Geostrophic and Drift Current in the South China Sea, Area IV: Vietnamese Waters

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ABSTRACT

The water circulation in area IV was calculated by 2 methods. The circulation for the area where water depth exceeded 600m was calculated by the geostrophic balance method. In a shallow water area effect of wind absolutely surpasses geostrophic balance, so wind induced drift current is greater than geostrophic current many times. So, for the whole area (shallow deep) the drift current was calculated by two-dimensional nonlinear shallow water equation based on typical monsoon fields. The results of 2 methods showed common picture of the circulation with divergence and convergence changing by season.

Introduction

The water circulation is one of the most essential characters in the marine hydrodynamical regime. They are always very important factors for the management of fisheries and living resources in the Ocean. There are some methods to determine currents in the sea. The net current can be determined directly by the observation data measuring the direction and speed of the current at each station. This method requires observation duration of at least 25 hours at each station in a study area in order to obtain separately tidal components and remainder current (non-periodic or stable components). Clearly that, the observation data of the Survey Cruise (30 April - 29 May 1999) of SEAFDEC in Vietnamese sea (Area IV) don't satisfy the requirements of a direct method for current calculation.

The indirect methods to determine the net movement of sea water are enough abundant now. The classical geotrophic balance is one of widely used indirect methods in Oceanography. It is somewhat appropriate under the conditions of this survey. It requires accurate temperature, salinity and pressure data which could be measured by CTD at each station. The current obtained from this geostrophic balance method will be relative current between 2 layers. It is necessary to choose a deep water layer which can be assumed to be the level of no motion. The absolute current at any levels above the level of no motion can be then calculated. This procedure can be realized only in deep ocean, where the current speed at a sufficiently deep water layer is usually very slow relatively to the surface current (less than 1 cm/s). So the method of classical geotrophic balance is calculated suitably only for deep ocean. In a shallow water the level of no motion couldn't be chosen, the results calculated by this method will be incorrect. On the other hand, in a shallow water the effect of wind always surpasses absolutely geostrophic balance and wind induced drift current always is dominant in the remainder current.

The drift current will be calculated by numerical method from two dimensional nonlinear shallow water equation system with the typical wind fields taken into account.

Thus, combining two methods (calculation from geostrophic balance and numerical modelling), it is possible to obtain the common picture of water circulation in the study area: in the deep water the current abides by the laws of geostropic balance, in the shallow water the current has an essence of drift current.

Materials and Methods

The Study Area

The study area is the surrounding Vietnam sea included the Gulf of Tonkin and the continental shelf of Central and Southern Part of Vietnam. The study area is spreading from 6^o to 22^{o}N latitude and from 105^o to 112^{o}E longitude. The shallow water zone occupied most of area. Among the total of 58 survey stations of Cruise from 30 April to 29 May 1999, only 16 stations had bottom depth exceeded 600 meter and at these station there level of no motion can be assumed.

The location of these stations and the bottom topography of the study area are shown in Fig.1.

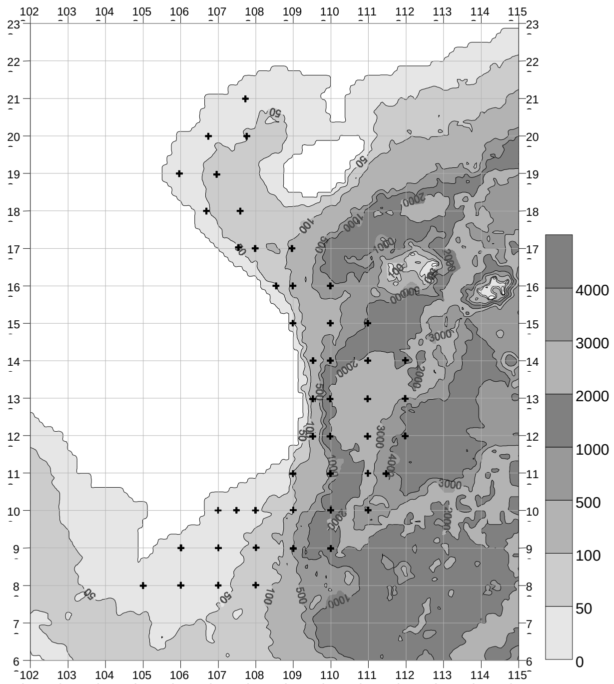

Fig. 1. Depth contours (m) of the study area and the location of stations (+).

