ABSTRACT

Indian Ocean (IO) circulation and its biological processes are largely different from those in the other oceans. The two distinct features of the IO have a significant impact on its biological processes. The first is the northern land boundary, which stretches southward to at least 26°N, with the Indian subcontinent dividing the north Indian Ocean (NIO) into two basins namely, the Arabian Sea (AS) in the west and the Bay of Bengal (BoB) in the east. The second unique feature is the seasonal reversal of surface winds north of 10°S in the IO. The winds are southwesterly during summer monsoon season (June-September) which is accompanied with substantial precipitation across the northern half of the basin and Indian sub-continent. The winter monsoon season (December-February) experiences northeasterly surface winds. In response to the change in wind direction, the surface currents over the NIO also undergo a seasonal reversal in the northern part of the IO. The biological productivity of ocean is primarily governed by the availability of nutrients in the near-surface sun-lit layers. Ocean upwelling process brings the subsurface cold and often nutrient rich water to the surface and, therefore, enhances biological productivity. The physical foundation that leads to significant biogeochemical variability throughout the basin is provided by the yearly evolution of oceanic current patterns and upwelling distributions that form in response to wind forcing.

In recent decades, the IO has been found to have a significant influence on regional and global climate variability. As a result, improving our knowledge of the biophysical (i.e. physical and biological) processes in the IO through observational and modelling studies has become essential for both science and society. In the present thesis, a coupled physical-biogeochemical model comprising of the Regional Ocean Modelling System (ROMS) and Bio-Fennel (the biogeochemical (BGC) model component) is used to study the biophysical variability of the NIO at various temporal scales. The coupled physical-biogeochemical model is configured with

a $1/4° \times 1/4°$ horizontal grid resolution, 40 vertical sigma levels, and an eddy-permitting resolution over the IO region covering from 30°E to 120°E and 30°S to 30°N. In order to calculate the surface heat and momentum fluxes as surface forcing fields, the daily mean values of meteorological parameters are acquired from the NCEP and QuikSCAT/ASCAT data.

In chapter 2, sixteen models from the 'Coupled Climate Model Intercomparison Project phase 5' (CMIP5) are assessed for their capability in simulating the Chlorophyll-a (Chl-a) concentration against satellite observations and regional coupled physical-biogeochemical model (ROMS + Bio-Fennel) over the NIO. The sixteen CMIP5 models are categorized into three groups based on their relative skill. Group-A models overestimated the phytoplankton bloom over prominent productive regions, whereas the Group-B and Group-C models mostly failed to reproduce the bloom in the NIO. However, the regional coupled model captured the phase of the bloom intensity in all seasons as noticed in observations. The observed annual variations were poorly simulated by all the CMIP5 models. Group-A models showed a negative bias in Chl-a concentration over the northern AS (NAS) and a positive bias in Chl-a simulation off Somalia over the western IO (WIO). High Chl-a associated with the coastal upwelling along the west coasts of India and off Sri Lanka was poorly simulated by CMIP5 models. In contrast, the regional coupled model has a low positive Chl-a bias. The study highlights the regional deficiency in CMIP5 climate models in simulating Chl-a and the need for improved coupled physical-biogeochemical models over the NIO.

In chapter 3, the coupled model interannual simulations were performed for the period of 2000-2017. The model simulations are validated with respect to *in-situ* observations and satellite data over the BoB. The BoB is known to have high primary productivity at its northwestern margin close to the coast with an offshore extent of $\sim 400\ km$ during the Indian summer monsoon season. This coastal productivity is mainly caused due to the near-surface nutrient availability maintained by the local coastal upwelling process. The surface winds in the IO significantly vary during El-Niño/La-Niña and Indian Ocean dipole (IOD). The sea surface temperature (SST) and Chl-a anomalies in the western BoB are analyzed for the period of 18 years (2000 to 2017) using the coupled model and observations. All considered positive IOD (pIOD) years show distinct behavior of biophysical features in the western BoB during the study period. The co-occurrence years of pIOD and El-Niño modes are associated with contrasting biophysical anomalies. In the analyzed pIOD events, years 2006 and 2012 show an enhancement in the Chl-a anomalies whereas, the other two years (2015 and 2017) experience Chl-a decrement. The western BoB was anomalously warmer during 2015 and 2017 pIOD years compared to the other two pIOD years (2006, 2012). This inconsistent response of biophysical features associated with pIOD years is investigated in terms of local surface flux (momentum, heat, and freshwater) changes over the western BoB. The combined impact of local surface flux changes during the individual years remains the major contributing factor affecting the upper-ocean stratification. Ultimately, the stratification changes are responsible for the observed inconsistent response of biophysical features by significantly altering the upper-ocean mixing, upwelling, and nutrient availability in the western BoB.

