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Impact of monsoon-driven circulation on phytoplankton assemblages near fringing reefs along the east coast of Hainan Island, China

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ABSTRACT

Monsoonal hydrodynamic prevails over the east coast of Hainan Island induced by southwest monsoon (SWM) and northeast monsoon (NEM) which drives coastal Ekman divergence/convergence cycle and the reversal of Guangdong coastal current (GCC) between the sGCC in the SWM season and nGCC in the NEM season. We report the control of such hydrodynamics on biological properties such as phytoplankton assemblages in the east coast of Hainan Island. Physico-chemical and biological observations were carried out in two oceanographic cruises along the east coast of Hainan Island during SWM period (July–August) of 2008 and NEM period (March–April) of 2009. Results indicated that phytoplankton assemblages in coastal regions (fringing reefs and coastal shelf) changed dramatically accompanied with the reverse of monsoonal hydrodynamic processes, with chain-forming diatoms (mainly, *Pseudo-nitzschia* spp. and *Thalassionema nitzschioides*) dominating during SWM cruise when coastal Ekman divergence and the sGCC were prevailed, but the pelagic *Noctiluca scintillans* and *Trichodesmium erythraeum* dominating during NEM cruise when coastal Ekman convergence and the nGCC were prevailed. Furthermore, phytoplankton assemblages in fringing reefs along coastline were somewhat different from ones of coastal shelf, as fringing reefs are just located at dynamic boundary of offshore (or onshore) Ekman transport processes. Offshore diffusion of pelagic cells (such as *T. erythraeum*) driven by offshore Ekman transport process led to the lower abundance of *T. erythraeum* in fringing reefs than ones in coastal shelf during SWM cruise; on the contrary, onshore aggregation of pelagic cells (such as *N. scintillans* and *T. erythraeum*) driven by onshore Ekman transport process leads to higher abundances of *N. scintillans* and *T. erythraeum* in fringing reefs than ones in coastal shelf during NEM cruise; especially, *N. scintillans* formed bloom in fringing reefs. Last, we suggested that hydrodynamic processes must be taken into account in scientific management of fringing coral reefs health of the east coast of Hainan Island, especially during northeast monsoon season when blooming specie cells (such as *N. scintillans*) could be introduced from eutrophic South China mainland coast to the east coast of Hainan Island and piled to high-abundance at fringing reefs by monsoonal hydrodynamics.

1. Introduction

Hydrodynamic process is an important factor to be considered in marine phytoplankton ecology research. On one side, the vertical-dimension hydrodynamic processes affect local phytoplankton assemblages by building habitat. Vertical turbulence facilitates nutrients availability from bottom water and is beneficial to diatom reproduction, but vertical stratification conversely impedes ventilation and is fit for reproduction of the shear-sensitive dinoflagellates (Smayda, 2002). On the other side, the horizontal-dimension hydrodynamic processes lead to the exchange of pelagic phytoplankton population between local and distant regions during watermass transport (Keafer et al., 2005; Dela-Cruz et al., 2003). Furthermore, hydrodynamic conditions in monsoon-controlled sea regions of the world are strongly and periodically perturbed by annual cycles of prevailing wind direction, consequently, phytoplankton assemblages usually present the distinct and predictable oscillations (Tan et al., 2006; Wiggert et al., 2002; Shalapyonok et al., 2001).

The South China Sea (SCS) is under the persistent influence of the East Asian Monsoon, with the strong NEM (northeast monsoon, winds speed ~9 m s^{-1}) prevailing during October–April, and the weak SWM (southwest monsoon, winds speed ~6 m s^{-1}) prevailing during May–September (Tseng et al., 2005). South China mainland and eastern Hainan Island coast were located at northern boundary of the SCS, the coastlines both of which oriented

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NE–SW so as to be just parallel to the prevailing wind directions. Consequently, annual transition of prevailing wind directions significantly induces monsoonal hydrodynamic phenomena: the reverse of flow direction of Guangdong Coastal Current (GCC) (i.e. nGCC during the NEM and sGCC during SWM) (Fig. 1A), as well as the coastal Ekman divergence/convergence cycle (Hu et al., 2000; Yang et al., 2002).

To our knowledge, research about relationship between monsoon-driven circulation and phytoplankton assemblages at the northern boundary of the SCS is mainly concentrated at South China mainland coast. Some important conclusions are that south-westerly movement of the nGCC during NEM season may guide the progression of red tides cases from northeast to southwest along South China mainland coast (Yin et al., 1999). Monsoon-driven coastal Ekman divergence/convergence cycle along South China mainland coast powerfully controls the recurrence of coastal red tides phenomena (Ning et al., 2008; Wang et al., 2008), especially in Hong Kong near Pearl River Estuary (Yin, 2003; Yin et al., 2001; Yin, 2002; Lee and Qu, 2001).

However, systematic research of monsoonal hydrodynamics regulating phytoplankton assemblages is still a fundamental requirement along the east coast of Hainan Island. Considering the wide distribution of fringing reefs, it is important for the coral reefs health management to carry out systematic research for phytoplankton assemblages at the east coast of Hainan Island. This study presents the results of phytoplankton observations in the east coast of Hainan Island during SWM season, 2008 and NEM season, 2009. The results of this study have led to a better understanding of how the monsoonal-driven circulation affects the construction of phytoplankton assemblages near fringing reefs along the east coast of Hainan Island.