Geostrophic Current

The geostrophic balance method has been used widely for deep ocean and it can be said that probably most of the subsurface circulation of the World Ocean up to now was obtained by this approach. The basic assumption of this method is that in the case of an isobaric surface, for example, sea surface, to maintain an unequal level then the horizontal pressure gradient force due to gravity must be balanced by Coriolis force due the movement of water.

The general expression of the classical dynamic method is following:

$$fu = \frac{DYNH_1 - DYNH_2}{L} \qquad (3.1)$$

where f - Coriolis factor,

u - Current speed in the direction perpendicular to the pressure gradient,

L - Distance (m) between the 2 stations,

DYNH1,2 - Dynamic height (in dyn.m). Subscript refers to station.

For each station, dynamic height was calculated following.

$$DYNH = gz \qquad (3.2)$$

where g - gravitational acceleration,

z - vertical distance between the interested surface and the reference surface (in m).

A lot of observation data on temperature, salinity and pressure for many years in the study area has been collected. These are data in the summer period and the winter period. The summer consists of May, June, July and August. The winter consists of December, January, February and March. The data were collected for each square with one degree size. Based on the data collected during the Cruise 30 April - 29 May 1999 with these available data the picture of geostrophic current in the deep sea has been calculated for each season (summer and winter).

Wind Induced Drift Current

In order to simulate circulation and sea water level oscillation caused by wind stress, the TIDE-2D software developed in Center for Marine Environment Survey, Research, Consultation (CMESRC) was used. The calibration and verification of this model were implemented rather carefully by observation data for several coastal and offshore zones of Vietnam sea, for example Ha Long Bay, Hai Hau, Thanh Hoa, the mouth of the Gulf of Tonkin, Dinh An, Ca Mau... This software has been used to calculate the current regime in many coastal areas of Vietnam sea. This model is based on the two - dimensional nonlinear shallow water equations:

Conservation of mass:

$$\frac{\partial z}{\partial t} + \frac{\partial}{\partial x}(ud) + \frac{\partial}{\partial y}(vd) = 0 \qquad (4.1)$$

Conservation of momentum:

$$\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} = -g\frac{\partial z}{\partial x} - f\,\frac{u\sqrt{u^2+v^2}}{d} + \Omega v + \gamma\frac{\tau_x\sqrt{\tau_x^2+\tau_y^2}}{d} + D(\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2})$$

$$\frac{\partial v}{\partial t} + u\frac{\partial v}{\partial x} + v\frac{\partial v}{\partial y} = -g\frac{\partial z}{\partial y} - f\,\frac{v\sqrt{u^2+v^2}}{d} - \Omega u + \gamma\frac{\tau_y\sqrt{\tau_x^2+\tau_y^2}}{d} + D(\frac{\partial^2 v}{\partial x^2} + \frac{\partial^2 v}{\partial y^2}) \qquad (4.2)$$

where: u, v - Depth averaged components of velocity in the x - direction and y - direction (m/s),

z - Water surface elevation above reference level (m),

h - Water depth below reference level (m),

d - Total water depth (d = h + z),

W - Coriolis parameter (S^{-1}),

g - Acceleration of gravity (m/s^2),

t_x, t_y - The components of wind stress in x - and y - direction with the wind velocity taken at 10m above the Mean Sea Level,

f - The friction coefficient,

g - The wind drag coefficient,

D - The horizontal turbulent coefficient.

The above equations are solved using implicit different scheme and alternating direction method in space (not in time).

Because the study area is influenced strongly by the Monsoons: the North-Eastern wind in winter and the South-Western Wind in summer, the circulation regime also has the characters changing in accordance with seasons. The drift current in the study area has been calculated by model TIDE-2D for two season - winter and summer - in correspondence with two wind fields: NE and SW. The chosen wind fields are the average wind in the typical month in winter and in summer (January and June).

Results and Discussion

Geostrophic Current in the Deep Sea

The data of temperature, salinity and pressure in the study area were collected for the winter (from December to March) and the summer (from May to August) at each square with one degree size from oceanographic database. In addition the summer data also were supplemented by the observation data of the survey cruise (May 1999).

