ABSTRACT

The Andaman Sea in the Indian Ocean is known for the presence of large-amplitude Internal waves (IWs). Internal tides (ITs) are IWs of tidal frequency whose temporal variability is unknown in this region. Therefore, we used *in-situ* observations collected at (10.5°N, 94°E) from March 2017 to February 2018. The analysis shows that the kinetic energy of semidiurnal ITs is dominant to that of diurnal ITs by a factor of 4–5. The ellipticity of both semidiurnal and diurnal motions is dominated by rectilinear zonal flow, indicating generation at the slopes of the Andaman and Nicobar islands. Maximum isopycnal displacement reached 46 m for semidiurnal ITs. The semidiurnal ITs displayed significant seasonal variability — stronger in summer and autumn but weaker in spring and winter, whereas the diurnal ITs are relatively stronger in summer and winter. Furthermore, salinity plays a dominant role in controlling the near-surface stratification, whereas the temperature variations control the subsurface stratification. This led to the formation of a strong double pycnocline during autumn and winter. Baroclinic coherent semidiurnal (diurnal) variance accounts for 49% (27%) of the semidiurnal (diurnal) motions.

Furthermore, we explored the interannual variations of the internal wave activity in this complex region. We found that the Dipole Mode Index, which represents the Indian Ocean Dipole, influences the circulation in the Andaman Sea, which in turn impacts its density stratification on interannual scales. Ocean Reanalysis System 5 data (1993–2018) is used to see an increasing trend in the sub-surface stratification, whereas

it showed a decreasing trend in the near-surface waters.

We used a global climate model (CanESM5) to investigate the long-term variability of internal waves in the Andaman Sea under a range of shared socioeconomic pathway (SSP) scenarios. SSPs are future societal development pathways related to emissions and land use scenarios. We project that mean values of depth-averaged stratification will increase by approximately 6% (SSP1-2.6), 7% (SSP2-4.5), and 12% (SSP5-8.5) between 1871-1900 and 2081-2100.

Model simulations carried out for March, June, September, and December of 2017 using the Massachusetts Institute of Technology General Circulation Model showed significant seasonal variability in the generation and dissipation of IT. The isopycnal displacement near the generation sites is about 88 m. The experiments suggest that the presence of the Andaman Nicobar Ridge contributes nearly 89% to the total IT generation. Numerical model simulations carried out from 2009 to 2018 have shown that the interannual variability in the generation of semidiurnal internal tides is governed by distinct parameters (tidal forcing and stratification) at different sites in different months. Enhanced upwelling (downwelling) is observed during positive (negative) IOD events. Sensitivity experiments conducted between extreme IOD events (2006 and 2016) revealed an increase in internal tide generation from positive IOD to negative IOD. Furthermore, a sharp decrease in local baroclinic dissipation is seen during negative IOD, increasing baroclinic flux into the Andaman Sea. An increase in the strength of positive IOD could lead to enhanced diapycnal mixing due to strong local dissipation, whereas an increase in the intensity of negative IOD could result in amplified propagation of internal waves. Simulating changes in internal tides between the present (2005-2014) and the end-century (2091-2100), we find that the increase in stratification will enhance

internal tide generation by approximately 4 to 8%. We project that the propagation of internal tides into the Andaman Sea and the Bay of Bengal will increase by 8 to 18% and 4 to 19%, respectively, under different SSP scenarios. Such changes in internal tides under global warming will have implications for primary production and ecosystem health not only in the Andaman Sea but also in the Bay of Bengal.

The changes in the physical properties of the ocean on a diurnal scale primarily occur in the surface mixed layer and the pycnocline. Price–Weller–Pinkel model, which modifies the surface mixed layer, and the internal wave model based on Garrett–Munk spectra that calculates the vertical displacements due to internal waves are coupled to simulate the diurnal variability in temperature and salinity, and thereby density profiles. The coupled model is used to simulate the hourly variations in density at RAMA buoy (15° N, 90° E), in the central Bay of Bengal, and at BD12 (10.5° N, 94° E), in the Andaman Sea. The simulations are validated with the *in-situ* observations from December 2013 to November 2014. The primary advantage of this model is that it could simulate spatial variability as well. An integrated model is also tested and validated by using the output of the 3D model to initialize the coupled model during January, April, July, and October. The 3D model can be used to initialize the coupled model at any given location within the model domain to simulate the diurnal variability of density. The simulations showed promising results which could be further used in simulating the acoustic fields and propagation losses which are crucial for Navy operations.

KEYWORDS: Internal Waves; Internal Tides; Andaman Sea; Internal tide energetics; Indian Ocean Dipole; Climate change; Corals.