2. Materials and methods

2.1. Study area, sampling stations and cruises

East coast of Hainan Island faces the broad continental shelf of the north SCS, with fringing reefs well developed along its coastline. Two lagoons systems, Bamen lagoon and Boao lagoon, collect small-scale insular runoffs into the SCS from Wenchang river (i.e. Wenchanghe, with discharge 9.09 $m^3 s^{-1}$), Wenjiao river (i.e. Wenjiaohe, with discharge 11.6 $m^3 s^{-1}$) and Wanquan river (i.e. Wanquanhe, with discharge 166 $m^3 s^{-1}$). Two multidisciplinary investigations were repeatedly conducted at the east Hainan Island coast, in boreal summer from 25 July to 13 August, 2008 when SWM prevailed (hereafter referred to SWM cruise), and in early spring from 27 March to 14 April, 2009 when NEM prevailed (hereafter referred to NEM cruise). Study area covered Bamen lagoon and Boao lagoon, fringing coral reefs, coastal shelf and offshore shelf at east Hainan Island coast. Sampling stations in lagoons went along the salinity gradients, sampling stations in fringing coral reefs covered the typical fringing reefs platforms or reefs edges, and sampling stations in shelf are composed of 25 gridding stations with the maximum water depth of 90 m (Fig. 1B-C). The SWM cruise was carried out smoothly; however, the NEM cruise was interrupted at the beginning of the cruise by the severe sea condition (rainy and high wind).

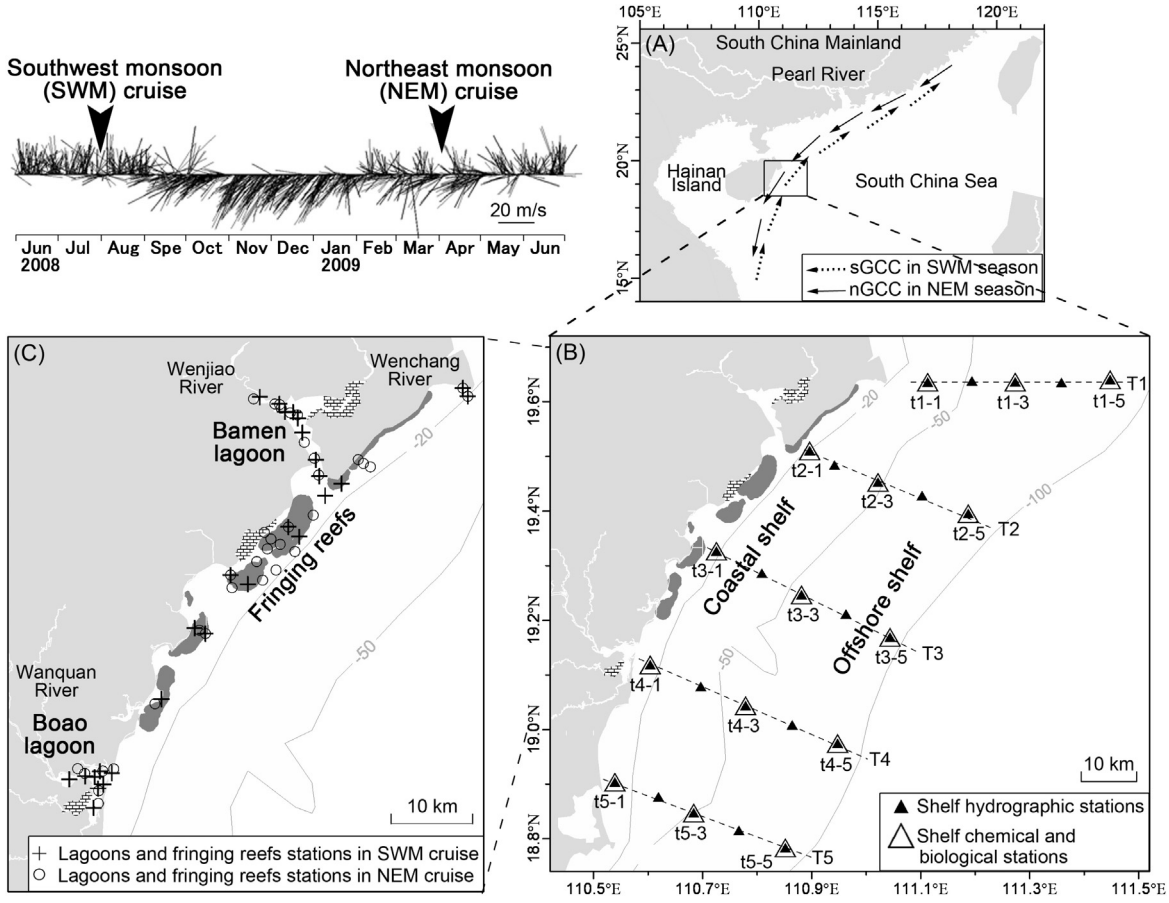

Fig. 1. (A) The seasonally reversed Guangdong Coastal Current (GCC) between the sGCC in the SWM season and nGCC in the NEM season along the north shelf of the South China Sea (SCS) (after Hu et al., 2000). (B) Locations of sampling stations in shelf. (C) Locations of sampling stations in lagoons and fringing reefs. The year-round vector plots of the six-hourly wind velocities at eastern Hainan Island coast from June 2008 to June 2009 were detected by using the six-hourly wind vector data of NASA's Quick Scatterometer (QuikSCAT) which is available online at http://podaac.jpl.nasa.gov/quikscat.