In chapter 4, the coupled model interannual simulations were performed for 19 years (2000 to 2018) over the AS. The model simulations are validated with respect to satellite and *in-situ* (Bio-Argo, gridded Argo) observations over the AS domain including the NAS. The NAS is a highly productive basin in the IO. The marked seasonal variation of surface winds has the major control on the oceanic primary productivity in the NAS. The coupled physical-biogeochemical model used to examine the control of marine physical processes on the primary productivity in the NAS. It is found that the pure positive IOD (PPIOD) events had positive anomalies, whereas a co-occurrence of El-Niño and positive IOD (CEPIOD) events lead to negative anomalies in winter-time Chl-a concentration. The CEPIOD events are characterized by weaker winter convective mixing than in PPIOD events. The evolution of this discrepancy in the convective mixing process is sufficiently explained by the presence of weaker northeasterly (dry and cold) winds and a lower amount of net heat flux loss during CEPIOD as compared to the PPIOD events. During PPIOD, higher convective mixing resulted in intense surface cooling, a deeper mixed layer depth (MLD), increased nutrients supply towards surface, and a stronger winter bloom. Whereas, weak convective mixing cause warming and a shallow MLD leading to weak winter bloom in CEPIOD. The interannual variability in the NAS region, including Chl-a concentration, is more strongly related to El-Niño forcing than to pIOD.

In chapter 5, an attempt is made to provide a better understanding of the tropical cyclones' (TCs) interactions with the surface as well as subsurface oceanic physical and biological features along the tracks of TCs. The coupled physical-biogeochemical model simulations are performed to analyze the before-, during-, and after-cyclone conditions of both, the physical and biological features in the NIO. The different surface and subsurface physical and biological features along the track of TCs depicted a cyclone-generated surface phytoplankton bloom and associated decline of dissolved oxygen (DO). It is found that the intense cyclonic wind stress caused upwelling in the wake of cyclone track. The excess surface freshwater flux due to precipitation establishes stronger stratification in the coastal region. This enhanced stratification restricts the supply of nutrients to the euphotic zone and, hence, limits the surface primary productivity. The passage of two TCs sequentially makes the upper-ocean water column cooler (SST drops by 3°-6°C) and higher primary productivity (Chl-a up to 6 $mg.m^{-3}$) compared to the passage of single TC. The primary productivity on the surface persists more than two weeks after the passage of sequential TCs, due to TC generated upwelling and mixing, which is favorable for shoaling of nutrients and higher consumption of DO.

In chapter 6, the impact of pandemic-driven lockdown on ocean biophysical parameters is investigated using coupled model and observations. The unprecedented nationwide lockdown due to the 'coronavirus disease 2019' (COVID-19) affected humans and the environment in different ways. It provided an opportunity to examine the effect of reduced transportation and other anthropogenic activities on the environment. The impact of lockdown on Chl-a concentration, an index of primary productivity, over the NIO is investigated using the observations and a physical-biogeochemical model. A comparison of the observed and model-simulated data during the lockdown period (March–June, 2020) and pre-pandemic period (March–June, 2019) shows significant differences in the physical (temperature and salinity) and biological (Chl-a, nutrient, and dissolved oxygen concentration) parameters over the western AS, western BoB, and regions off Sri Lanka. During the pandemic, the reduced anthropogenic activities led to a decrease in Chl-a concentration in the coastal regions of western BoB. The enhanced aerosol/dust transport due to stronger westerly winds enhanced phytoplankton biomass in the WAS in May–June of the pandemic period.