Based on the collected data the dynamic height was calculated and corrected to 600 dbar level, the assumed level of no motion. From the obtained dynamic height the dynamic topography map was established for each isobaric level: sea surface, 50, 150 and 500 dbar. After that these results were used to calculate velocity components u and v for each grid cell at each isobaric level.

Fig.2 - Fig.5 show dynamic height and current vectors at different isobaric level in summer.

Fig.6 - Fig.9 present dynamic height and current vectors and different isobaric level in winter.

Some characteristics of circulation calculated from geostrophic balance at the deep water are following:

In Summer (the period of Survey Cruise)

On the maps for dynamic topography and geostropic current at isobaric level 0, 50, 150 and 500 dbar it can be noted that in general the isolines of dynamic height were parallel to the coastal line. The current has Northern and North-Eastern direction (N and NE). There are two rather large and strong eddies at the Southern zone: anticyclonic eddy near Vietnam shelf and cyclonic eddy near Kalimantan Island. The current in anticyclonic eddy was strengthened at the South Central Part of Vietnam zone with maximum speed over 30cm/s.

Near the Central Part of Vietnam there exist the cyclonic eddy at the area zone from 13°N to 16°N latitude with maximum speed about 25-30cm/s.

Generally spreading the system of eddies, general direction and tendency of the circulation are similar from sea surface to deep levels, only the value of speed is quickly decreased with depth. Example, of maximum speed at the surface was over 30cm/s then at 500 dbar level that is less than 5cm/s.

In correspondence with the cyclonic and anticyclonic eddies there exist the divergence zone and the convergence zone. In the divergence zone the upwelling process occurs usually and on the contrary in the convergence zone there is a downwelling process. These vertical processes could be very important for fishery because it relates to fishing grounds in the sea.

Thus in the summer there exists the upwelling at offshore zone of the Central Part of Vietnam about 13°N - 16°N latitude and the downwelling at South - Eastern zone about 300 km far from the coast.

In Winter

From Fig.6 - Fig.9 presenting dynamic height and geostrophic current at different levels (0, 50, 150 and 500 dbar) it would be possible to recognize that the system of dynamic height isolines on the whole is oriented North-East (NE) to South-West (SE) direction similar to that in summer, although these isolines in winter are more complicated.

There are two large and strong eddies: the cyclonic eddy in the Central Part of Vietnam zone from 9°N to 16°N latitude and anticyclonic eddy in the South Part from 5°N to 8°N latitude. In the cyclonic eddy zone the current is strengthened at the zone near to the South-Eastern coast of Hai Nam Island and along the shore of Central Part of Vietnam from Da Nang to Phan Thiet. The speed can reach 30 cm/s at the surface. In the anticyclonic eddy zone the current is strengthened at the zone along the shelf of South Vietnam. The speed is over 30 cm/s at the surface.

Thus along the Vietnam shoreline over the area of 200 km width from Central Part to South Part there exist the cold water current flowing from North to South in winter.

As in summer the eddies and tendency of circulation are somewhat similar from sea surface to deep levels in winter, only the speed value quickly decrease with depth.

In correspondence with the cyclonic and anticyclonic eddies there exist divergence and convergence zones. Specially, the divergence zone in winter is very large.

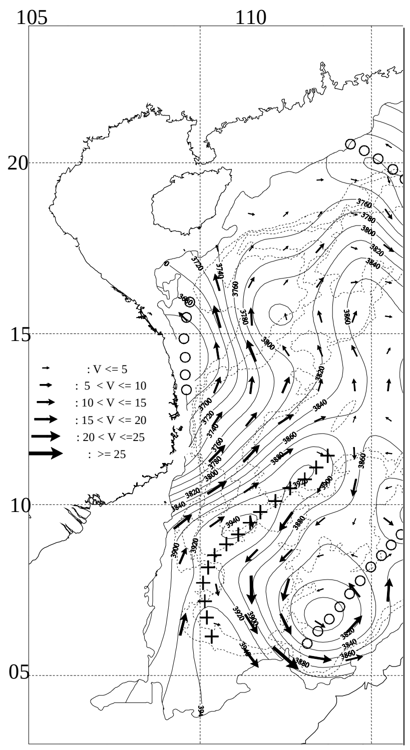

Fig. 2. Dynamic height (dyn.mm) and geostrophic current at sea surface (0 dbar) in summer.
∾ isolines of dynamic height
o o o divergence zone
\+ + + + convergence zone

