Influence of coastal Kelvin waves and local wind on the genesis and characteristics of mesoscale eddies in the western Bay of Bengal

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November 22, 2022

Abstract

The western region of Bay of Bengal (BoB) is of high importance because of its variability in Western Boundary Current (WBC) pattern, numerous eddy genesis and biogeochemical activities. The WBC is northward in pre–Indian Summer Monsoon (ISM) season and southward in post–ISM season with the presence of anticyclonic and cyclonic gyres respectively. During ISM, the western BoB is dominated by various cyclonic and anticyclonic eddies with discontinuous WBC. The seasonally reversing wind pattern also favors the variation in the circulation pattern of the bay. The mechanism of eddy genesis in the western BoB and their characteristics specially during ISM, when the WBC is discontinuous, is not studied well. Our study uses the Regional Ocean Modeling System (ROMS) to investigate the role of coastal Kelvin wave, which originated from the equatorial wave guide, and local wind on the mesoscale eddies in the western BoB. To better understand the forcing mechanism involved, river influx and modified wind fields are incorporated in the experiments. The simulated Kelvin wave propagation is consistent with the satellite altimetry observations. Two upwelling and two downwelling Coastal Kelvin Wave (CKW) signals are identified. First upwelling signal (UCKW1) exists from January to April whereas the second signal (UCKW2) appears in September. Two downwelling signals are seen from May to August (DCKW1) and October to December (DCKW2), respectively. Depth of 20°C isotherm (D20) shows good correlation with the remote forcing signals as well as surface wind variability. The CKW signals during pre– and post–ISM (UCKW1 and DCKW2 respectively) are dominant. The reversing weaker signals (DCKW1 and UCKW2) contribute to the WBC discontinuity during ISM. Reduction in wind fields results in weak WBC during pre– and post–ISM. Increase in wind field results in strengthening of the weaker CKW modes rather than strengthening the WBC. Average surface eddy kinetic energy along with eddy intensity, radius and lifetime are sensitive to the change in wind field. The eddies are seen to propagate clockwise (anticlockwise) in general due to decrease (increase) in wind field. The study indicates that the CKWs and the local wind have significant impact on seasonally reversing WBC, eddy genesis and their characteristics in the western BoB.

Abstract Number: OS31D-1813 (Abstract ID: 390169)

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AGU 100 FALL MEETING Washington, D.C. | 10–14 Dec 2018

Abstract

- The western region of Bay of Bengal (BoB) is of high importance because of its variability in Western Boundary Current (WBC) pattern, numerous eddy genesis and biogeochemical activities.
- The East India Coastal Current (EICC), WBC in BOB, is northward in pre–Indian Summer Monsoon (ISM) and southward in post–ISM with the presence of anticyclonic and cyclonic gyres respectively. During ISM, the western BoB is dominated by various cyclonic and anticyclonic eddies with discontinuous flow.
- Regional Ocean Modeling System (ROMS) is used to investigate the role of Coastal Kelvin Wave (CKW), which originated from the equatorial wave guide, and local wind on the mesoscale eddies in the western BoB. To better understand the forcing mechanism involved, river influx and modified wind fields are incorporated in the experiments.
- Two upwelling and two downwelling CKW signals are identified. First upwelling signal (UCKW1) exists from January to April whereas the second signal (UCKW2) appears in September. Two downwelling signals are seen from May to August (DCKW1) and October to December (DCKW2), respectively.
- The CKW signals during pre and post–ISM (UCKW1 and DCKW2 respectively) are dominant. The reversing weaker signals (DCKW1 and UCKW2) contribute to the WBC discontinuity during ISM.
- Average surface eddy kinetic energy along with eddy intensity, radius and lifetime are sensitive to the change in wind field.

Background

- CKW propagation is significant in BOB (Rao et al., 2010).
- Seasonally reversing wind pattern contributes to the variations in upper ocean characteristics (Suryanarayana et al., 1992).
- EICC is discontinuous during ISM (Sil and Chakraborty, 2011). Positive wind stress curl helps the genesis of cyclonic eddies in the northern BOB (Dandapat and Chakraborty, 2016).

