Acta Oceanol. Sin., 2021, Vol. 40, No. 11, P. 196–199
https://doi.org/10.1007/s13131-021-1963-3
http://www.aosocean.com
E-mail: ocean2@hyxb.org.cn

News and Views

Advances in interscale and interdisciplinary approaches to the South China Sea

Lingling Xie[1, 2, 3], Yi Guan[1, 2, 3*], Jianyu Hu[4], Quanan Zheng[5]

[1] Laboratory of Coastal Ocean Variation and Disaster Prediction, College of Ocean and Meteorology, Guangdong Ocean University, Zhanjiang 524088, China

[2] Key Laboratory of Climate, Resources and Environments in Continent Shelf Sea and Deep Ocean, Zhanjiang 524088, China

[3] Key Laboratory of Space Ocean Remote Sensing and Applications, Ministry of Natural Resources, Beijing 100081, China

[4] State Key Laboratory of Marine Environmental Science, College of Ocean and Earth Sciences, Xiamen University, Xiamen 361005, China

[5] Department of Atmospheric and Oceanic Science, University of Maryland, College Park 20742, USA

Received 1 November 2021; accepted 10 November 2021

The South China Sea (SCS) connects the Pacific Ocean and the Indian Ocean, and acts as an important part in regional and global climate systems (e.g., Qu et al., 2009; Wang et al., 2009). Multi-scale dynamic and biogeochemical processes in the SCS, comprising a hot spot in marginal sea studies, have attracted great attentions from researchers (e.g., Chen et al., 2020; Hu et al., 2020). The South China Sea Annual Meeting (SCSAM) 2021, recently held on October 22–24 in Zhanjiang, China, focused on academic exchanges of the newly research results and progresses in the interdisciplinary multi-scale processes in the SCS. The SCSAM 2021 is the eighth international workshop of the series, which started in April 2013 (Zhu, 2013) and renamed as SCSAM in 2018. There were 90 oral presentations and 57 posters in the meeting this year, which attracted attentions of more than 2 000 audiences both on line and on site. This short article summaries the cutting-edge advances in interscale and interdisciplinary approaches to the SCS from the meeting presentations and the associated research.

Three-dimensional (3D) basin circulation provides the basic and important dynamic environment for processes in the SCS. Previous investigators have revealed that the large-scale three-layer ocean circulation in the SCS is featured by cyclonic/anticyclonic circulation in the upper layer, anticyclonic in the middle layer, and cyclonic in the deep layer (e.g., Gan et al., 2016; Cai and Gan, 2021). The new findings further show the meridional overturning circulation in the upper layer (Lan and Jiang, 2021) and the variability of the deep circulation in the SCS (Zhu et al., 2021). Meanwhile, intra-seasonal variations of currents in the upper and deep layers of the northern SCS were observed and attributed to the topographic Rossby waves (Zheng et al., 2021b; Shu et al., 2021). Subseasonal variability in the SCS was revealed by numerical simulations (Xie et al., 2020). In terms of energy and vorticity balances, Huang (2021) diagnosed the roles played in regulating the SCS circulation by the SCS throughflow, the local wind stress, the deep overflow through the Luzon Strait, the local thermohaline forcing and the meso/submeso-scale eddies, and concluded that the contribution from the open ocean plays a dominant role.

The interaction between the SCS with its adjacent open oceans attracts more input from many research teams. Wei and Xu (2021) summarized couplings within a system consisting of the Pacific Ocean, the SCS and the Indian Ocean, indicating that the interannual variations in the Pacific and Indian Oceans change the monsoon-derived circulation in the SCS, the freshwater transport by the SCS throughflow into the Indonesian seas significantly influences the Indonesian Throughflow (ITF), and the SCS summer monsoon contributes to the development of the Indian Ocean Dipole (IOD). Susanto et al. (2021) reported the tidal mixing in controlling the ITF and regional circulation. Wu et al. (2021a), Zhou and Liu (2021) and Zhou (2021) investigated the multiscale variations of the main currents in the North Pacific, and Gong (2021) presented the variation of the deep circulation in the Pacific in the paleoclimate. Zhong et al. (2020) evidenced the Kuroshio intrusion into the SCS as a form of interaction between the SCS and the Pacific.

The mesoscale eddies are quite active and energetic in the SCS. Recently, the interscale interactions of meoscale eddies and other processes have become a research hot spot. The reported new results include modulation of eddies to small-scale processes such as sea surface waves (Tan et al., 2021), internal tides (Deng and Xie, 2021) and turbulent mixing (Liu and Liao, 2021). Besides, Sun et al. (2021b) studied abnormal eddies, i.e., cyclonic warm-core eddies and anticyclonic cold-core eddies, in the northeastern SCS associated with the Kuroshio intrusion. Sun et al. (2021a) found a strong Kuroshio intrusion into the SCS and its accompanying cold-core anticyclonic eddy in winter 2020–2021. Dong et al. (2021a) analyzed the symmetric instability, gravitational instability and centrifugal instability in the surface mixed layer of an anticylonic eddy and found that the symmetric instability dissipation plays a key role in the eddy kinetic energy budget. Xie (2021) revealed the seasonal reversal of eddy polarity distribution (PDR) in the SCS and

Foundation item: The National Natural Science Foundation of China under contract Nos 41776034 and 91958203; the Innovation Team Plan in Universities of Guangdong Province under contract No. 2019KCXTF021; the Guangdong Province First-Class Discipline Plan under contract No. CYL231419012.
*Corresponding author, E-mail: yiguan@gdou.edu.cn

surrounding marginal seas and the formation mechanism of the banded PDR derived from the solitary Rossby wave packet theories.