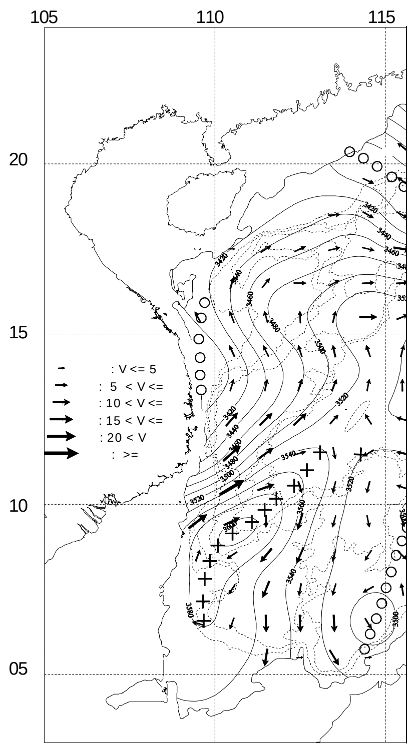

Fig. 3. Dynamic height (dyn.mm) and geostrophic current at 50 dbar in summer.

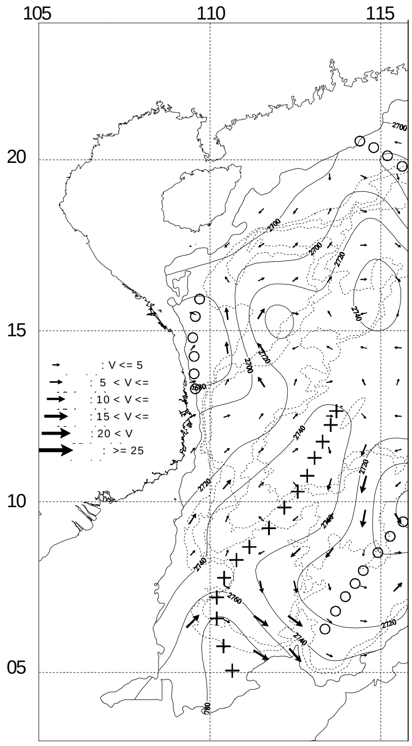

Fig. 4. Dynamic height (dyn.mm) and geostrophic current at 150 dbar in summer.

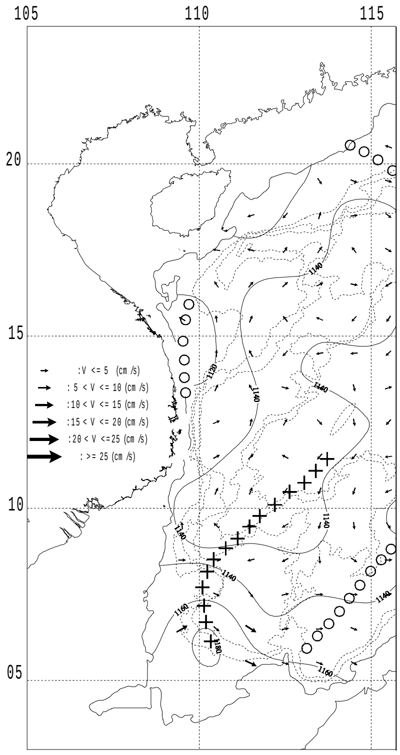

Fig. 5. Dynamic height (dyn.mm) and geostrophic current at 500 dbar in summer.

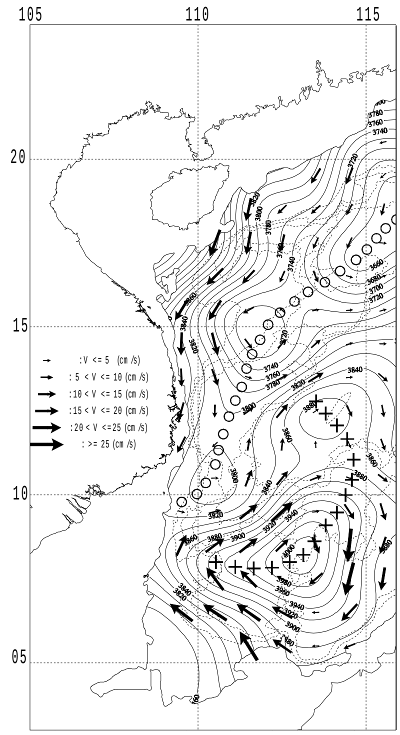

Fig. 6. Dynamic height (dyn.mm) and geostrophic current at sea surface 0 dbar in winter.

