# Study on the South China Sea Circulation, the Taiwan Strait Upwelling and Their Interaction

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| 学位の種類 | 博　士(理　学) |
| 学位記番号 | 理第1174号 |
| 学位授与年月日 | 平成13年4月18日 |
| 学位授与の要件 | 学位規則第4条第2項該当 |
| 研究科，専攻 | 昭和57年7月厦門大学海洋学部卒業 |
| 学位論文題目 | Study on the South China Sea Circulation, the Taiwan Strait Upwelling and Their Interaction<br>(南シナ海の循環，台湾海峡の湧昇，及びそれらの相互作用に関する研究) |
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# 論 文 内 容 要 旨

The South China Sea (SCS) is the largest marginal sea in the Southeast Asia, and the Taiwan Strait connects the SCS and the East China Sea and Plays a very important role on the water exchange between both seas. The study on the SCS circulation and the Taiwan Strait upwellig have been paid great attentions to for decades. However, the interaction between the SCS circulation and the Taiwan Strait upwelling has not been well understood. Therefore, the motivations of the present study are to review and summarize the general pattenrns of the SCS circulation and the Taiwan Strait upwelling, and to further investigate their features and interaction using hydrographic data and satellite data.

Chapter 1 presents a general introduction to the SCS, the Taiwan Strait and the monsoon system in the studied area.

Chapter 2 reviews the studies on the SCS circulation pattern, the SCS Warm Current (SCSWC) and the Kuroshio intrusion. The overall seasonal SCS circulation pattern is concluded from hydrographic observations, satellite observations and numerical experiments, and is summarized as: (1) At the top layer (approximately 0～5m), the SCS current is considered as the Ekman drift that is in accord with the local wind direction. The northeastly winter wind induces the westward current at the top layer, while the wind and the Ekman drift reverse in summer. (2) As for the upper layer (0～200m) mean circulation in the SCS, it is cyclonic in winter but anticyclonic in summer. In addition, two cyclonic eddies exists in winter in the west of the Luzon Island and southeast of the Zhongnan Peninsula, respectively. An anticyclonic eddy appears in the southeast of the Zhongnan Peninsula while another cyclonic eddy in the east of Vietnam coast in summer.

The reveiw of the SCSWC includes the observational evidences of the SCSWC, extension of the SCSWC in the Taiwan Strait, and the mechanism for the SCSWC formation. It is indicated that the SCSWC flows northeastward along the continental slope off the southern Guangdong and in the south of the Taiwan Bank, and extends to the Taiwan Strait both in winter and in summer. As for the Kuroshio intrusion to the NSCS and the Taiwan Strait, some viewpoints on the Kuroshio intrusion through the Luzon Strait are firstly introduced, and the water exchange in the Luzon Strait and the intrusion into the Taiwan Strait are then described. It is regarded that the Kuroshio has a branch intruding into the NSCS in winter, but it sometimes intrudes to the NSCS in summer, mostly in the form of "loop"or "extend".

In Chapter 3 , the variability of the SCS circulation is analyzed using six years′ of TOPEX/POSEIDON(T/P) altimeter data. The detection of the SSH variation with the period of 3～6 months (SSH36 variation)is carried out by using spectrum analysis and wavelet analysis, and the characteristics of SSH 36 variations are examined by cross correlation analysis, and the spatial distributions and section-time diagrams of the SSH 36 variations. The results show that: (1) There exist greater energy of the SSH36 variations both in the east of the Luzon Strait and in the some

areas of the SCS. The SSH36 variations in the SCS have a strong correlation with those in the North Pacific Ocean(NPO), they propagate westward from the western NPO and usually turn to propagate northward in the east of the Luzon Strait, but they sometimes enter into the SCS through the Luzon Strait. The phase speed is about 7-15 cm/s in the east of the Luzon Strait and about 11-12 cm/s if it propagates into the NSCS. It is considered that the SSH36 variations in the SCS are Rossby Waves which sometimes propagate into the SCS through the Luzon Strait from the NPO.

Chapter 4 reviews studies of the Taiwan Strait upwelling using some previous results derived from hydrographic observations and numerical modellings. It is summarized that there are four main upwelling regions in the Taiwan Strait, which are located along the southwestern coast of the Taiwan Strait (called SW-upwelling region here),along the northwestern coast of the Taiwan Strait (NW-upwelling region), near the Taiwan Bank (TB-upwelling region) and around the Penghu Islands (PH-puwelling region). Specifically, i) The SW-upwelling region mainly spreads along the coast between Xiamen an Shantou and appears during the southwest monsoon period in summer. It can be mostly cosidered as a wind-driven upwelling region with its location, scale and strength mainly depending on the wind conditions. ii) The NW-upwelling region chiefly centers in the east of Pingtan and sometimes extends southwards to the Meizhou Island. It usually appears in spring and summer, beginning in late May, strengthening in July with wider scale and then declining in late August. iii) It has been considered that the TB-upwelling is principally induced by the ascending of bottom currents towards the Taiwan Bank. However, it is often observed that this upwelling is sometimes strong but some other time weak because of the influences of tidal current and internal tide. iv) It is suggested that the PH-upwelling region exists all the year round. It mostly appears in the southern Penghu Islands, while it can sometimes appear in the northern Penghu Islands. The location variation is associated with the alternation of monsoons. Besides, the bottom topography around the Penghu Islands is also favorable for the northward flowing current at the lower layer to climb towards the surface layer in the southern Penghu Islands.