The ocean submesocale process investigations closely follow the development footsteps of the world, which has been a cutting-edge research topic in recent years (McWilliams, 2016; Dong et al., 2020; Zheng et al., 2020; Cheng et al., 2021; Jing et al., 2021a). Observations of submesoscale density filaments and submesoscale coherent vortices in the SCS were reported (Jing et al., 2021b; Zhang et al., 2021c). Wu et al. (2021b) found the importance of barotropic instability in the generation of the submesoscale waves at the frontal region. Lu and Li (2021) revealed the submesoscale dynamics of cross-shelf transport. Liu et al. (2021) proposed that the unbalanced submesoscale motions facilitate the forward cascade of kinetic energy through interacting with background motions. For the submesoscale high-frequency motions, new observations of solitary internal wave, internal tides and near-inertial internal waves and the interaction between internal waves and circulation were reported (Delvin et al., 2021; Hou et al., 2021; Xie and Cai, 2021; Zhang et al., 2021b). Interdisciplinary data analysis methods have been used for the submesoscale process research, such as multi-scale motion decomposition from mooring observations and submesoscale information extraction from satellite observations (Miao et al., 2021; Wang et al., 2021; Yu et al., 2021), as well as the seismic detection (Tang et al., 2021). Gan et al. (2021) developed a physical-biogeochemical coupled ocean model of the China seas and found that the vertical motion and primary productivity in the SCS deep basin are enhanced by submesoscale processes.

The continental shelf research is still a characteristic topic in the SCS. Xu et al. (2021a), Kong et al. (2021) and Huang et al. (2021) showed interdisciplinary research results on responses of ocean temperature and productivity in the upwelling regions to the paleoclimate change from sediment records. The dynamic and biological responses to typhoons were reported (Li et al., 2021b; Zhang, 2021a; Zhou and Song, 2021; Qiu et al., 2021). Deng et al. (2021) associated the interannual variability of the coastal-shelf-slope circulation with the El Niño-Southern Oscillation (ENSO) events in the northern SCS. Lin et al. (2021) proposed an efficient dynamic model for the sea level variation along the coastal of the Chinese mainland. For the estuarine research, the effects of meteorological tides, ocean tides, the Coriolis force and the wave-current interaction on the circulation and the asymmetrical turbulent kinetic energy (TKE) production were investigated (Rohli and Li, 2021; Gong et al., 2021; Song, 2021; Chen, 2021). Feng et al. (2021) evaluated the estimate of carbon budget in coastal zones and the improvement in model simulation. Li et al. (2021a) presented the TKE dissipation rate in the upwelling region east of Hainan Island. Zheng et al. (2021a) reported an interesting phenomenon, i.e., circular cloud ring around the Hainan Island. They proposed interdisciplinary dynamic interpretations, i.e., the katabatic air flow down the island induced by the high-pressure ridge and the circular hydraulic jump surrounding the island comprise the formation mechanism of cloud rings.

High techs have been adopted into the SCS research on time. In the new era of big data based on the great improvement of satellite observations (Lin, 2021), the interdisciplinary studies of artificial intelligence (AI) oceanography are flourishing (Li et al., 2020). Dong et al. (2021b) introduced the ocean big data, the AI methods, and the application results, such as detection of ocean eddies, internal waves, ice, and green tides. AI methods have been used for prediction of ENSO, storm surge, surface waves, and ice, and for improvement of ocean numerical forecast accuracies (Xu et al., 2021c; Bethel et al., 2021; Zhou et al., 2021). Zhang et al. (2021a) developed a deep learning EMTnet model to improve the satellite humidity retrieval over the China seas. Xu et al. (2021b) presented the successful implication of typhoon prediction with physical-constrained Convolutional Neural Network and Deep Neural Network methods. Zhang (2021b) reported the intelligent prediction method for ocean disasters under global warming. Cutting-edge technologies, such as underwater glider and satellite-board radar, have been developed for field surveys in the SCS (Sun et al., 2021c; Pan et al., 2021).

In summary, the interscale and interdisciplinary research on the SCS has achieved important advances in recent years. It is expectable that the future efforts will focus on clarifying the 3D circulation in the middle and deep layers, the basin-shelf interaction and exchange, as well as coupling of physical and biogeochemical processes in the basis of *in situ* observations. For a marginal sea, its parent ocean always has deterministic influences on all aspects. Thus, it is reasonable to treat the SCS as a component of the Pacific Ocean-western boundary current-marginal sea system. It is also expectable that high-resolution model products and reanalysis data products, as well as applications of cutting-edge technologies, such as big data and AI, will provide new opportunities for breakthrough in the research on complicated multiscale processes in the SCS.

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