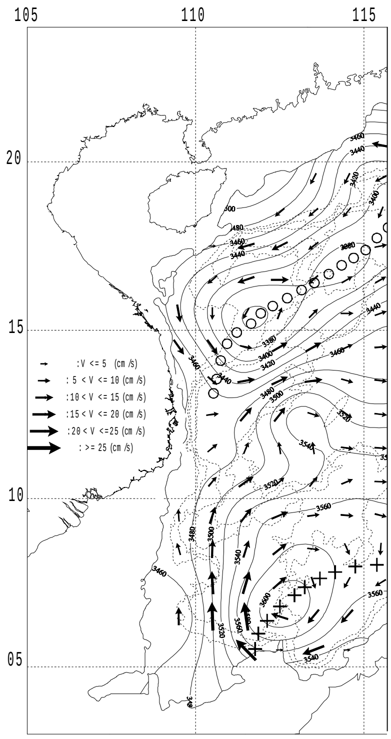

Fig. 7. Dynamic height (dyn.mm) and geostrophic current at 50 dbar in winter.

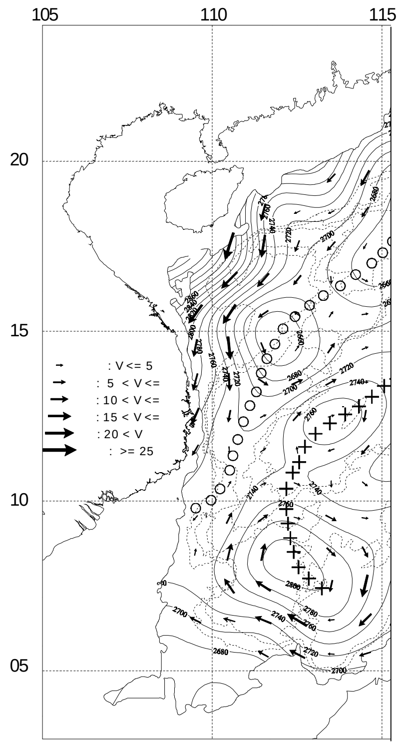

Fig. 8. Dynamic height (dyn.mm) and geostrophic current at 150 dbar in winter.

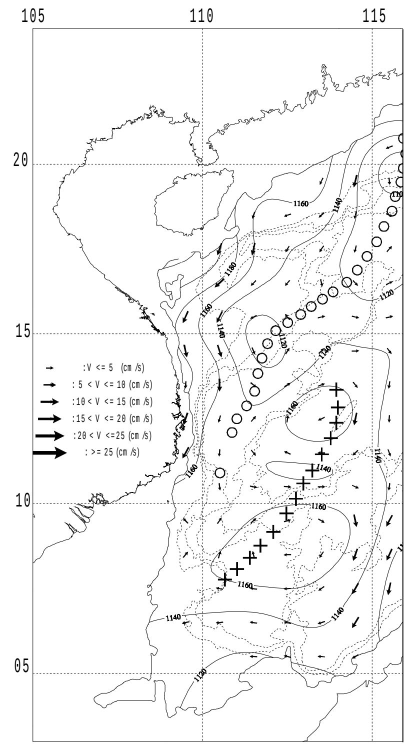

Fig. 9. Dynamic height (dyn.mm) and geostrophic current at 500 dbar in winter.

The Drift Current in the Shallow Water

The model TIDE-2D was used to calculate the depth averaged current induced by wind stress. As above said that in the shallow sea the effect of wind is more important in comparison with geostrophic balance. So it is necessary to calculate the drift current in a shallow water area. Together with the geostrophic current in the deep water the drift current in the shallow water establishes the picture of circulation in whole study area.

