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STRUCTURAL FEATURES OF GEOSTROPHIC CIRCULATION IN OPEN REGION OF THE SOUTH CHINA SEA

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ABSTRACT

On the basis of observation data of water temperature and salinity the mean seasonal geostrophic circulation in open region of the South China Sea (SCS) was computed by the dynamic method relative to the 800 decibar reference surface. The results of computation let go to following notices:

In both main monsoons (winter and summer) there are two main geostrophic eddies: the anticlockwise eddy in the northern and northwestern part, and the clockwise eddy in the southern part of the SCS with corresponding divergent and convergent zones. The main frontal zones go along the middle latitudes of the sea from the southern continental shelf of Vietnam to the area west of Luzon Island. The strength and stability of the current in winter are higher than in summer.

The Kuroshio has an enough strong branch intruding into the SCS through Bashi Strait in winter creating in the sea the water structure similar to that of the Northwest Pacific subtropical and tropical regions. In summer the Kuroshio water can intrude directly only into the area southwest of Taiwan.

CAC ÑAC ÑIEM CAU TRUC CUA HOAN LÖU ÑÒA CHUYEN VUNG KHÔI BIEN ÑONG

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TOM TAT

Tren cô sô mot von so lieu thuy van nhieu lan lôn hôn tröôc ñay (bay lan ve nhiet ño nöôc va bon lan ve ño man), ña tien hanh tính toan lai böc tranh dong chay ñòa chuyen vung khôi Bien Ñong bang phöông phap ñong löc so vôi mat 800 decibar. Ket qua tính cho phep khang ñònh nhöng ñac ñiem cau truc cua hoan löu loai nay trong Bien Ñong nhö sau:

Trong mua ñong cung nhö mua he ton tai hoan löu xoay thuan (ngöôc chieu kim ñong ho) ô vung tay bac va bac va hoan löu xoay nghòch (theo chieu kim ñong ho) ô vung nam Bien Ñong. Trong mua he hoan löu xoay thuan ep sat them luc ñòa Nam Trung Quoc va mien Trung Viet Nam, ñong thôi xoay nghòch cung dòch chuyen ve vung tay nam Bien Ñong, nhöông cho cho mot xoay thuan cuc bo ô vung quan ñao Tröông Sa.

Ô dai trung tam cua hoan löu xoay thuan ton tai ñôi phan ky kem theo hien töông nöôc troi manh, con ô dai trung tam cua hoan löu xoay nghòch ton tai ñôi hoi tu kem theo hien töông nöôc chìm manh. Ñôi front nam tai ñôi tiep giap giöa hai xoay cô ban noi tren, keo dai tö them luc ñòa Nam Viet Nam ñen vung bien Tay Philippine trong mua ñong va ñen Eo Bashi trong mua he.

Dong chay trung bình tang mat bò cöông hoa manh (>30 cm/s) ô phía tay Bien Ñong va ô lan can Eo Bashi. Dong chay trung bình mua ñong manh hôn va on ñònh hôn mua he. Toc ño dong noi chung giam theo ño sau: neu ô tang mat co the ñat tren 25-30 cm/s, thì ô tang 500 m chæ ñat nho hôn 5 cm/s.

Dong chay rìa Tay Bac Thai Bình Döông (dong Kuroshio) co chi nhanh xam nhap vao Bien Ñong kha manh me trong mua ñong, nhöng rat yeu trong mua he.

INTRODUCTION

The geostrophic current is an important component of general circulation in barocline layer of deep-sea regions. It is caused by water density ununiformity under complex action of wind, earth rotation, bottom topography and thermohaline factors. It plays an important role in the region of strong currents and a determinant role in subsurface and intermediate water layers where it is almost equal to real observation data [1].

The SCS is one of the biggest marginal seas of the Pacific and World Oceans. Its surface area is about 3.5 million km^2. The mean bottom depth is 1200 m. The maximum bottom depth can reach 5.000 m. It is interlinked with the Pacific Ocean mainly through the Bashi Strait having the sill depth of 2.600 m and width of 380 km, and with the Sulu Sea through the Mindoro Strait having the sill depth of 450 m. Other straits are shallower than 100m. Therefore, the geostrophic current unconditionally plays an important role in general circulation of the Sea.

