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SPECIAL SECTION: EDITORIAL

Regional Environmental Oceanography in the South China Sea and Its Adjacent Areas (REO-SCS): I

Introduction to the special section on regional environmental oceanography in the South China Sea and its adjacent areas (REO-SCS)

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1 Introduction

The South China Sea (SCS) plays important roles in the interactions between the Pacific and Indian Oceans and between the Asian continent and the oceans. In recent years, oceanographers, especially those from surrounding countries and regions, have carried out several government-supported projects in the SCS and have harvested valuable in situ measurements, satellite data, and numerical modeling results. In order to deliver these new results to the regional environmental oceanography community, we organize and edit a special section entitled "Regional Environmental Oceanography in the South China Sea and Its Adjacent Areas (REO-SCS)". We hope that this section will contribute to the promotion of regional environmental oceanography research and serve as a platform for the community to exchange and share ideas and results. This special section appears in two issues in *Journal of Oceanography* (Nos. 4 and 5, Vol. 67).

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2 The South China Sea dynamics

The SCS is an important area connecting the tropical Pacific Ocean with the Indian Ocean through the South China Sea Throughflow (Fang et al. 2002; Qu et al. 2006a; Wang et al. 2006; Tozuka et al. 2009). It is a semi-enclosed marginal sea with a deep basin and broad shelves. As it is affected by the seasonal solar radiation, monsoon, and the surrounding continent and islands, the temperature in the SCS has a significant seasonal variation. The sea surface temperature (SST) ranges are 20–28, 26–28, 27–30, and 23–29°C in winter, spring, summer, and autumn, respectively. In winter, a typical Luzon cold eddy appears at depths from 50 downward to 300 m to the west of Luzon Island (Yang and Liu 1998). It has a spatial scale of 300–400 km and a temperature difference of at least 3–4°C between the cold core and its surroundings at 100 m depth. In summer, the Vietnam cold eddy (spatial scale 200–300 km, temperature difference 3–4°C) exists east off the Vietnamese coast (Guo et al. 2004; Su and Yuan 2005; Sun 2006).

The annual mean salinity in the SCS is about 34.0 psu (Su and Yuan 2005). The sea surface salinity is lower in the northern SCS, particularly in the sea area off the Pearl River (the Zhujiang River) where the Pearl River plume extends offshoreward and forms a strong salinity front. In the SCS basin, the water is stratified in 4 layers of different salinity: relatively low salinity surface water (thickness 50–100 m, S 33.50–34.50 psu), relatively high salinity subsurface water (between 100 and 300 m, $S > 34.60$ psu), low salinity intermediate water (300–900 m, $S < 34.50$ psu), and high salinity deep water (1000–2500 m, S 34.50–34.60 psu).

The circulation patterns in the SCS and its adjacent areas are very complicated (Hu et al. 2000, 2010; Su 2005; Fang et al. 2005; Zheng et al. 2006a; Liu et al. 2008b; Isobe

2008). As a result of the monsoon–mountain interaction, the seasonal pattern of the sea surface wind stress curl is spatially non-uniform and therefore induces basin-scale circulations and gyres together with very active mesoscale eddies in the SCS (Wang et al. 2003). At the top layer, the SCS current is the Ekman drift influenced by local winds. The upper layer mean circulation is cyclonic in winter with one cyclonic eddy west of Luzon Island and another southeast off Vietnam, but in summer it is anticyclonic with an anticyclonic eddy southeast off Vietnam and a cyclonic eddy east of Vietnam coast (Hu et al. 2000). In addition, the SCS Warm Current (Guan and Fang 2006), the Kuroshio intrusion into the SCS, and the multiple mesoscale eddies are also incorporated into the general seasonal circulation patterns.

The SCS upwelling studies are mainly concentrated in the northern SCS and its northwestern continental shelf, especially along the Guangdong coast and the eastern coast of Hainan Island (Gan et al. 2009; Jing et al. 2009; Su and Pohlmann 2009). Wu and Li (2003) and Hu et al. (2003) summarized more than 40 years of upwelling research in the SCS and the Taiwan Strait, respectively. They concluded that the upwelling is a common phenomenon on the whole continental shelf in the northern SCS and in the Taiwan Strait in summer. One major dynamical factor inducing such upwelling is the prevailing southwesterly monsoon. Therefore, the summertime upwelling can appear along the northeastern coast of Hainan Island and along the coasts of Fujian and Guangdong. The upwelling around the Taiwan Bank is characterized by multi-cell structure existing year-round with different features in terms of chemistry and biology. Additionally, coastal upwelling also occurs along the eastern coast of Vietnam in summer (Xie et al. 2003) and off the northwestern coast of Luzon Island in winter (Shaw et al. 1996).

3 Research hotspots related to SCS regional environmental oceanography

3.1 Hydrodynamics in the Luzon Strait

Being a strong western boundary current in the North Pacific Ocean, the Kuroshio plays an important role in the seawater volume transport between the North Pacific Ocean and the SCS. Previous investigations revealed that the Kuroshio may intrude into the SCS through the Luzon Strait in many ways (Caruso et al. 2006), such as a direct branch (Qiu et al. 1985; Yuan et al. 2006), warm-core eddy (Wang and Chern 1987), looping current (Li and Wu 1989; Xue et al. 2004; Yuan et al. 2006; Sheu et al. 2010), detached ring (Li et al. 1998; Yuan et al. 2006), extending pattern (Hu et al. 2000), westward Rossby wave propagation (Hu et al. 2001; Wang et al. 2008), eddy shedding process (Jia and Liu 2004; Jia et al. 2005), and as ocean vortex trains (Zheng et al. 2008). Some researchers also focused on the deep water overflow through the Luzon Strait (Qu et al. 2006b) and the flow pattern in the intermediate layer of the Luzon Strait (Yuan et al. 2008; Xie et al. 2011a). The volume transport through the Luzon Strait was estimated to range from 0.5 to 10 Sv (Wyrtki 1961; Metzger and Hurlburt 1996; Qu et al. 2000; Fang et al. 2005; Tian et al. 2006; Yang et al. 2010). However, the Kuroshio intrusion and the volume transport through the Luzon Straitremain disputed.