In correspondence with averaged monthly wind field (see Fig.10 - Fig.12) the averaged drift current fields are calculated as follows:

- The drift current field averaged for May (coincidence with the period of the Survey Cruise)
- The drift current field averaged for June (typical for Summer)
- The drift current field averaged for January (typical for Winter)

The Fig.13 - Fig.15 shows the averaged current fields for May, Jun and January respectively. The picture of drift current changes by season has some characteristics as follows:

In Summer

At first it would be possible to realize that the averaged drift current manifests itself clearly only in shallow water zone such as the Gulf of Tonkin or coastal zone along shore from North to South. In the Gulf of Tonkin there exist the large and strong cyclonic eddy, the center of which is in the middle of the Gulf. Thus along Vietnam shoreline from 21^{o}N to 15^{o}N latitude the current always flows to the South. The depth averaged speed can reach 20 cm/s over there. In the North part of Gulf the current is rather weak.

In the Coastal zone of the Central and Southern Parts of Vietnam from 8^{o}N to 15^{o}N latitude there exist the current flowing along shoreline to the North, the value of the depth averaged speed is over 20 cm/s in the Southern coastal zone.

In Winter

It would be possible to say that in winter the drift current is stronger than in summer in the whole coastal zone. Almost everywhere in the coastal zone from North to South the value of the depth averaged speed is about 20 cm/s.

The drift current flowed along the shoreline to the South everywhere. Whole the Gulf of Tonkin is a half of big eddy. The Cold water from the South China Coastal zone flows into the Gulf of Tonkin by strait Quynh Chau and around Hai Nam Island, after that the current continued to flow along the Vietnam shoreline to the South.

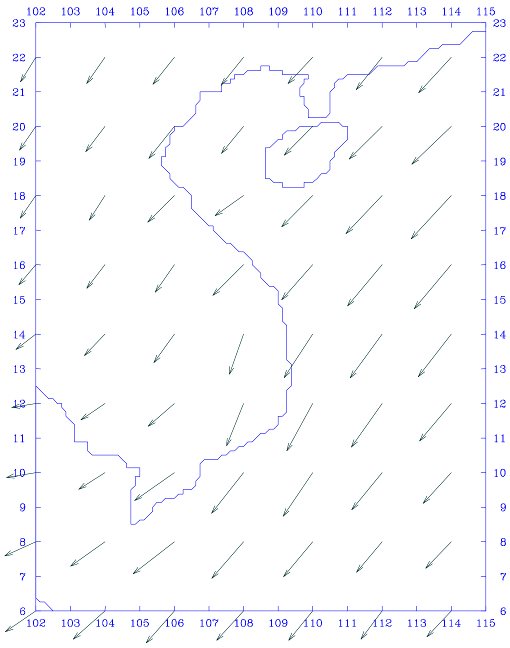

Fig. 10. The wind field averaged for January.

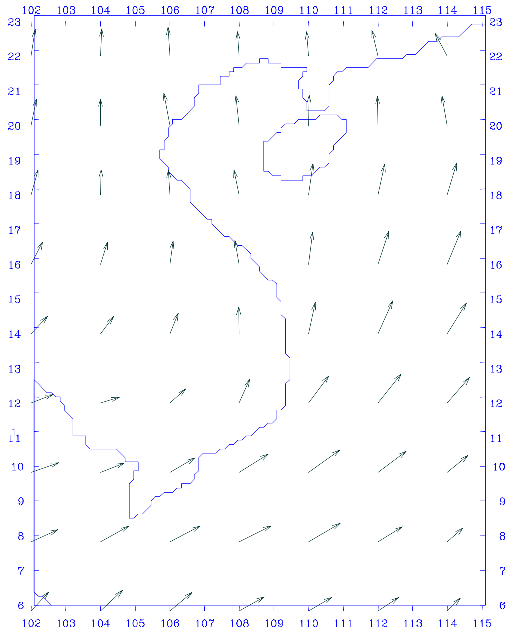

Fig. 11. The wind field averaged for June.

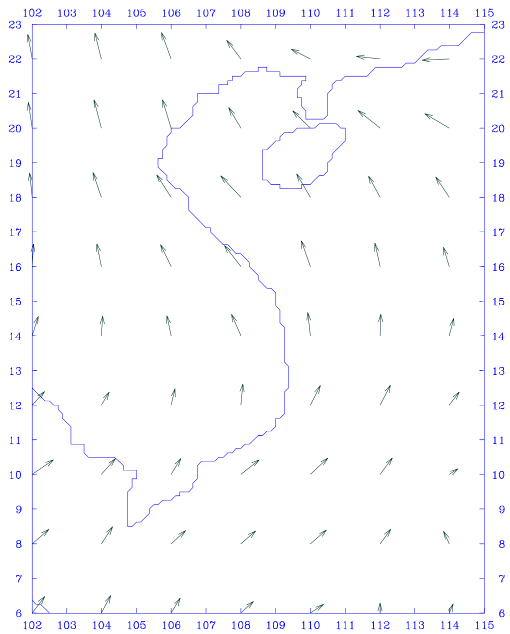

Fig. 12. The wind field averaged for May.

