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Phytoplankton communities and acclimation in a cyclonic eddy in the southwest Indian Ocean

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ABSTRACT

A study of phytoplankton in a cyclonic eddy was undertaken in the Mozambique Basin between Madagascar and southern Africa during austral winter. CHEMTAX analysis of pigment data indicated that the community comprised mainly haptophytes and diatoms, with *Prochlorococcus*, prasinophytes and pelagophytes also being prominent to the east and west of the eddy. There was little difference in community structure, chlorophyll-specific absorption [$a^*_{ph}(440)$] and pigment:TChla ratios between the surface and the sub-surface chlorophyll maximum (SCM), reflecting acclimation to fluctuating light conditions in a well mixed upper layer. Values for $a^*_{ph}(440)$ were low for diatom dominance, high where prokaryote proportion was high, and intermediate for flagellate dominated communities. Chlorophyll *c* and fucoxanthin:TChla ratios were elevated over most of the eddy, while 19′-hexanoyloxyfucoxanthin ratios increased in the eastern and western sectors. In a community comprising mainly flagellates and *Prochlorococcus* to the west of the eddy, there was high $a^*_{ph}(440)$ at the surface and elevated ratios for divinyl chlorophyll *a*, chlorophyll *b* and 19′-hexanoyloxyfucoxanthin at the SCM. An increase in diadinoxanthin:TChla ratios and a decline in the quantum efficiency of photochemistry in PSII under high light conditions, indicated some photoprotection and photoinhibition at the surface even in a well mixed environment. Diadinoxanthin was the main photoprotective carotenoid within the eddy, while zeaxanthin was the dominant photoprotective pigment outside the eddy. The results of this study will be useful inputs into appropriate remote sensing models for estimating primary production and the size class distribution of phytoplankton in eddies in the southwest Indian Ocean.

1. Introduction

Early research in the southwest Indian Ocean indicated that there is a southern extension of the South East Madagascar Current (SEMC) across the northern part of the Mozambique Basin (MB) (Duncan, 1970; Wyrtki, 1971). Deep sea eddies also occur in the MB (Grundlingh, 1985) and both cyclonic and anticyclonic eddies can originate in the Mozambique Channel (Schouten et al., 2002) and move in a southerly or westerly direction (Grundlingh et al., 1991). De Ruijter et al. (2005) also noted an abundance of eddies to the south and southwest of Madagascar, with the cyclones and anticyclones propagating towards southern Africa. These eddies can appear as dipole pairs (De Ruijter et al., 2004; Ridderinkhof et al., 2013) and the cyclonic eddies are usually formed as lee eddies on the inshore edge of the SEMC (De Ruijter et al., 2004).

To the north, more recent investigations in the Mozambique Channel showed that anticyclonic eddies are very prominent and cyclonic eddies are usually present in a dipole pair (Ternon et al., 2014). Independent cyclonic eddies can occur and it appears that southward drifting anticyclonic eddies occur mainly on the western side of the Channel, while the distribution of cyclonic eddies is more ubiquitous, with a slight tendency toward greater occurrence to the east closer to Madagascar (Halo et al., 2014; Hanke et al., 2014). Phytoplankton studies revealed that chlorophyll *a* concentrations were low in surface waters, with sub-surface levels being significantly greater (Lamont et al., 2014). Pigment indices indicated that prokaryotes were the most significant phytoplankton group at the surface, with small flagellates being of secondary importance, while flagellates dominated at the DCM, except for some diatom domination close to the coast (Barlow et al., 2014). These prokaryote dominated communities displayed a large range in the proportion of chlorophyll *a* within the total pigment pool and a high proportion of photoprotective carote-

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noids, while diatoms had relatively high proportions of chlorophyll *a,* photosynthetic carotenoids and chlorophyll c. Flagellate dominated communities had a lower proportion of chlorophyll *a*, increased levels of photosynthetic carotenoids and intermediate proportion of chlorophyll *c* (Barlow et al., 2014). Similar adaptations have been observed in a shelf sea where picoeukaryote-*Synechococcus* communities in the surface mixed layer had more photoprotective carotenoids, while flagellates and diatoms > 5 µm at the deep chlorophyll maximum contained a high proportion of photosynthetic carotenoids (Hickman et al., 2009).

Variability in the photosynthetic performance of phytoplankton depends on changes in both the taxonomic composition of communities and prevailing environmental conditions. The functional absorption cross-section of photosystem II (σ_{PSII}) can vary as a result of spatial taxonomic differences, whereas electron transport rates usually decrease with depth from the surface to the subsurface chlorophyll maximum in stratified waters (Moore et al., 2006). In contrast, communities within a mixed water column that is characterised by low mean irradiance actually acclimate to relatively high irradiance (Moore et al., 2006). Electron transport rates are closely linked to the diurnal cycle of light availability, however, with peak rates occurring at about solar noon in surface communities (Schuback et al., 2016). In populations where microphytoplankton usually dominate, it was noted that σ_{PSII} and the maximum photochemical efficiency generally increased with depth, while electron transport rates were greater near the surface under elevated irradiance but decreased progressively as irradiance decreased deeper in the water column (Zhu et al., 2016), complementing the observations of Moore et al. (2006).

