June (*Fig. 6*). For a dynamic interpretation of the circulation during the SW monsoon season, the reader is referred to Saadon and Camerlengo (1995).

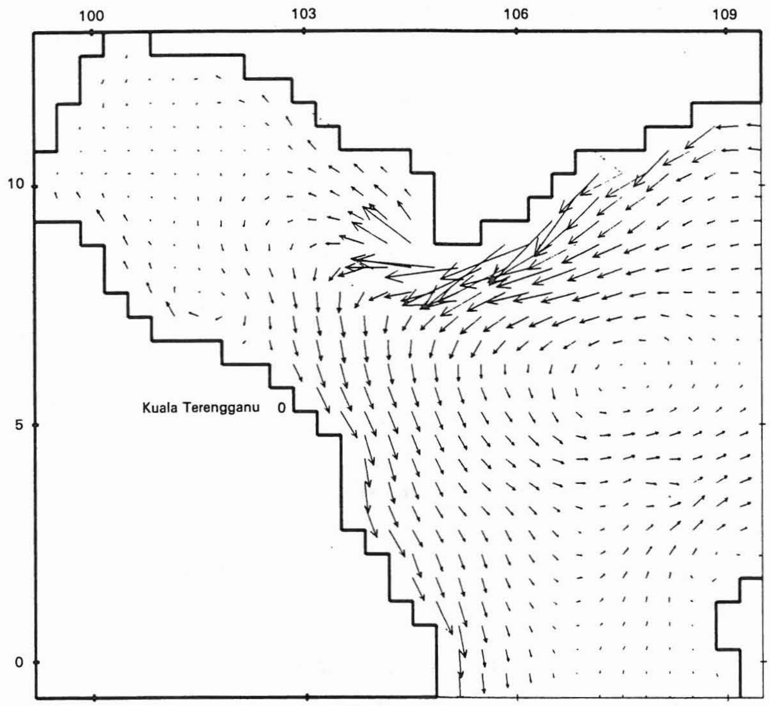

Fig. 5 Model results of circulation in July.
Thicker lines represent closed boundaries; thinner lines represent open boundaries. Numbers in the abscissa represent degrees of longitude; numbers in the ordinate represent degrees of latitude

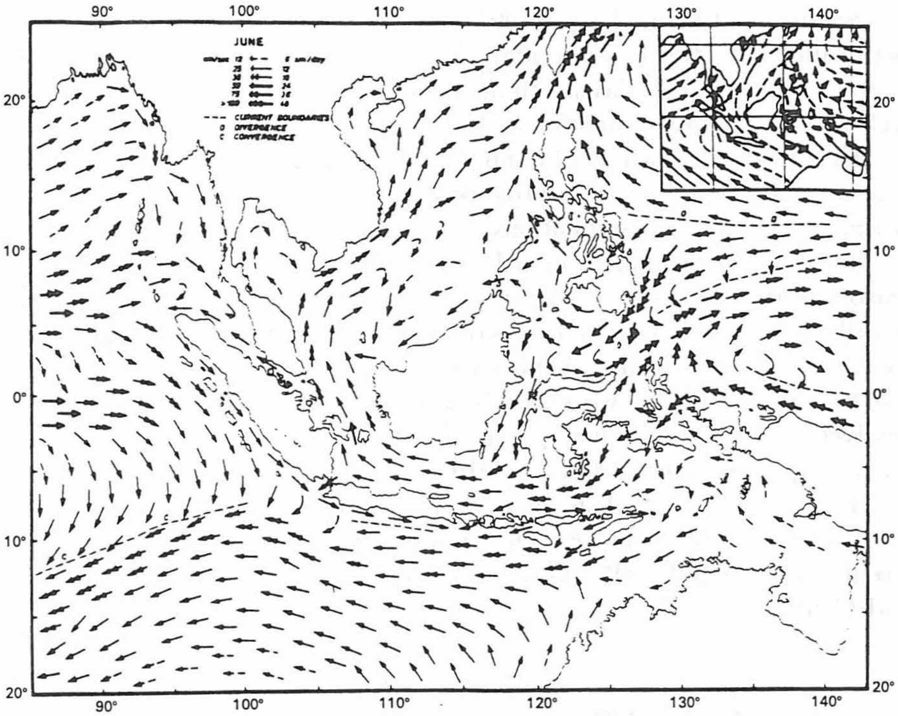

Fig. 6. Surface currents in June, according to Wyrtki (1961)

In view of our results, it can be stated that no contamination of the interior solution due to the implementation of the radiative open boundary conditions employed is detected.

A numerical model solving the external mode has been developed. The model equations are the classic hydrodynamic equations of mass and momentum, vertically integrated. The model resolves reasonably well the circulation of the South China Sea, driven by the NE and SW monsoons. Our numerical simulations for the months of February and July are in agreement with Wyrtki's (1961) observations.

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REFERENCES

ARAKAWA, A. and V. LAMB. 1977. *Computational Design of the UCLA General Circulation Model.* Methods of Computational Physics, 17. New York: Academic Press.

AZMY, A.R., Y. ISODA and T. YANAGI. 1991. Sea level variation due to wind around West Malaysia. *Memoirs of the Faculty of Engineering Ehime University* **XII**: 148-161.

CAMERLENGO, A.L. 1982. Large scale response to the Pacific Ocean subarctic front to momentum transfer. *J. Phys. Ocean* **12(10)**: 1106-1121.

CAMERLENGO, A.L. and J.J. O'BRIEN. 1980. Open boundary conditions in rotating fluids. *J. Comp. Phys.* **35**: 12-35.

HELLERMAN, S. and M. ROSENSTEIN. 1983. Normal monthly windstress over the world ocean with error estimates. *J. Phys. Oceanogr.* **13**: 1093-1104.

LIEW, C.H., K. SAMO and S. MASAMITSU. 1987. Subsurface currents off the south western portion of the South China Sea. In *Ekspedisi Matahari, 1985: A Study on the Offshore Waters of the Malaysian EEZ*, ed. A.K.M. Mohsin, M. Mohd. Ibrahim and Mohd. Azmi Ambak. Faculty of Fisheries and Marine Science Universiti Pertanian Malaysia Occasional Publication No **4**, p.49-79.

MATSUNO, T. 1966. Numerical integration of the primitive equations by a simulated backward difference method. *J. Meteor. Soc. Japan* **2**: 76-84.

PHILANDER, G. 1990. *El Nino, La Nina and the Southern Oscillation.* Academic Press.

POHLMANN, T. 1987. A three dimensional circulation model of the South China Sea. In *Three Dimensional Models of Marine and Esturine Dynamics ed. C.J. Nihouil and M.J. Bruno, p. 245-268. New York.*

SAADON, M.N. and A.L. CAMERLENGO. 1995. Response of the ocean mixed layer, off Kuala Terengganu, during typical NE and SW monsoons. Submitted for publication to *GEOACTA (Argentina).*

WYRTKI, K. 1961. *Physical Oceanography of the Southeast Asian Waters.* NAGA report vol. 2. La Jolla: University of California.