Chapter 5 presents results of the summertime upwelling in the Taiwan Strait with the uses of some new cruise data and high resolution Advanced Very High Resolution Radiometer(AVHRR) Sea Surface Temperature (SST) satellite data. Following results have been obtained: (1) Four main LTZs, which are considered as being induced by the corresponding upwelling, appear in the Taiwan Strait in summer. These LTZs are located along the southwestern coast of the Taiwan Strait (SW- LTZ), along the northwestern coast of the Taiwan Strait (NW-LTZ), near the Taiwan Bank(TB-LTZ) and around the Penghu Islands (PH-LTZ), respectively. The SW-LTZ usually has two centers located in the east of Dongshan and in the southwest of Nan-ao, and the NW-LTZ is often seen in both northeast and southwest of Pingtan. The low temperature features of three LTZs were captured by the recent August cruises during 1997-1999. The cruise data show that these LTZs also possess relatively higher salinity(greater than 34). (2) Monthly or more long-term mean SST images derived from the satellite observations clearly indicate the summertime pattern of these upwelling-related LTZs and also demonstrate their inter-annual and inter-monthly variability. In the southern Taiwan Strait, the LTZs often have quite different scale and location from June to September. Along the western coast of the Taiwan Strait, both LTZs had smaller scale in 1997 but larger scale in 1998 and 1999.

In Chapter 6, the interaction between the SCS circulation and the summertime Taiwan Strait upwelling is discussed using current structure and water property analyses. Through the present thesis, the following aspects on the interaction between the SCS circulation and the Taiwan Strait upwelling have been obtained: (1) It is evident that the SCS circulation is an important factor for generation of the four main upwelling regions in the Taiwan Strait. The flowing pattern of the SCSWC may induce the upwelling near the Taiwan Bank and around the Penghu Islands(TB-

upwelling and PH-upwelling regions). Meanwhile, as the northeastwards current flows along the sea area between the coast and the Taiwan Bank, it may have the tendency to climb towards the upper layers along the uplifting bottom topography and thus induce the upwelling near Dongshan (SW-upwelling region). In addition, the currents in the near-coast area southwest of Pingtan also tend to climb towards the upper layer to form the upwelling near Pingtan(NW-upwelling region). (2) It can be deduced that the upwelling water comes from the subsurface layer of the NSCS. The surface layer of the Taiwan Strait is usually dominated with the typical Taiwan Strait water, with relatively higher temperature and lower salinity summer. This surface water has a large annual variability because it is affected by the radiative heating and cooling, atmospheric thermal forcing, river discharge, rainfall and currents. However, the water at the lower layer does not change so much in a year. The water mass analysis indicates that temperature and salinity features of the surface water in the Taiwan Strait upwelling region are very close to those of the subsurface water in the SCS. Obviously, the lower layer water, originating from the subsurface layer of the SCS and to be the upwelled water, may sometimes be driven to the upper layer by some forces such as winds, currents and tides. Since the SCS circulation and the Taiwan Strait upwelling have the temporal and spatial vatiability, and their formation mechanisms, their rules on the material circulation and their interaction with the marine ecosystem are not known well, we should conduct a comprehensive research in new directions, i.e., long-term hydrographic observations, high-resolution satellite observations, multi-disciplinary observations and numerical modelling.

Finally, the general conclusions are summarized in Chapter 7.

# 論文審査の結果の要旨

南シナ海は東南アジア最大の縁辺海である。台湾海峡は南シナ海と東シナ海を結ぶ重要な位置にあり，両者の海水交換において主要な役割を果たしている。近年，これらの海域に関する研究が増加しつつあるが，両者の相互作用まで踏み込んだ研究はほとんどない。

本研究では，まず東シナ海の循環に関する広範なレビューを行い，以下のことを明らかにした； 季節とともに風向を変えるモンスーン海上風が南シナ海の海流形成に主要な役割を果たしており，冬季は低気圧性の，夏季は高気圧性の循環が形成され，それに伴って特徴的な渦が生じる。中国南部の沿岸域には，季節によらず沿岸に沿って北向きに流れる南シナ海暖流が存在し，台湾海峡へと流入している。また，ルソン海峡からの黒潮の流入についても，幾つかの形態があることが示された。

南シナ海の海流変動の要因である3-6ヶ月周期の変動について，海面高度計を用いた研究を行った。北西太平洋においてこの周期帯の変動が卓越することが知られていたが，これらの変動の南シナ海への侵入に関しては研究が行われていない。本研究により，この周期帯の変動がロスビー波としてルソン海峡を通過して南シナ海に侵入すること，南シナ海において7-15cm/sの位相速度を持つことが明らかとなった。

これまでに中国語で書かれた文献の調査から，台湾海峡には４つの主要な湧昇域があることが明らかとなった。それらを改めてSW(the southeast coast of the Taiwan Strait), NW (the northwestern coast of the Taiwan Strait), TB(Taiwan Bank), PH(Penghu Island)湧昇域と名付けてその特徴をレビューした。さらに，1997年から3年間にわたって毎年８月に行われた集中船舶観測と多数の衛星海面水温データを用いた研究により，上記４湧昇域で低温・高塩分の特徴的な湧昇水を見いだし，新しい知見を得るとともに文献調査の妥当性を確認した。

南シナ海の循環と台湾海峡の湧昇に関する広範なレビューと，船舶観測と衛星観測資料を活用した新しい研究によって，これらの実態の把握と現象の理解大いに進んだ。さらに両者の相互作用について広範な議論を展開し，将来の研究の方向が明らかとなった。したがって，Hu Jianyu提出の学位論文は，博士（理学）の学位論文として合格と認める。