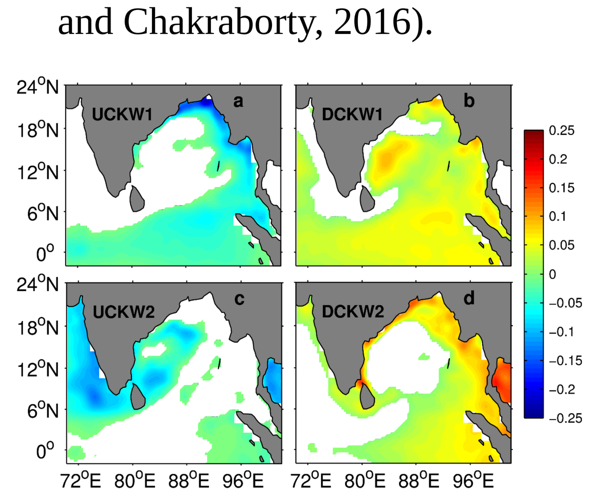

Figure 1. Two upwelling and two downwelling CKW signals from AVISO.

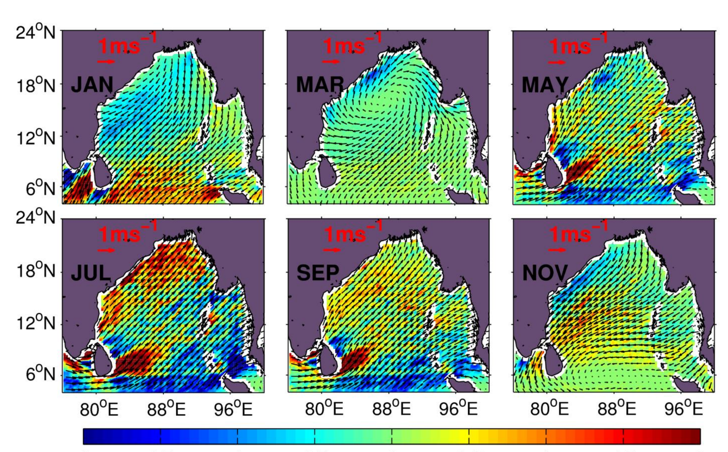

Figure 2. Bimonthly wind vectors (m/s) with wind stress curl (× 10^-6 N/m²) from QuikSCAT.

Objectives

- Role of coastal Kelvin wave, which originated from the equatorial wave guide, on the mesoscale eddies in the western BoB.
- Role of coastal Kelvin wave, which originated from the equatorial wave guide, on the mesoscale eddies in the western BoB.
- Variability of cyclonic and anticyclonic eddy characteristics during ISM associated with the EICC discontinuity.

Methods

- AVISO TOPEX Poseidon, ERS and Jason1 combined Sea Surface Height Anomaly (SSHA), Ocean Surface Current Analysis Real–time (OSCAR) surface current and high resolution (1/12°) Regional Ocean Modelling System (ROMS) simulations are analyzed in the study.
- Regional Ocean Modelling System (ROMS) is a general class of free surface, terrain-following numerical model, that solves the three dimensional Reynolds averaged Navier–Stokes equation using hydrostatic and Boussinesq approximations.
- The analysis is done mainly in seasonal scale with particular emphasis on ISM period since the EICC varies seasonally and the discontinuity occurs during ISM.
- Point source river discharge (Jana et al., 2015) for the rivers with high discharge (**Fig. 3**) are included in the simulation to better capture the CKW propagation. For local wind impact, the sensitive experiments are done with enhancing/suppressing (10%) wind field.

Model Simulations

- The simulation region is 4°S–24°N and 75°E–102°E. The lateral boundary condition is open in south, semi–open in east and west and close in north.
- For understanding KW impact, two ROMS experiments are carried out.

Experiment1 (Exp1): Control run for the region
Experiment2 (Exp2): Control run with river discharge

- For understanding local wind impact, two separate sensitivity experiments are carried out.

Experiment3 (Exp3): sensitivity experiment with river discharge and enhanced wind
Experiment4 (Exp4): sensitivity experiment with river discharge and suppressed wind

- River discharge of Ganges, Brahmaputra, Irrawaddy, Subarnarekha, Mahanadi, Godavari and Krishna are included.