15 years ago on the basis of very limited amount of the marine hydrographic data (3.500 stations) available in Nhatrang Institute of Oceanography the first results of computation of the mean seasonal (winter and summer) geostrophic current of the whole SCS were obtained [8]. But, because of lack of data in some large regions (for example, in regions of Paracels and Spratly Archipelagos) the calculated current pattern was not fully completed.

Nowadays, based on the collected amount of hydrographic data in many times more than before we decided to compute once again the mean seasonal geostrophic current in open region of the SCS with the goal to determine more exactly its pattern and structure.

DATA SOURCES, DATA TREATMENT AND COMPUTATION METHOD

The geostrophic current in open region of the SCS was calculated from the mean seasonal water density by the dynamic method [2, 14] relative to the 800 decibar (db) reference surface. The 800 db surface was selected as reference surface because this surface lies in the layer of relatively high water density uniformity and also in the layer of minimum oxygen content (~ 2 ml/l) for the whole SCS where the Defant criteria for the "surface of no motion" is satisfied. This surface can be approximately considered as the lower boundary level of the barocline water layer of the SCS.

In this study we have computed the mean long-term seasonal geostrophic circulation in the open region of the SCS in winter (December - February) and in summer (June - August), or in the seasons of prevailing northeast and southwest monsoons for the area from the latitude of 5^0N northward.

The data used in this study are CTD data derived from oceanographic data sets of American and Russian Oceanographic Data Centers [5,12]. They consist of 17.870 serial water temperature measurement stations and 3.428 salinity measurement stations for winter and 18.524 temperature stations and 3.443 salinity stations for summer, covering all over the SCS. These data were gathered from very different data sources accumulated mainly since early thirties to 1993. Their accuracy is different. Therefore, in order to have objective distribution of different hydrographic fields, it is necessary to apply appropriate processing methods.

The first step of data treatment is to exclude from the data set those data the values of which are out of the limiting values of the SCS. The limiting values of water temperature and salinity of the SCS are given in [11].

The second step is to interpolate the parameters onto standard depths and to make their arithmetic average for one-degree squares and for two main seasons.

The next step is to apply methods of objective analyzing and two-dimensional smoothing to interpolate the averaged parameters onto the meshes where they are missing and to correct the unqualified data.

The data obtained after 3 above mentioned treatment steps were used to compute the mean long-term seasonal water density and dynamic heights of different isobaric surfaces.

RESULTS OF COMPUTATION AND DISCUSSION

On the basis of the results of computing the dynamic heights relative to the reference 800 db surface, the dynamic relief maps of the isobaric surface 0, 150 and 500 db were built. The map of 0 db surface reflects the geostrophic current regime of the sea surface layer. The map of 150 db surface reflects the current regime in the undersurface high salinity water mass (The mean depth of the undersurface maximum salinity level is 160 m [10]). The map of 500 db surface reflects the current regime in the intermediate low salinity water mass (The mean depth of the intermediate minimum salinity surface is 480 m [10]). The unit of the dynamic heights is dynamic millimetre. The interval between the isolines is 20 dynamic millimetres. The value and direction of the current velocity were determined by the popular method [14]. The dynamic height topography and geostrophic current charts in two main seasons of the SCS are presented in figures 1-3. From this it is possible to make some important notices about the structural features of the geostrophic circulation in open region of the SCS as follows:

1- Main geostrophic eddies

The geostrophic circulation of the SCS in two main seasons has relatively stable dynamical structure consisting of two following main eddies:

