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Complex interplay of physical forcing and *Prochlorococcus* population in ocean

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ABSTRACT

Physical forcing can replenish nutrients within the mixed layer by convective mixing or via upwelling. Conventional wisdom holds this enrichment fuels phytoplankton growth, for example ventilation of subsurface water during winter monsoon is known to enhance primary productivity in the northern Arabian Sea. One important numerically dominant phytoplankton known to have ecological niche in the ocean is *Prochlorococcus*. In the Arabian Sea, they occur in oligotrophic surface water and below the oxycline representing two different light and biogeochemical regimes. Here we show convective mixing in the northern Arabian Sea inhibits *Prochlorococcus* growth owing to change in physical environment. Pigment observations carried out during early and peak winter monsoon revealed contrasting picoplankton distribution. Divinyl chlorophyll *a* (a marker for *Prochlorococcus*) which was the most abundant picoplankton pigment during early winter monsoon was not detected with the onset of winter convection covarying with high nutrients in the surface water. We propose two possible mechanisms for such sudden disappearance which involves changes in light and biogeochemical regimes. This physico-chemical control could be critical for their existence but not limited to and can play an important role in regions experiencing such phenomenon. We also highlight the linkages between *Prochlorococcus* succession and basin scale dynamics from the Arabian Sea which hitherto remains poorly understood.

1. Introduction

Seasonal variation in the atmospheric forcings in the Arabian Sea causes remarkable changes in physical environment such as upwelling during south west monsoon and convective mixing during winter (Banse, 1968; Banse and McClain, 1986; Shetye et al., 1994; Madhupratap et al., 1996; Brock et al., 1993). December–February, the northern Arabian Sea is cooled due to reduced incoming solar radiation as well as enhanced evaporation under the influence of the dry northeast trade winds from continental origin (Banse, 1968; Shetye et al., 1994) causes density of upper ocean to increase, initiating convective mixing (Banse and McClain, 1986; Madhupratap et al., 1996) and ventilates the upper part of the permanent pycnocline. This convective mixing and ventilation of the subsurface water together with irradiance exerts ecological pressure on different phytoplankton enforcing changes in food web dynamics. *Prochlorococcus* is one such autotrophic picoplankton having an ecological niche in the ocean (Bouman et al., 2006; Johnson et al., 2006). Members of the genus are small (0.6–0.8 μM) in diameter and biochemically different than other cyanobacteria (Chisholm et al., 1992). They do not contain chlorophyll *a*, but has divinyl chlorophyll *a* and divinyl chlorophyll *b* and can be identified by pigment analysis (Goericke et al., 2000; Wright and Jeffrey, 2006).

Prochlorococcus in the Arabian Sea has been found in oligotrophic surface water and below the oxycline representing two different biogeochemical environments (Goericke et al., 2000; Latasa and Bidigare, 1998). The low-light *Prochlorococcus* (LL) adapted strains have high divinyl chlorophyll *b*/divinyl chlorophyll *a* ratio and high-light (HL) adapted strains have lower divinyl chlorophyll *b*/divinyl chlorophyll *a* ratio (Chisholm et al., 1992; Partensky et al., 1999) making it easy to distinguish by HPLC pigment analysis. Spatio-temporal distribution of *Prochlorococcus* was modestly investigated during US Joint Global Ocean Flux Studies (JGOFS) however was largely confined to central and western Arabian Sea. The regions influenced by intense convective mixing received little attention. Decade old studies from the Arabian Sea suggest presence of *Prochlorococcus* HL and LL types. However, elaborate molecular analysis of these populations is yet to be carried out. Single-cell genomics have recently revealed many coexisting subpopulations in the wild *Prochlorococcus*

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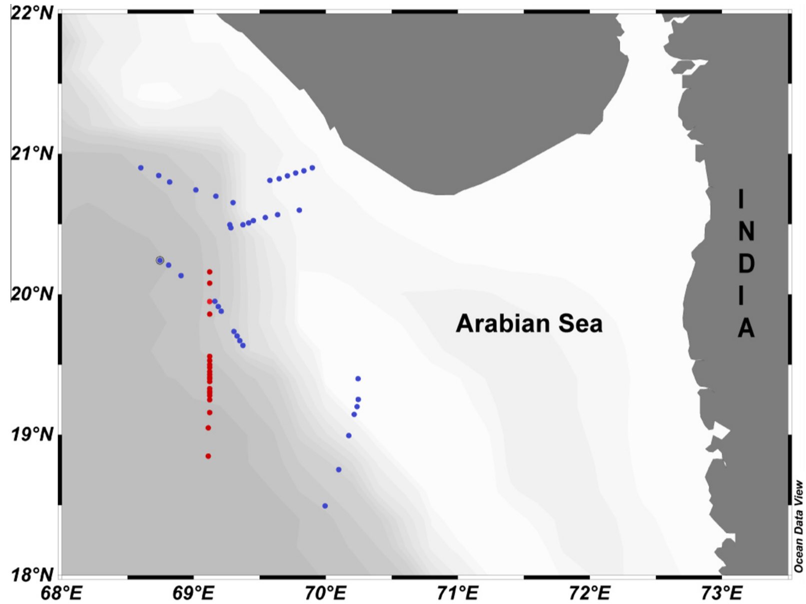