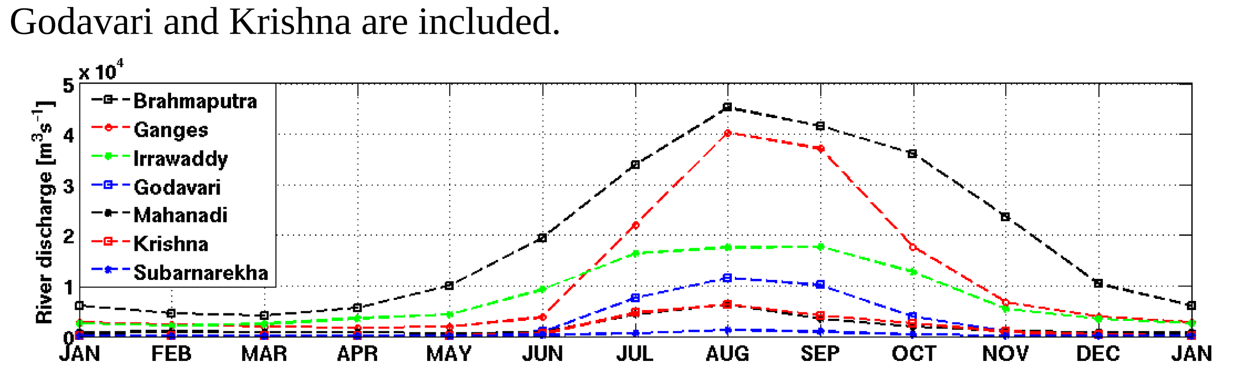

Figure 3. Monthly climatology of river run off from Dai and Trenberth, 2002.

Results

CKW propagation

- River discharge inclusion in Exp2 improves the simulation of CKW propagation and eddy activities along the western boundary of BOB compared to Exp1.

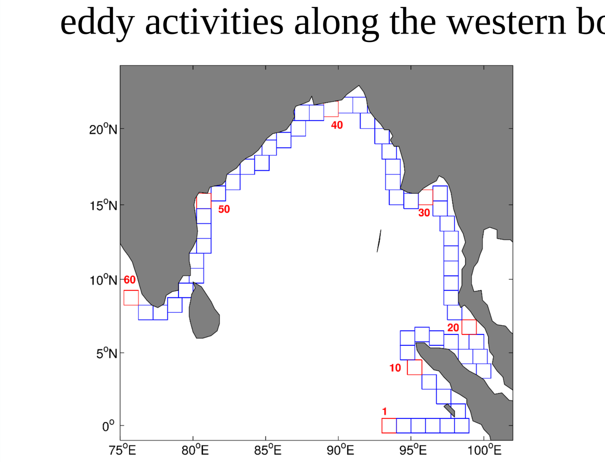

Figure 4. CKW propagation is evaluated along the boxes. Box 40 to 55 represents western boundary of BOB.

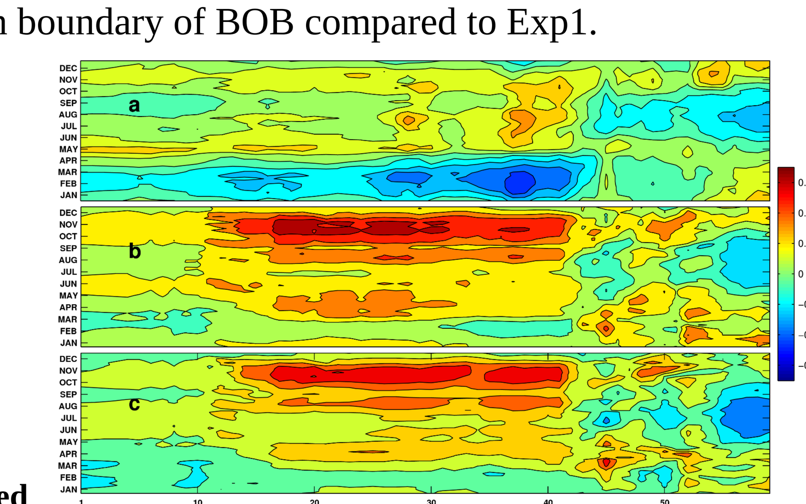

Figure 5. CKW propagation from a) AVISO, b) Exp1 and c) Exp2.