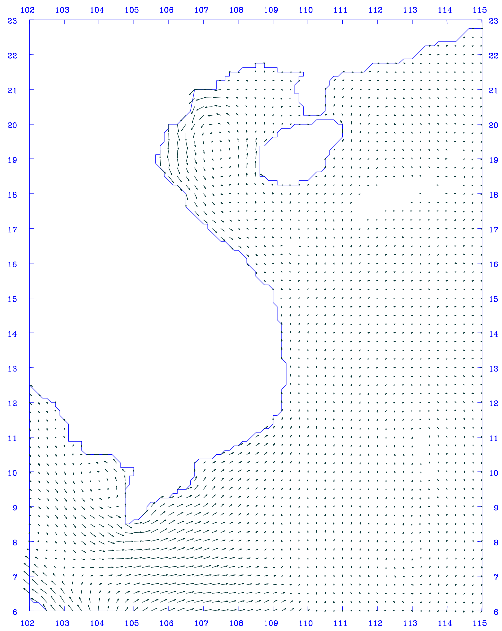

Fig. 13. The depth averaged drift current for May.

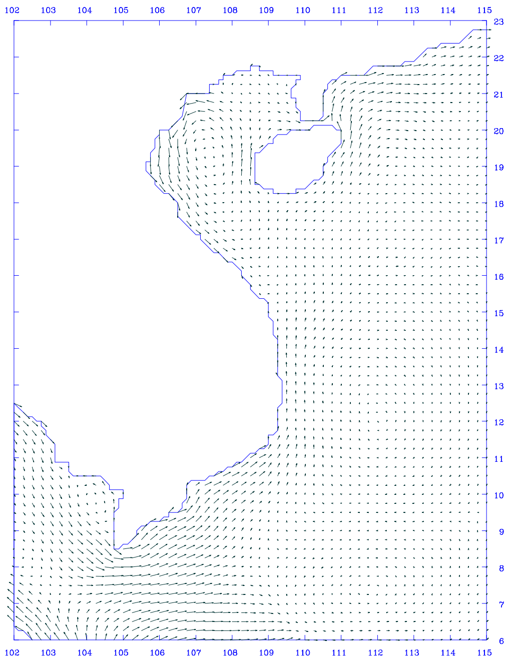

Fig. 14. The depth averaged drift currentfor June.

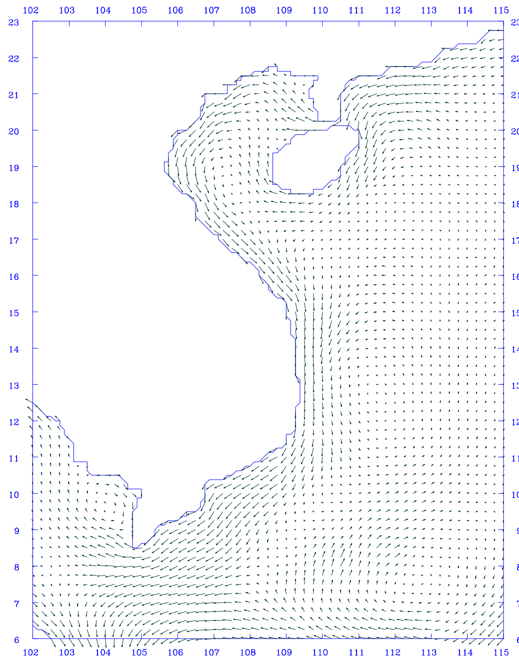

Fig. 15. The depth averaged drift current for January.

Conclusion

The study area consists of the shallow water and the deep sea. The system of the circulation there includes correspondingly the wind induced drift current and geostrophic current.

The circulation in study area changes clearly by seasons. The pictures of the circulation in summer and winter have contrary characters.

There existed the divergence and convergence zones in correspondence with the upwelling and downwelling processes, which could be important for fisheries purposes.

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