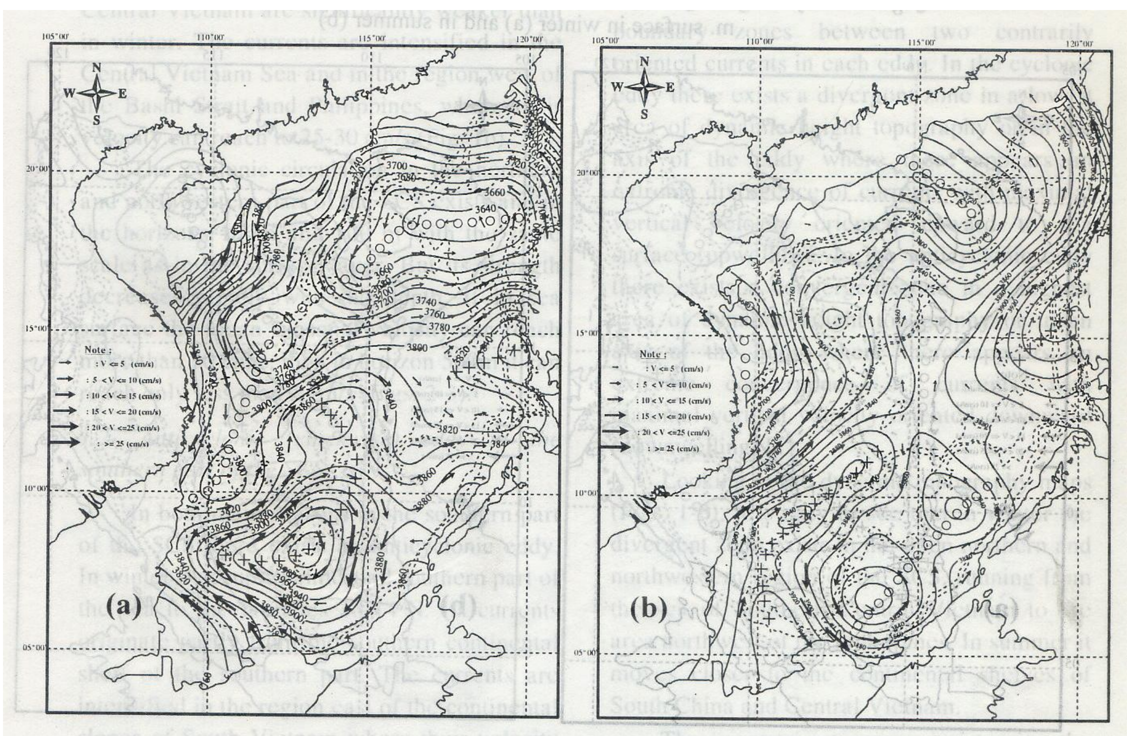

Figure 1: Dynamic height topography (dyn.mm) and geostrophic current of sea surface in winter (a) and in summer (b). oooo: divergent zone
++++: convergent zone