Results (contd.)

Surface Currents

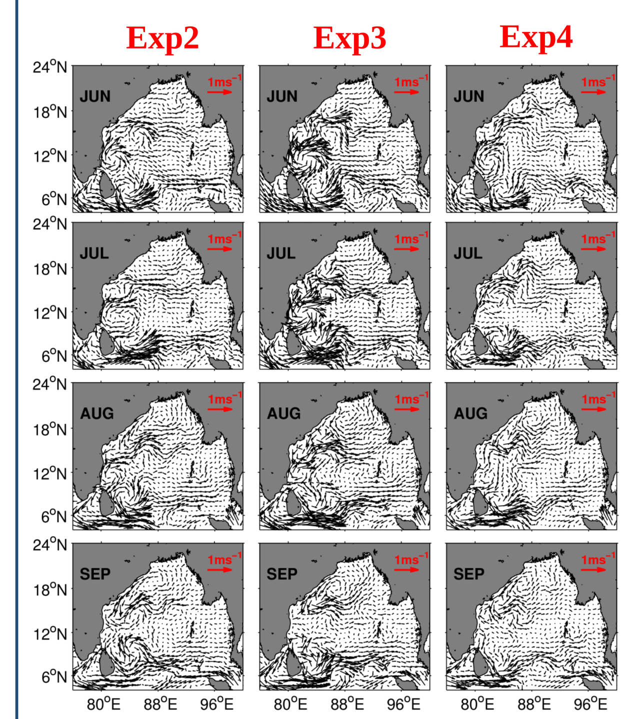

Figure 7. Monthly surface currents from simulations during ISM (June–September) period.

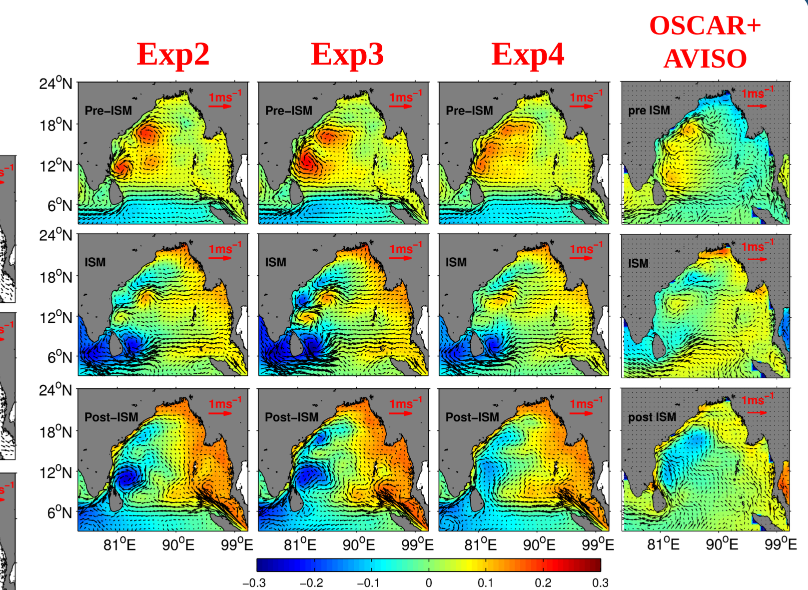

Figure 6. Seasonal surface current with SSHA from simulations and measurements (last column includes OSCAR current with AVISO SSHA).

