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Circulations in Coastal Areas off South China

Ye Longfei (L.-F. Ye)*

1. Introduction

Understanding the flow circulation is of primary importance for studies of marine ecology and pollution protection etc. However the circulation in coastal area is complicated with various processes and can not be considered as forced only by tides. The coastal area off South China is now playing an important role in economic development in southeast Asia with Hong Kong, Macao, Guangzhou and other cities situated in its central part (Fig. 1).

In order to obtain a better understanding of the circulation, it may be devided into several parts for investigation. These are :

1) the estuaries, especially the Pearl River estuary;

2) the continental shelf areas, with different characteristics in the east and in the west of the Pearl River respectively;

3) the continental slope area, along which anti-parallel currents flow; and

4) the deep sea, where circulations are mainly wind drifts driven by monsoons.

2. Pearl River Estuary

The Pearl River runs into a wide embayment seawards from Humen and thus resembles to an inverted funnel (Fig. 2). Tidal waves from the sea are partially reflected near Humen. The hydrological conditions can be described in terms of a Kelvin tidal wave system by a 2-D analytical model (Ye and Feng, 1987; Ye and Johnson, 1994) and further confirmed by a 3-D baroclinic numerical model (Ye, Pfeiffer and Duwe, 1990).

The good agreement between the models and the observed data suggests that the major factors responsible for the hydrological conditions in the Pearl River estuary are that:

1) The width of the estuary is sufficiently large so that the Coriollis effect is significant and therefore Kelvin tidal waves are generated;

2) The partial reflection near Humen exists so that phase shifts between the tidal height, currents, salinity and sand content occur;

3) River discharges in the northwest together with the effect of Kelvin waves produce transverse gradients in the salinity, density and sand content giving rise to baroclinic effect; and

4) The funnel shape of the estuary favours the tidal proccess as the tidal range increases in the upstream direction.

It is interesting to notice the difference in water levels between the west and the east coasts as shown schematically in Figure 3. The mean water level in the west is shifted higher due to baroclinic effect and the river discharge while the tidal range in the east is larger due to the Kelvin wave characteristic.

* South China Sea Institute of Oceanology
Academia Sinica, Guangzhou 510301, P.R. CHINA

Also from the Kelvin wave characteristic, the flood current in the east is stronger while the ebb current in the west is stronger so that a counter-clockwise residual circualtion is resulted. Clear saline sea water flows inwards along the east while turbid fresh river water discharges seawards along the west. This should be well considered for studies of eco-system and pollution control. The topography with alternating channels and shoals indicates the features of a typical tidal-dominant estuary. Thus the east flood channel should be chosen for navigation for sea-going vessels.

3. Continental Shelf

Coastal currents in the continental shelf are mainly derived from river discharges in South China driven by monsoons. However the Pearl River, situated in the middle, with a large river discharge devides this area into two parts (Ye, 1993a). In the east part, the coastal current flows southwestwards in winter with the northeast monsoon and northeastwards in summer with the southwest monsoon. But in the west part, coastal current flowing always southwestwards is mainly derived from the output of turbid polluted fresh water of the Pearl River turning to the right by Coriollis effect.

Often in summer, southwest monsoon induces Ekman drift current offshore and thus upwellings in the east part. For inistance significant upwellings of cold waters in summer in Daya Bay (east of Hong Kong) (Li, 1991) and in Shantou (Chen et al, 1982) had been observed. The important fishing areas in the northeast as well as in the east coast of Hainan Island are famous for upwellings of the similar mechanism (Han et al, 1990).

4. Continental Slope

Here exist two anti-parallel currents in this area, namely the northeastward South China Sea Warm Current (SCSWC) and the southwestward Kuroshio South China Sea Branch (KSCSB) (Fig. 4). It seemed surprising that the SCSWC becomes even stronger against the strong northeast monsoon in winter (Guan, 1978).

The flow of KSCSB, especially in winter, had been confirmed by various observations (SCSIO, 1985; Pu et al, 1992). This may be attributed (Ye, 1994a; 1994b) to the intrusion of the warm water of Kuroshio into the cold South China Sea through the Bashi Strait as a case of gravity density current (Nof and Van Gorder, 1988) similar to the Tsushima current (Yoon and Suginohara, 1977). The fact that the KSCSB flows at first northwestwards and then southwestwards along the outer part of the continental slope may be explained by the conservation of potential vorticity ("trapped by topography"). Also this may be assisted by the northeast monsoon in winter.

Strong front developed by the intruding KSCSB warm water against cold water near the coast giving rise to strong temperature gradient had been observed by survey cruises (SCSIO, 1985) and by satellite imagery (Ye, 1994a). Thus geostrophic effect ("thermal wind") drives currents resembling the SCSWC northeast wards strong enough to flow against the northeast monsoon (Ye, 1993b). The fact that the SCSWC becomes even stronger in winter may be easily understood as the colder the weather, the stronger the temperature gradient and thus the stronger the SCSWC.

5. Deep Sea With Typhoon

Surface circualtions in deep sea area are mainly wind drifts consisting of gyres (confined by topography) controlled by monsoon (Wyrtki, 1961; Xu, 1982). Since monsoons are remarkably seasonal (northeast in winter and southwest in summer) the circulation in summer is almost just the reverse in winter.

It is believed that typhoon (or tropic low pressure) often occurs if sea surface temperature is higher than 28 degree Centigrade within certain depth. Significant water elevation together with cycleonic strong currents causes disastrous effect (Ye, 1991) in addition to stormy winds and heavy rain.

6. Conclusion

It can be summarized that there are several processes for the circulations in the coastal areas off South China:

1) Kelvin tidal wave system with partial reflection with relatively large river discharge in the Pearl River estuary;

2) Coastal currents controlled by monsoons and effect of river discharge together with upwellings in the continental shelf;

3) Anti-parallel currents mainly due to thermal effect from the intrusion of Kuroshio along the continental slope;

4) Wind drifts due to monsoons in the deep sea; and

5) Typhoons generated both from the tropical Pacific and in the South China Sea.

Hence, the driving forces for these processes include tides, monsoons and gravity density currents (both form river discharge and intrusion of Kuroshio) as well as typhoon. Any attempt to study the circulations in these areas by taking account of only a tidal model is not adequate.

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