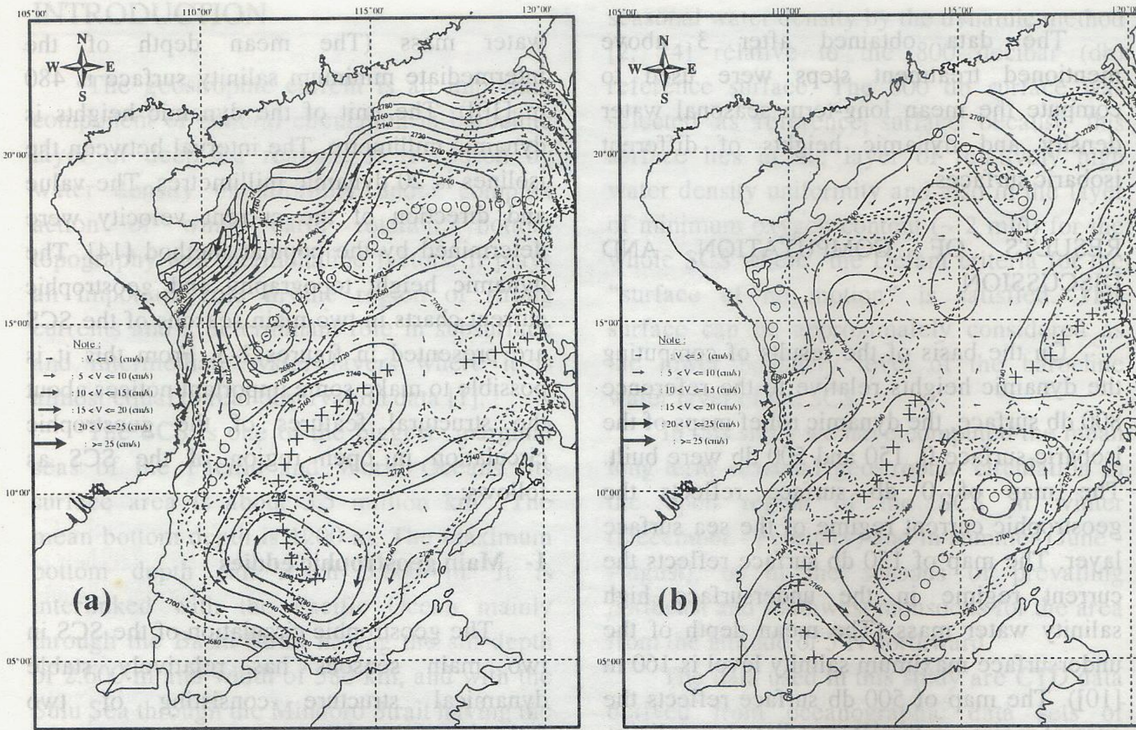

Figure 2: Dynamic height topography (dyn.mm) and geostrophic current of 150 m. surface in winter (a) and in summer (b)

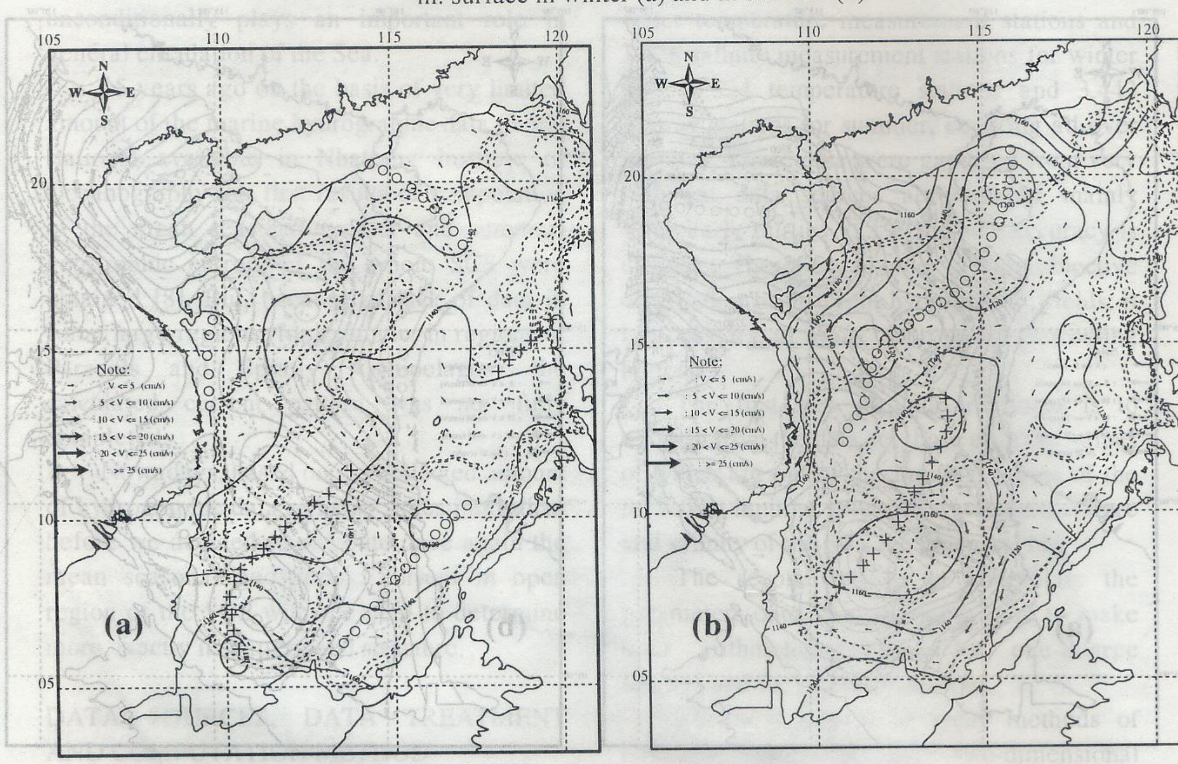

Figure 3: Dynamic height topography (dyn.mm) and geostrophic current of 500 m. surface in winter (a) and in summer (b). oooo: divergent zone ++++: convergent zone