Eddy detection and tracking

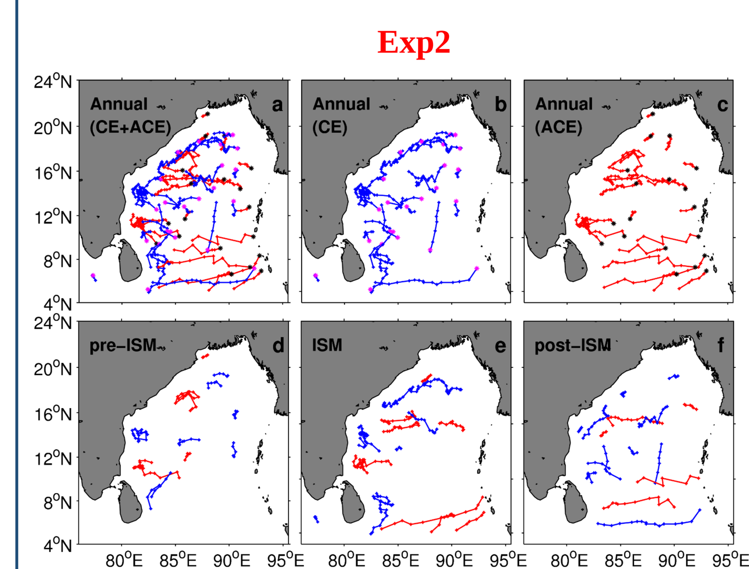

Figure 9. Mesoscale eddy tracking from Exp2. a) all eddies, b) Cyclonic Eddies (CEs), c) Anticyclonic Eddies (ACEs). Season wise eddies present during d) pre–ISM, e) ISM and f) post–ISM. Eddy genesis points are marked by black (ACE) and magenta (CE).

Subsurface Currents

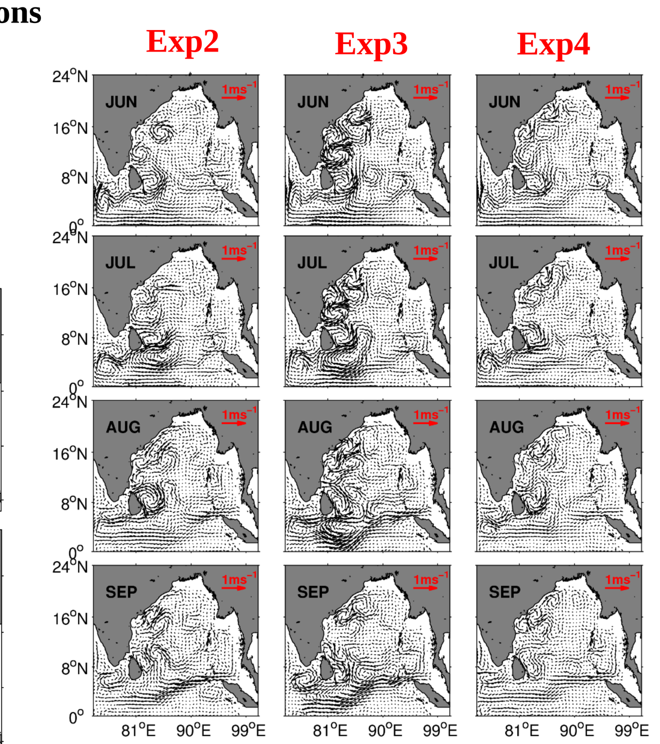

Figure 8. Monthly subsurface (100 m) currents from simulations during ISM (June–September) period.

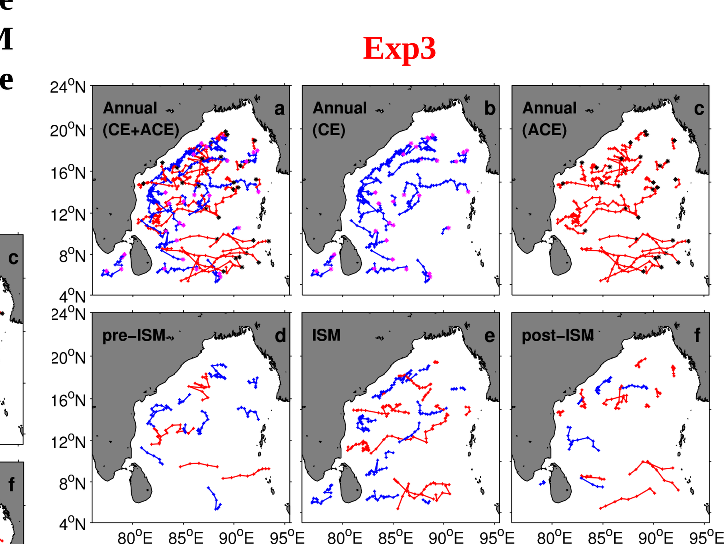

Figure 10. Same as fig. 9 but for Exp3.

