ABSTRACT

Mesoscale oceanic eddies are a fundamental component of the oceanic circulation system. They play a key role in the process of mixing oceanic tracers, including temperature, salinity, and nutrients. Mesoscale eddies are ubiquitous in the oceans and they have an essential role in facilitating the horizontal and vertical mixing. At any given time, approximately 20% of the global ocean surface is occupied by the eddies. Eddies with positive relative vorticity are referred to as cyclonic eddies (CE), whereas those with negative relative vorticity are known as anticyclonic eddies (AE). In the northern hemisphere, the AE rotates clockwise, while the CE rotates anticlockwise. Mesoscale eddies refer to eddies with a space-scale ranging from 10 to 100 km, whereas submesoscale eddies refer to eddies with a space-scale ranging from 1 km to 10 km. Features with a spatial scale of less than 1 km are referred to as microscale. Mesoscale eddies can have kinetic energy that is ten times higher than the parent current from which they originate. The formation, lifespan, and kinetic energy of these swirling currents are primarily influenced by the intensity of surface currents, the stratification of the ocean, and the bathymetry of the area.

The dynamics of the Bay of Bengal (BoB) is highly complicated. It goes through a semi-annual reversal of monsoon winds leading to significant change in surface circulation. During the winter season, a large clockwise circular formation known as an anticyclonic gyre develops throughout the whole BoB. During the summer, this pattern transforms into an anticlockwise circular pattern known as a cyclonic gyre. During the transition period from summer to winter or vice versa, two counter-rotating gyres forms. The BoB receives a huge amount of freshwater discharge from rivers in the northern part during the monsoon and postmonsoon periods. The dynamics of the BoB is mainly controlled by stratification and the formation of barrier layer (BL) during the monsoon and postmonsoon periods. The surplus freshwater it receives from the rivers is exchanged with the Indian Ocean

(IO) from the south of the BoB with the help of the Indian Monsoon Current (IMC) and the East India Coastal Current (EICC). The BoB dynamics is not only influenced by local forcings but also by forcings generated in the equatorial IO region, e.g., Kelvin Waves (KW) and Rossby Waves (RW). During an Indian Ocean Dipole (IOD) event, an equatorial IO phenomenon, the oscillation of sea surface temperature (SST) influences both the local forcings, e.g., wind and precipitation, and the remote forcings, e.g., KW, RW, and coastally trapped KW. Under the varying IOD conditions, the nature of the forcings also undergoes changes, which in turn impact the circulation and mesoscale activities in the BoB.

The study involves the climatological analysis of the mesoscale oceanic eddies of the BoB using a regional numerical ocean model (ROMS). Using a high-resolution ($\frac{1}{18^\circ} \times \frac{1}{18^\circ}$) Regional Ocean Modelling System (ROMS) output, the mesoscale eddies in the BoB were detected, and their variability was examined. The model results show good agreement with the available observations for different variables on the surface as well as for the subsurface. An investigation is conducted on the seasonal distribution of eddies, examining their geographical characteristics and propagation path. The formation of eddies in the western BoB is dictated by the variability in EICC. In the northern BoB (NBoB) the freshwater discharge from the rivers and bathymetry are important factors in the formation of eddies and their characteristics. Throughout the year, the radius of AEs is consistently larger than that of CEs, with its peak occurring in the pre-monsoon season. AEs exhibit a more pronounced association between their size and energy when compared to CEs. The contribution of mesoscale eddies to the total kinetic energy of the BoB's varies from 7.2% in March to 19.1% in November. The numerical experiments with positive and negative IOD phases of atmospheric forcing reveal the influence of anomalous circulation during IOD years on mesoscale eddies and their kinetic energy in the BoB relative to a normal year. A notable disparity in the eddies' characteristics was observed in both negative IOD (nIOD) and positive IOD (pIOD) years when compared to normal years. In pIOD or nIOD, the number of eddies was increased, but their average lifespan was reduced in the BoB. The increase in eddies was higher (38%) in nIOD than pIOD (11.2%) when compared to normal (non-IOD) years. The contribution of eddies to the total eddy kinetic energy (EKE) of the BoB increased from about 10% in normal years to about 25% in either of the IOD phases. The most significant impact of the IOD is observed at the thermocline depth. During the IOD years, the Andaman Sea (AdS) region experienced the most significant variations at thermocline depth over eddies' zones.

Oceans acts as the repository for the atmosphere, and the atmospheric motions drives the ocean.To study the effects of oceanic mesoscale eddies on the atmosphere, a fully coupled atmosphere-ocean model (COAWST) was used. The atmospheric columns lying over the AEs and CEs was analyzed for their thermodynamical properties. Model results reveal that the lower atmosphere is highly influenced by the relative vorticity of the oceanic mesoscale eddies. Different variables, such as relative humidity, moist static energy (MSE), water vapor mixing ratio, and equivalent potential temperature in the lower atmosphere, show a significant difference for the air column over AEs and CEs. There is a significant correlation between the relative vorticity of oceanic mesoscale eddies and the atmospheric column over them.

The presence of AEs or CEs modulates ocean heat content over their effective depth in the ocean. This thermal energy significantly contributes to the tropical cyclone heat potential (TCHP) of the ocean, which is crucial for the intensity and longevity of a cyclone whenever it traverses over the AEs or CEs. Presence of AEs in the path of a cyclone can rapidly intensify it and can change its category from severe to very severe in a short time, the vice-versa occurs in case of CEs. To study the role of mesoscale eddies in influencing the intensity and longevity of tropical cyclone, numerical experiments with the coupled model COAWST were performed for the case of FANI cyclone which formed in the BoB on 26 April 2019 and remained active till 5 May 2019. It was a unique tropical cyclone that remained continuously intensified for a long duration in the shallow depth and made landfall in the extremely severe cyclonic storm (ESCS) category. The mean duration for cyclones in the BoB is normally 22 hours but FANI remained in the ESCS category for about 60 hours. The presence of very high tropical cyclone heat potential due to the presence of warm core eddies facilitated high latent heat flux consistently at the air-sea interface resulting in availability of high MSE leading to prolonged intensified stage of FANI cyclone.