1.1- Cyclonic (anticlockwise) eddy in the northern and northwestern part of the SCS

In winter this eddy consists of the currents from the Philippine Sea flowing through the Bashi Strait westward along the continental shelf of South China, then southward along the coast of Central Vietnam reaching to the continental shelf of South Vietnam at the latitudes 8-9^{0}N, and then turning back to the Bashi Strait (Fig. 1a). The currents are intensified along the eastern coast of the Hainan Island, along the coast of Central Vietnam and in the region of the Bashi Strait where the current velocity in surface layer can reach to more than 30 cm/s.

In summer there is also the cyclonic eddy in the northern and northwestern part of the SCS, but it is located closer to the coasts of South China and Central Vietnam. The currents westward along the coast of South China and southward along the coast of Central Vietnam are significantly weaker than in winter. The currents are intensified in the Central Vietnam Sea and in the region west of the Bashi Strait and Philippines, where their velocity can reach to 25-30 cm/s (Fig. 1b).

The cyclonic circulation in the northern and northwestern part of the SCS exists and in the horizons 150m and 500 m with the same scale as in the surface layer. But its strength decreases rapidly with the depth. If in sea surface the mean seasonal velocity can reach more than 30 cm/s, then in horizon 500m it can reach only less than 5 cm/s (Figs. 2-3).

1.2- Anticyclonic (clockwise) eddy in the southern part of the SCS

In both main seasons in the southern part of the SCS there exists an anticyclonic eddy. In winter it occupies almost all southern part of the sea to the latitudes 13-14^{0}N. Its currents originate partly from the southern continental shelf of the southern part. The currents are intensified in the region east of the continental slopes of South Vietnam where their velocity can reach to more than 30 cm/s (Fig. 1a).

In summer the anticyclonic eddy moves to the southwestern part of the sea because in the southeastern part there appears the cyclonic eddy covering all the Spratly Archipelago (Fig. 1b).

The anticyclonic eddy in the southern part of the SCS exists and in the horizons 150 m and 500 m with the same scale as in the sea surface, but its strength decreases rapidly with the depth (Figs. 2-3).

And so, although in two main seasons the wind circulation on the SCS are contrary, the general geostrophic circulation of the sea is similar by occurrence of the cyclonic eddy in the northern and northwestern part and anticyclonic eddy in the southern part of the sea. There are only some differences between them that in summer there appear some small scale and unstable eddies in the southeastern part of the sea.

2- Main convergent and divergent zones, upwelling and downwelling phenomena

Convergent and divergent zones are boundary zones between two contrarily oriented currents in each eddy. In the cyclonic eddy there exists a divergent zone in a lowest area of dynamic height topography or in the axis of the eddy where there appears an extreme divergence of currents with maximal vertical velocity oriented upward to sea surface (upwelling). In the anticyclonic eddy there exists a convergent zone in a highest area of dynamic height topography or in an axis of the eddy where there appears an extreme convergence of currents with maximal vertical velocity oriented downward (downwelling) [1].

Looking at the dynamic topography maps (Figs. 1-3), it is easy to see that in winter the divergent zone exists in the open northern and northwestern region of the SCS, running from the sea of Southern Central Vietnam to the area northwest of the Philippines. In summer it moves closer to the continental shelves of South China and Central Vietnam.

The convergent zone exists in the southern part of the SCS in two main seasons, but in summer it moves to the southwestern part of the sea and exists together with the local divergent zone in the southeastern part.

