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Cover Story

New insight into the South China Sea: Rossby normal modes

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The South China Sea (SCS), the largest marginal sea of the Northwest Pacific Ocean, is characterized by frequent occurrence of energetic mesoscale eddies. The eddy diameters range from 100 to 300 km. The eddy lifespan varies from several days to several months with the longest time of seven months (Zheng et al., 2017). The eddy disturbance reaches down to the ocean bottom layer. Before 2011, eddies in the SCS were treated as a single process. Thus, their generation was individually attributed to various mechanisms, such as the Kuroshio intrusion, local winds and disturbances from the Pacific (Wang and Chern, 1987; Li et al., 1998; Wang et al., 2003; Hu and Kawamura, 2004; Xie et al., 2011; Zheng et al., 2011). Since 2011, some investigators have found that eddies in the SCS behaved as grouped phenomena. Nan et al. (2011) observed three long-lived anticyclonic eddies appearing as an eddy train along 18°N in the northern SCS in summer 2007, and suggested the frontal instability of the local current as their generation mechanism. Zheng et al. (2014) found that there is internal coherence among alternatingly distributed anticyclonic and cyclonic eddies in the SCS, and suggested existence of 2-D standing wave modes in the SCS deep basin.

Recently, Xie et al. ① adopted theories of the Rossby normal modes in the enclosed ocean basin to analyze 2-D distribution patterns of the sea level anomaly (SLA) in the SCS deep basin. Their results give a new insight into the SCS eddy dynamics.

The Rossby normal mode solutions to the linear potential vorticity equation on the β-plane for a rectangular ocean basin with a zonal length L ($0 \leqslant x \leqslant L$), a meridional width l ($0 \leqslant y \leqslant l$), and a uniform depth are

$$\zeta_{mn}(x,y,t) = \cos\left(\frac{\beta}{2\sigma_{mn}}x + \sigma_{mn}t\right)\sin\left(\frac{m\pi}{L}x\right)\sin\left(\frac{n\pi}{l}y\right), \quad m,n = 1,2,3,\ldots, \tag{1}$$

where β is the northward gradient of the Coriolis parameter f and the corresponding eigenvalue

$$\sigma_{mn} = \frac{\beta}{2\left[\left(\frac{m\pi}{L}\right)^2 + \left(\frac{n\pi}{l}\right)^2 + \left(\frac{1}{R_i}\right)^2\right]^{\frac{1}{2}}}, \tag{2}$$

where R_i is the ith Rossby deformation radius (Pedlosky, 1987)①. One can see that the solution consists of two components: westward travelling waves, $\cos\left(\frac{\beta}{2\sigma_{mn}}x + \sigma_{mn}t\right)$, and 2-D ($x$-$y$) standing waves, $\sin\left(\frac{m\pi}{L}x\right)\sin\left(\frac{n\pi}{l}y\right)$. This implies that the 2-D sea level structures of the solutions vary with time, and may appear as complex patterns. Within a short observation time interval, however, the 2-D sea level patterns of the Rossby normal modes would show very much like the standing waves.

Figure 1 shows comparisons of the Rossby normal modes for m=1, n=1, 2, 3 to 2-D satellite altimetry SLA patterns in the SCS deep basin from 11°N to 19°N and from 110°E to 120°E with the central latitude at 15°N and R_i=60 km. One can see that similarities of theoretical solution of Rossby normal mode ζ_{11} (period: 114 d, zonal wavelength: 364 km, and meridional wavelength: 1 760 km) to SLA patterns of the SCS deep basin on August 17 and 25, 2015 are 6/6 and 6/6. Similarities of Rossby normal mode ζ_{12} (period: 121 d, zonal wavelength: 342 km, and meridional wavelength: 880 km) to SLA patterns on September 16 and 23, 2007 are 11/12 and 12/12. Similarities of Rossby normal mode ζ_{13} (period: 132 d, zonal wavelength: 314 km and meridional wavelength: 587 km) to SLA patterns on February 23 and March 5, 2012 are 17/18 and 16/18. The high similarities reveal that the Rossby normal modes indeed exist in the SCS deep basin.