No detailed studies of phytoplankton have been undertaken in eddies in the MB, and particularly not in cyclonic eddies that are generated near Madagascar. An opportunity arose to undertake an investigation in such an eddy during an austral winter research cruise between South Africa and Madagascar (Fig. 1). The objective of the study was to use pigment, absorption and active fluorescence data to understand some aspects of the acclimation of phytoplankton communities to environmental conditions in the eddy. The following scientific questions were posed: (1) What is the community structure within and outside the eddy? (2) Are there significant differences in the absorption and pigment characteristics between the surface and the sub-surface chlorophyll maximum? (3) How variable is photosynthetic activity across the eddy?

2. Methods

2.1. Hydrography and sampling

Hydrographic measurements were conducted at 25 stations spaced at 18.52 km intervals on a transect through the eddy during 17–23 July 2013 (Figs. 1 and 2) with water column profiling of temperature, salinity, photosynthetically available radiation (PAR) and fluorescence during CTD deployments. Fluorescence data was converted to chlorophyll equivalents by scaling to the chlorophyll *a* concentrations measured by HPLC. Conservative temperature (°C) and absolute salinity (S_A (g kg^{-1})) were calculated from in situ temperature and salinity profiles, according to the new thermodynamic equation of seawater (IOC et al., 2010). Nutrient samples were taken at selected depths and stored frozen at −80 °C for later analysis ashore using standard autoanalyser techniques (Mostert, 1983). Seawater samples were collected at the surface and at a sub-surface chlorophyll maximum (SCM) only for pigment, absorption and active fluorescence analysis. CTD fluorescence profiles did not display a distinct deep chlorophyll maximum at most of the stations but only a broad vertical band of sub-surface chlorophyll. A depth at approximately the middle of this broad band was therefore selected for samples to represent phytoplankton deeper in the water column. Active fluorescence measurements were conducted on board, while pigment and absorption samples were stored frozen at −80 °C for

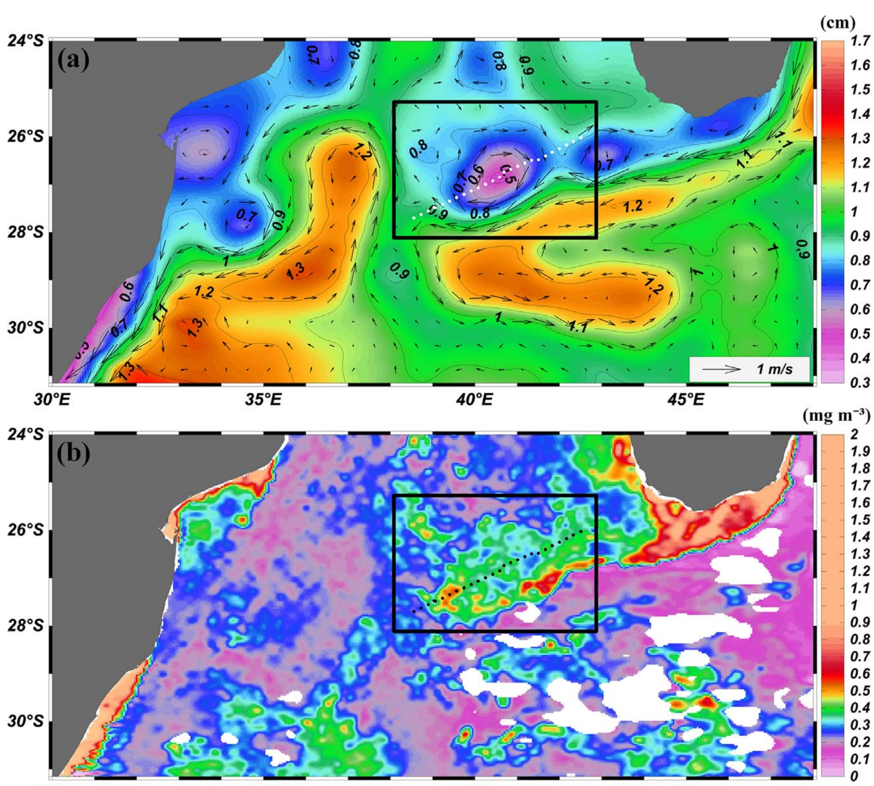

Fig. 1. (a) Sea Surface Height (colour contours) and geostrophic velocity (black arrows) on 17 July 2013, and (b) MODIS Aqua chlorophyll *a* concentration for 12–19 July 2013 over the Mozambique Basin. Black boxes highlight the location of the eddy and white and black dots indicate positions of the sampling stations. White areas indicate missing data due to cloud cover.