The computed geostrophic current maps (Figs. 1-3) and the above mentioned conception show that in the divergent and convergent zones the horizontal component of the current velocity is minimum and the vertical component is maximum.

Thus, although the vertical current velocity was not computed yet, but from the maps of dynamic topography and geostrophic current (Figs. 1-3) it is possible to notice that the upwelling phenomenon occurs in the northern and northwestern part of the SCS in winter and in summer. In winter the large upwelling area, the centre of which is in the divergent zone, appears in the open region of the northern and northwestern part of the SCS. In summer it moves closer to the continental shelves of South China and Central Vietnam. Beside this, in summer a weaker upwelling appears in the region of the Spratly Archipelago. The large downwelling area, the centre of which is in the convergent zone, occupies the southern part of the SCS in winter and moves to the southwestern part of the sea in summer.

3- Main frontal zones

Frontal zone is a boundary zone between two contrarily oriented eddies. Because each eddy has its specific water structure, a frontal zone, in the mean time, is a boundary between two different water structures. This boundary can be called as a frontal surface [1].

The main frontal zone of the SCS is located in the boundary zone between the cyclonic eddy in the northern and northwestern part and the anticyclonic eddy in the southern part of the sea. It runs from the continental shelf of Southern Central Vietnam along the middle latitudes of the SCS to the region west of the Philippines in winter and west of Bashi Strait in summer. Besides, there is a weaker frontal zone west of the Spratly Archipelago where there is a boundary between the anticyclonic eddy in the southwestern part and the local cyclonic eddy in the southeastern part of the SCS in summer.

4- Water exchange between the SCS and Northwest Pacific

The computed geostrophic circulation of the SCS shows that the Northwest Pacific Boundary Current (The Kuroshio) has an enough strong branch intruding into the SCS through Bashi Strait in winter, becoming the main dynamical source of the cyclonic eddy in the northern and northwestern part of the Sea (Figs. 1a-3a). In summer the intrusion is weak and the Northwest Pacific Waters can directly enter only the area southwest of the Taiwan (Figs. 1b-3b).

The main water supply for the cyclonic eddy in summer is from the southwestern and southeastern continental shelves and for the anticyclonic eddy in summer and winter is from the southern and southwestern continental shelves. Therefore, the water structure of the cyclonic eddy in the northern and northwestern part of the SCS is similar to that of the Northwest Pacific subtropical and tropical water structure [9]. The water structure of the anticyclonic eddy in the southern part of the Sea must be another and it needs to be investigated further.

5- Some comparisons

In order to show the reality of above mentioned computed results we tried making some comparisons with other results of computation and observation.

- Beside the computation of the geostrophic current by dynamic method we tried making calculation by more objective method - method of isopicnic analysis, and see that two results are quite similar (see [10]).
- Although, as indicated above, the geostrophic current is only one component (gradient component) of total observation current. But, comparing the computed results with some available surface current maps [3,4,5,7,13], it can be seen that between them there are many similar features. This fact indicates the reliability of the computed results and the important role of geostrophic current in the formation of dynamical structure of the SCS. Of course, the velocity values here are

usually smaller than observation data because they are averaged for seasons and for one-degree squares; further more, they are not a total velocity, especially, in surface layer.

CONCLUSION

On the basis of above mentioned computation and discussion the following main features of geostrophic circulation in open region of the SCS in two main seasons have been affirmed:

- There is a cyclonic circulation in northern and northwestern part and an anticyclonic circulation in southern part of the sea.
- In central area of the cyclonic circulation there is the divergent zone where the extreme divergence of currents and the strong upwelling phenomenon occur. In central area of the anticyclonic circulation there is convergent zone where the extreme convergence of currents and the strong downwelling phenomenon occur.
- The frontal zone is situated in the boundary zone between the cyclonic circulation and the anticyclonic circulation. It runs from the shelf of Southern Central Vietnam along the middle latitudes to the area west of the Philippines.
- The water exchange between the SCS and the Northwest Pacific through the Bashi Strait is very strong in winter, but very weak in summer.

The above mentioned structural features play an important role in formation of the hydrological and ecological conditions of the SCS.

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