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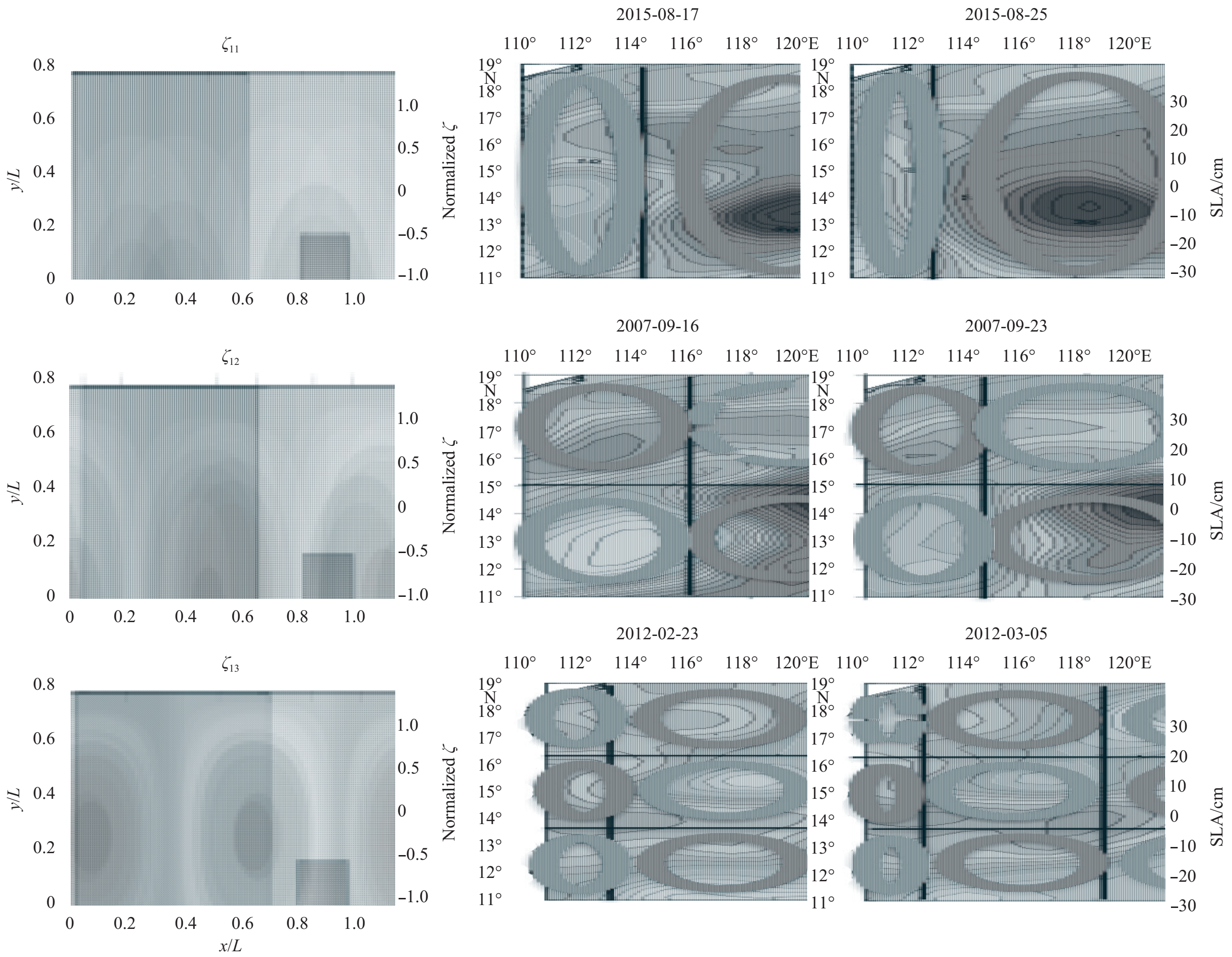

Fig. 1. Comparisons of Rossby normal modes ζ_{mn} for m=1, n=1, 2, 3 (left panels) to 2-D satellite altimetry SLA patterns in the SCS deep basin (right two panels). Numbers on the top of SLA image read year-month-day. Color bars are in arbitrary unit for theoretical modes and in cm for SLA images.

The results by Xie et al. [①] indicate that the Rossby normal modes are intrinsic features of the SCS deep basin, which are mainly controlled by the basin geometry and location (β-effect). In fact, complexity and variability of chessboard-like SLA patterns of the basin, consisting of alternatingly distributed anticyclonic and cyclonic eddies, can be explained by superposition of multiple Rossby normal modes with different tempo-spatial scales. Thus, the results by Xie et al. [①] provide a new point of view and new methodology to understand the eddy dynamics in the SCS.

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