CHAPTER 8
SUMMARY AND OUTLOOK

The Arabian Sea is one of the dustiest places on the globe. Dust aerosols over the Arabian Sea have been known to have numerous effects on the climate of the region by modifying the radiative balance, hydrological cycle and the large-scale monsoon circulations. Also, it has been seen in other parts of the globe that dust can potentially fertilize the ocean by supplying nutrients. However, there remain huge gaps in understanding the dust cycle and its variability and how dust-derived nutrients can impact the phytoplankton biomass so far as the Arabian Sea is concerned. To this end, the present thesis investigates the temporal variability of the dust cycle over the Arabian Sea at seasonal scale and what factors control this variability, the influence of the climate modes in controlling the interannual variability of dust and the effect of dust depositions on the phytoplankton biomass of the region.

To achieve this, first, seasonal cycle of dust emission, transport and deposition in the Arabian Sea and its surroundings has been studied using a regional climate model RegCM4. The model has been run for total of ten years from 2001 to 2010 to study the horizontal as well as the vertical distribution of dust and along with the atmospheric circulations responsible giving maximum stress on the southwest monsoon period. Next, the influence of El Nino-Southern Oscillations and the Indian Ocean Dipole on the levels of dust activity has been investigated with the help of 26 years of Aerosol Index data from satellite remote sensing and meteorological fields derived from reanalysis products. The study tries to unravel how these climate modes might remotely control the moisture flux and hence the dust activity in the dust source regions.
Finally, the possible role of dust in supporting the phytoplankton biomass of the Arabian Sea by supplying different nutrients has been explored by tracking the satellite-derived chlorophyll concentrations following episodic dust storms during the northeast monsoon. The demand versus supply (oceanic + atmospheric) of different nutrients have been calculated for each of the observed cases of chlorophyll enhancements to decide if a phytoplankton bloom can be attributed to dust depositions or not.

The major outcome of the thesis is that at seasonal scale the southwest monsoon circulation system is the main controller of the dust cycle accounting for 47% of dust emissions in the regions surrounding the Arabian Sea and 79% of dust depositions into the Arabian Sea. During the southwest monsoon, the intertropical convergence zone divides the south and southwest Asian landmass into two regimes: (1) to the east and the south of the convergence zone dust emission and its subsequent transport is accomplished by the southwest monsoon wind system. However, the energetic Findlater Jet blocks the transit of the dust over the open Arabian Sea, thereby; confining dust-laden air mostly to the west, (2) to the west and the north of the convergence zone dust mobilization and its transport is accomplished by the northwesterly and northerly wind system associated with the surrounding high pressure regions. Being confined within the lower few kilometres (~3 km) of the atmosphere, the southwest monsoon system is overridden by dusty airmass coming from southwest Asia and the Middle East. However, near the top of the Troposphere (above 11 km), the easterly return flow of the southwest monsoon system recirculates dust towards the west. At this level, Asian dust can be transported to long distances and thereby influence the climate of large part of the globe.

At interannual scale, it is shown that El Nino-Southern Oscillations can significantly influence the dust activity in the Arabian Sea and its surroundings. It is seen that La Nina conditions favour
dust production by remotely suppressing the amount of winter precipitation in the principal dust source regions surrounding the Arabian Sea. The opposite is true for El Nino conditions. This is achieved by modulation of the intensity of convection over the Indo-Pacific warm pool region. This can strengthen or weaken the intensity of subsidence over the dust source regions which, in turn, can impact the precipitation over the region. El Nino-Southern Oscillations further modifies the conditions favouring dust transport during the following summer by affecting the geopotential height over south and southwest Asia. El Nino-Southern Oscillations accounts for 36% of the interannual variability of dust activity over the Arabian Sea. Indian Ocean Dipole acts to oppose the effect of the El Nino-Southern Oscillations in the Arabian Sea.

Finally, the thesis also illustrates the fact that dust can influence the phytoplankton biomass of the central Arabian Sea during the northeast monsoon by supplying micronutrient iron. In the central Arabian Sea the intensity of the winter convection is much less and the ferricline is deeper than the nitracline. It is probable that any deepening of the mixed layer can supply enough nitrate and phosphate, but not enough iron. This might lead to a situation of iron limitation. Following episodic dust depositions, if enough iron is supplied, then phytoplankton can proliferate. During the northeast monsoon period, years with high levels of dust contribute to 47% of the total chlorophyll concentrations in the Arabian Sea. Such conclusions cannot be arrived at for other seasons.

The thesis has tried to shed light into the factors that control the dust load over the Arabian Sea at different temporal scales. Over the last few decades, there are compelling evidences of shifts in the climate over the north Indian Ocean. By analyzing the dust variability at different temporal scales, the present study implies that any changes in the ocean-atmosphere conditions over the north Indian Ocean has huge potential to effect the dust cycle. This has serious implications
because of the feedback that dust has on the climate of the region. For example, a climate-induced change in the dust load will have effect on the radiative forcing at different levels of the atmosphere. This in turn influences the atmospheric circulations and the monsoons. Therefore, it is critical to understand the behaviour of the dust cycle under a global warming scenario. An analysis of paleo-dust data might provide some clues to this end. Furthermore, the thesis also shows how dust can influence the phytoplankton biomass over a region. This aspect of the thesis has particular relevance to the carbon cycle. An important way to take the work forward is by linking the surface productivity with the carbon flux at depths. It is crucial to understand if any signature of the change in the size of the dust cycle translates into deep ocean carbon flux. One way to approach this problem is to couple a carbon cycle model with an atmospheric model and explore the carbon flux by doubling or halving the dust depositions. Another route is though in situ experiments that will try to quantify carbon flux at some depths in the ocean following artificial fertilization by dust.