3.2 Near-inertial oscillation in the SCS

Near-inertial oscillation (NIO) is one of the significant components affecting upper ocean dynamics, particularly in the coastal oceans and continental shelves. The major mechanism for the NIO generation is believed to be sudden rising of wind stress caused by typhoons or storms (or hurricanes as mentioned in some references). Several field observations revealed strong near-inertial current in the wake of hurricanes (Shay and Elsberry 1987; Xie et al. 2009). Other mesoscale processes, such as eddies and loop currents, may modify the NIO propagation and induce the NIO frequency shift (Shay et al. 1998; Zhai et al. 2007; Oey et al. 2008).

The SCS has usually experienced frequent typhoon and tropical storm events, averaging up to 15 occurrences per year according to historical records. In addition, the SCS has variable hydrographic structures and circulation patterns due to the alternating monsoonal winds. The topography, stratification, and background flow are supposed to have significant influence on characteristics of the NIOs. Chu et al. (2000) employed the Princeton Ocean Model to simulate the response of upper SCS to tropical cyclone Ernie in 1996, and the simulation indicated the existence of the NIO-induced surface divergent currents. Zhang et al. (2005) studied the NIO at the upper 450 m of the northern SCS. Using the buoy or mooring observation data, Zhang et al. (2007) and Zhu and Li (2007) reported a typhoon-induced NIO in the deep basin SCS and the near-shore area off Hainan Island, respectively.

McComas and Bretherton (1977) predicted that the parametric subharmonic instability (PSI) of internal tides would lead to the generation of NIO waves. The SCS is located between 2.5 and 23.5°N, i.e., crossing the critical latitudes at which PSI of diurnal internal tides occurs (13.44°N for O_1 tide and 14.52°N for K_1 tide). Thus, the PSI mechanism should be considered as an important factor for generating the NIO waves in the SCS. Recently, Alford (2008) studied the NIO led by the PSI of the diurnal tides in the eastern SCS. Xie et al. (2009) analyzed the influence of PSI on the NIO spectra using mooring acoustic Doppler current profiler (ADCP) data measured in the SCS deep basin. They also observed the PSI-induced near-inertial waves equatorward of the critical diurnal latitude in the northeastern SCS from 75-day-long mooring current measurements (Xie et al. 2011b).

3.3 Responses of SCS regional environment to global changes and El Niño events

Kienast et al. (2001) presented the alkenone SST records for the tropical SCS that show an abrupt temperature increase of at least 1°C at the end of the last glacial period. Li et al. (2002) used TOPEX/POSEIDON satellite altimetry data to identify a general trend of sea level rising in the SCS during 1993–1999. Liu et al. (2007) analyzed the long-term variability of temperature and salinity in the SCS and demonstrated that the seawater at the SCS intermediate layer has become significantly fresher since the 1960s. Liu et al. (2009) reconstructed high resolution Sr/Ca-SST sequences extracted from the modern massive *Porites* coral in the northern SCS and concluded that a general intensification trend existed in the summer upwelling from 1906 to 1993 with significant interannual and decadal variations, which is consistent with the global warming in the twentieth century and El Niño and Southern Oscillation. Cai et al. (2011) studied spatial and temporal oscillation and long-term variation of SST in the SCS and analyzed SST interannual and long-term variations, which result from the meridional wind anomaly and zonal migration of the subtropical high over the western Pacific Ocean. Since "El Niño Modoki" (Ashok et al. 2007; Ashok and Yamagata 2009) was recently introduced, oceanographers are paying more and more attention to the responses of the SCS to this new type of El Niño phenomenon (Chang et al. 2008).

3.4 Applications of satellite data to SCS regional environmental oceanography

Data from satellite remote sensing, such as altimeters, synthetic aperture radar (SAR), visible and infrared spectrometers, and microwave scatterometers, have been widely used to study regional environmental oceanography in the SCS and its adjacent areas (Liu et al. 2008a). Satellite altimeter data have been employed to derive ocean circulation, mesoscale eddies, tides, sea level variations, and waves. Satellite-derived SST and ocean color data are usually used to study upwelling, oceanic fronts, different scales of variations in SST and chlorophyll *a* distributions, local responses to the climate change, El Niño events, and typhoons (Shang et al. 2008), to estimate the surface water pCO_2 and air–sea CO_2 fluxes (Zhu et al. 2009), and to assess aerosol impact on the SCS biogeochemistry (Lin et al. 2009). Scatterometer data provide ocean surface wind observations. SAR data are frequently utilized for the detection of internal waves (Zheng et al. 2007), bathymetry (Zheng et al. 2006b), and oil spills.

4 The special section

The special section, as a whole package of closely related papers including this introductory note, provides the readers with a convenient way to share newly obtained results and information on the regional environmental oceanography in the SCS and its adjacent areas. Using in situ data, satellite data, and numerical modeling, contributors to this special section cover studies including the NIO in the SCS, the interaction between nonlinear Rossby eddy and Kuroshio in the Luzon Strait, currents and upwelling in the northern SCS and the Taiwan Strait, water mass in the Beibu Gulf, and satellite data applications for shallow water depth retrieval, residual settlement detection, and SST and warm pool area variability in the SCS and its adjacent areas.

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