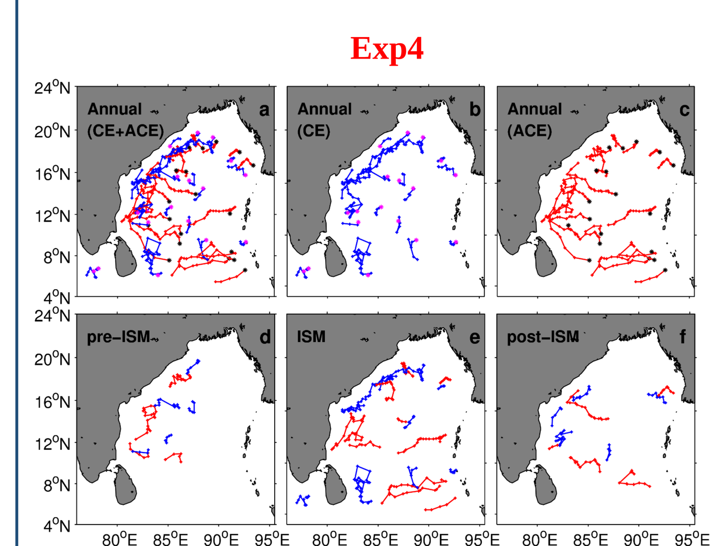

Figure 11. Same as fig. 9 but for Exp4.

Note: Eddy detection and tracking

- Here a combined method is used to detect the eddies when Okubo–Weiss (OW) parameter is negative and also embedded in closed SSH loop (Halo et al., 2013). Tracking follows the fact that an eddy detected in one frame is the same eddy in the subsequent frame if a generalized distance in a non-dimensional property space is minimum (Penven et al., 2005).

Results (contd.)

Table 1. Mean eddy properties (yearly and during ISM) from Exp2, Exp3 and Exp4.

Eddy parameters	Exp2				Exp3				Exp4			
	Annual		ISM		Annual		ISM		Annual		ISM	
	CE	ACE	CE	ACE	CE	ACE	CE	ACE	CE	ACE	CE	ACE
Number of eddies	24	19	8	9	31	31	16	13	18	19	10	10
area (× 10^{10} m²)	2.17	4.28	3.08	4.66	2.52	3.4	3.09	4.13	2.40	3.55	2.81	3.75
Radius (× 10^4 m)	7.97	11.1	9.45	11.9	8.48	9.86	9.44	10.88	8.40	10.10	9.12	10.33
energy (× 10^{-2} m²/s²)	7.35	6.94	10.33	7.58	9.74	8.2	9.05	9.41	4.97	5.50	5.84	7.67
vorticity (× 10^{-6} s^{-1})	11.09	-8.8	10.14	-8.04	12.9	-10.1	11.49	-9.1	9.35	-8.44	9.23	-8.57
amplitude (× 10^{-2} m)	8.03	10.1	10.45	11.22	9.75	8.72	10.82	11.13	7.38	8.97	8.82	9.86
U (× 10^{-2} m/s)	-3.34	-7.2	-2.2	-6.0	-3.8	-5.5	-3.46	-4.7	-1.70	-5.81	-2.70	-5.16
V (× 10^{-2} m/s)	-0.43	-1.09	0.82	-1.62	-0.59	-0.69	-1.32	-0.71	0.16	0.38	-1.43	-0.95
Westward Movement (%)	75	95	63	100	97	87	100	77	67	100	90	100
Northward Movement (%)	46	37	62	33	32	38	25	54	50	42	20	40

Conclusions

- Inclusion of river discharge reduced the SSHA bias and better simulate the CKW propagation with eddy activity along the western boundary of BOB.
- Enhanced wind field increases the intensification and genesis of both cyclonic and anticyclonic eddies particularly during ISM and along the boundary across depth.
- Suppressed wind field reduces the mesoscale eddies and leads the movement of weaker eddies towards southwest.
- Edited wind field increases the mean energy for ACEs during ISM which are more restricted along the boundary.

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Acknowledgement

- We acknowledge University Grants Commission (UGC), Government of India and Indian Institute of Technology Kharagpur for providing fund and facilities respectively for this research.