Fig. 1. Location map of the study site in the north eastern Arabian Sea. Red circles represent stations sampled during SSK-41 and blue circles represent SSK-60. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

(Kashtan et al., 2014) and existence of few other ecotypes (Jing and Liu, 2012).

Ecological succession driven by physical processes is little understood in the ocean and we believe this could be of key importance in the context of future evolution of Arabian Sea microbial ecology in response to global change. In this paper we evaluate the roles of convective mixing and surface circulation on *Prochlorococcus* abundance from the northern Arabian Sea based on published data and this investigation. Two hypotheses are postulated, involving changes in irradiance and biogeochemical

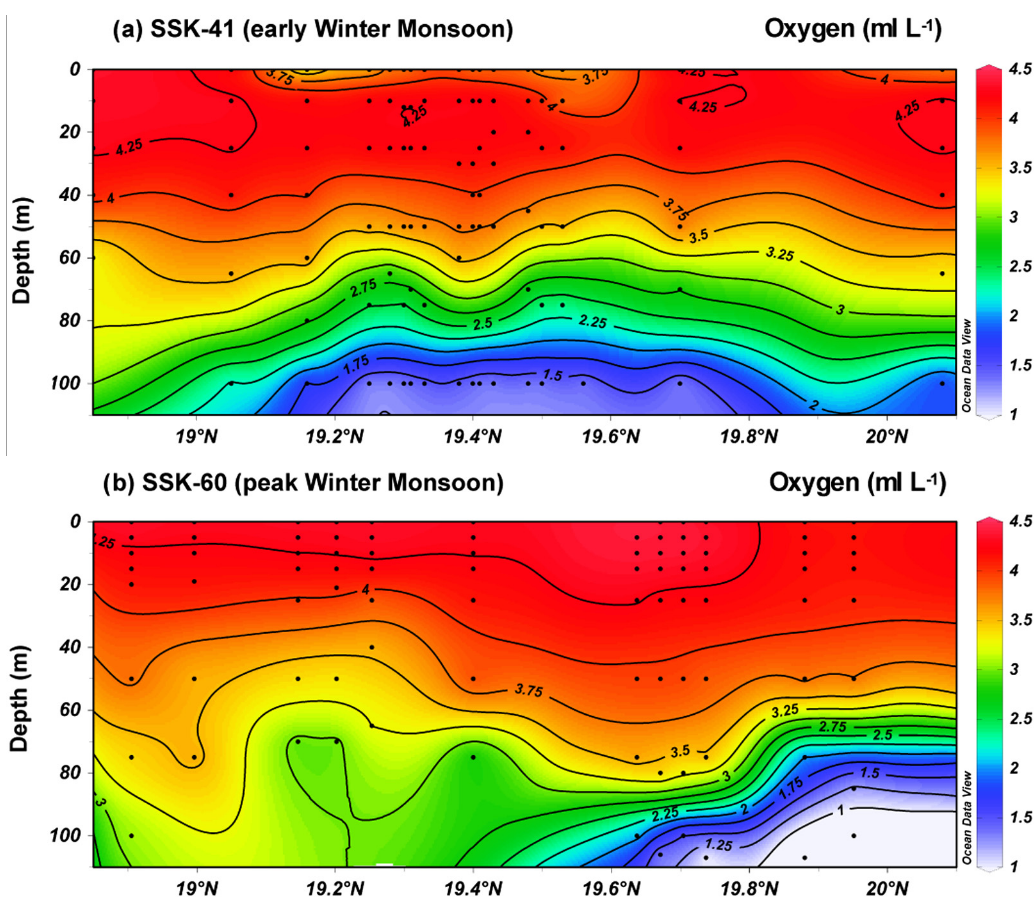

Fig. 2. Latitudinal distribution of oxygen concentrations within the top 110 m in ml L^{-1} observed during early (SSK-41) and peak (SSK-60) winter monsoon in the north eastern Arabian Sea.