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Basin-wide distribution of phytoplankton lipids in the South China Sea during intermonsoon seasons: Influence by nutrient and physical dynamics

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ABSTRACT

Four algal biomarkers, brassicasterol, C_{30}-diol/keto-ol, dinosterol and C_{37}-alkenone, representing diatoms, estigmatophytes, dinoflagellates and coccolithophorids, respectively, were detected in samples collected during two South China Sea cruises to study the modern phytoplankton community structure in the region. For the first time, the basin-wide distribution of these phytoplankton algal biomarkers in the sea surface water during two intermonsoon seasons (spring 2010 and autumn 2011) is documented and charted. Generally, the abundance of the biomass is higher in spring than autumn, with high productivity mostly in the regions of Pearl River estuary, off Palawan and around the Luzon Strait, showing the abundance order: diatoms > estigmatophytes > dinoflagellates > coccolithophorids. We run both redundancy analysis (RDA) and SPSS correlation analysis to interpret the relationship between individual groups and environmental variables. The results indicate that temperature and salinity play a dominant role in controlling the distribution of phytoplankton in these intermonsoon seasons, followed by nitrate playing a secondary role. Our biomarker survey provides important reference data for interpreting paleo-productivity in the geological records in the SCS.

1. Introduction

The carbon cycle plays an important role in the global climate system. In particular, the ocean contains billions of phytoplankton, which altogether account for nearly half of Earth's photosynthesis budget; consequently are of most significance in modulating the atmospheric CO_2, which affects the global climate mean state (Falkowski et al., 1998). Therefore, efforts to probe the modern and paleo-oceanic phytoplankton productivity and community structure are essential to better understand the global carbon cycle and its role in the climate dynamics.

For modern phytoplankton productivity investigation, many methods have been used, such as directly counting cells under microscopy, flow cytometry (Nicoletti et al., 1991), specific pigment (Yentsch and Menzel, 1963) and phytoplankton lipids biomarkers determination (Volkman, 1986). Compared with other indices, modern oceanic observations of the distribution of phytoplankton lipids, however, remain relative scarce, which may hamper proper interpretation of the paleo-phytoplankton lipids records (Li et al., 2014). Owing to their refractory nature, lipids biomarkers can be preserved in sediments after being coagulated and assembled in the suspended or sinking particles. This preservation provides some unique ways to probe the paleo-productivity variation in the ocean on different time scales (Schubert et al., 1998; Menzel et al., 2003; Calvo et al., 2004; Dahl et al., 2004; Seki et al., 2004; Zhao et al., 2006; Xing et al., 2008; He et al., 2013). Lipid biomarkers represent a small fraction of organic matter in the organisms, i.e. only several tens of femtogram per cell of alkyl diols in some strains of the class eustigmatophytes (Volkman et al., 1992), but their diversity, specificity and relative recalcitrance make them unique and useful in studying the sources, transportation and fate of their original organisms. The abundance of each specific biomarker in the organism may differ among species and may even vary according to different growing environments or growth stages for the same species (Volkman, 1986; Mansour et al., 2003). Although converting the abundance of lipids to the correct amount of primary production in the photic zone is difficult, lipids can be used to characterize the relevant biomass.

Currently, four kinds of lipids (brassicasterol, dinosterol, long-chain unsaturated alkenones with 37 carbons (C_{37}-alkenone) and diol/keto-ol) are frequently used in the paleoceanographic studies due to their well-known sources, high abundance, and widespread

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distribution (Volkman et al., 1998). Specifically, brassicasterol (24-methyl cholest-5, 22-dien-3b-ol) is a compound mainly related to diatoms or "diatomsterol"; C_{37}-alkenone are mainly synthesized by calcareous coccolithophorids such as *Emiliania huxleyi* and *Gephyrocapsa oceanica*, and other noncalcareous haptophyte algaes (Marlowe et al., 1984); Dinosterol (4a, 23, 24-trimethyl-5a-cholest-22E-en-3b-ol) is primarily produced by dinoflagellates (Boon et al., 1979; Volkman et al., 1998), while the *n*-alkyl diols are mainly produced by eustigmatophytes (Volkman et al., 1992, 1999; Gelin et al., 1997; Méjanelle et al., 2003). It is noteworthy that some of these biomarkers may not confined exclusively to the above listed sources but also likely come from some other algal classes, e.g. brassicasterol can also be synthesized by microalgae such as haptophytes and cryptophytes (Volkman, 1986). Studies over the last several decades, however, indicate that, although the multi-source nature in certain lipids may complicate the data interpretation, these biomarkers still provide the basic biomass information in representing their main phytoplankton groups as mentioned above (e.g. He et al., 2013).

The South China Sea (SCS) is one of the largest marginal seas in the West Pacific (Wang and Li, 2009). Topographically, the SCS is surrounded by South China and Indochina Peninsula in the northern and western parts, and a chain of islands in its southern and western parts (Wang and Li, 2009). Several large rivers, such as the Pearl River, Red River and Mekong River, discharge numerous nutrients into the SCS every year and fuel algal blooms in the estuaries. Compared with the estuaries and coastal areas, the central SCS basin is characterized by low algal productivity with chlorophyll-*a* generally less than 0.1 mg m^3 due to the low nutrients, while the chlorophyll concentration inside the SCS is still about twice that in the western Philippine Sea (Liu et al., 2002). Apart from riverine discharge, seasonal reversed eastern Asian monsoons also play a crucial role in the high primary productivity, especially off northwestern Luzon in the northeastern SCS and on the northern Sunda Shelf in the southern SCS affected by the prevalent northeast winter monsoon from November to February, and off southeastern Vietnam in the western SCS during the prevalent southwest summer monsoon from July to August (Tang et al., 1999; Liu et al., 2002). Cyclones, typhoons and eddies also influence the surface productivity by enhancing the short-term primary productivity in the oligotrophic SCS (Lin et al., 2003, 2010; Zhao et al., 2008, 2009; Chen and Tang, 2012).

Over the past decades, productivity studies in the SCS are mostly based on the remote sensing of ocean color changes from satellite images supplemented with limited shipboard survey. Although remote sensing may capture the continuous biomass changes, it can only provide the information related to the overall productivity variability but not the phytoplankton community structure or their relative abundance. The primary focus in most early investigations was on the response of phytoplankton to the monsoon-induced hydrological changes (Liu et al., 2002; Xie et al., 2003; Tang et al., 2004). Productivity is high during the monsoon prevailing season due to the monsoon induced nutrient pumping that fuels phytoplankton growth, with winter being the most productive because of the much stronger northeast monsoon (Liu et al., 2002, 2013; Chen, 2005; Tan and Shi, 2009; Palacz et al., 2011). Knowledge of the SCS phytoplankton lipids is scare, and mostly characterizes their variability during summer season in the northern SCS (Li et al., 2014). Comparatively, phytoplankton lipids in intermonsoon seasons may not be closely tied to nutrient variations during monsoon seasons: their production and export may have significant effects on the lipids, which accumulate in subsequent monsoon seasons.

Thus, this study is aimed to investigate the temporal and spatial variations of phytoplankton lipids in surface water samples from the basin-wide SCS during the intermonsoon seasons (spring of 2010 and autumn of 2011), and to explore the relationship between the biomarkers and source organisms and environmental parameters.

2. Materials and methods

2.1. Collection of suspended particulates

The sea surface suspended particles in over 500 L water from 5 to 10 m water depths were collected onboard using a filtration system that contained three parallel precombusted (at 450 °C) glass fiber filters (GF/F, 0.7 μm, 142 mm diameter, Whatman). Totally, particles at 132 stations were taken during two cruises in

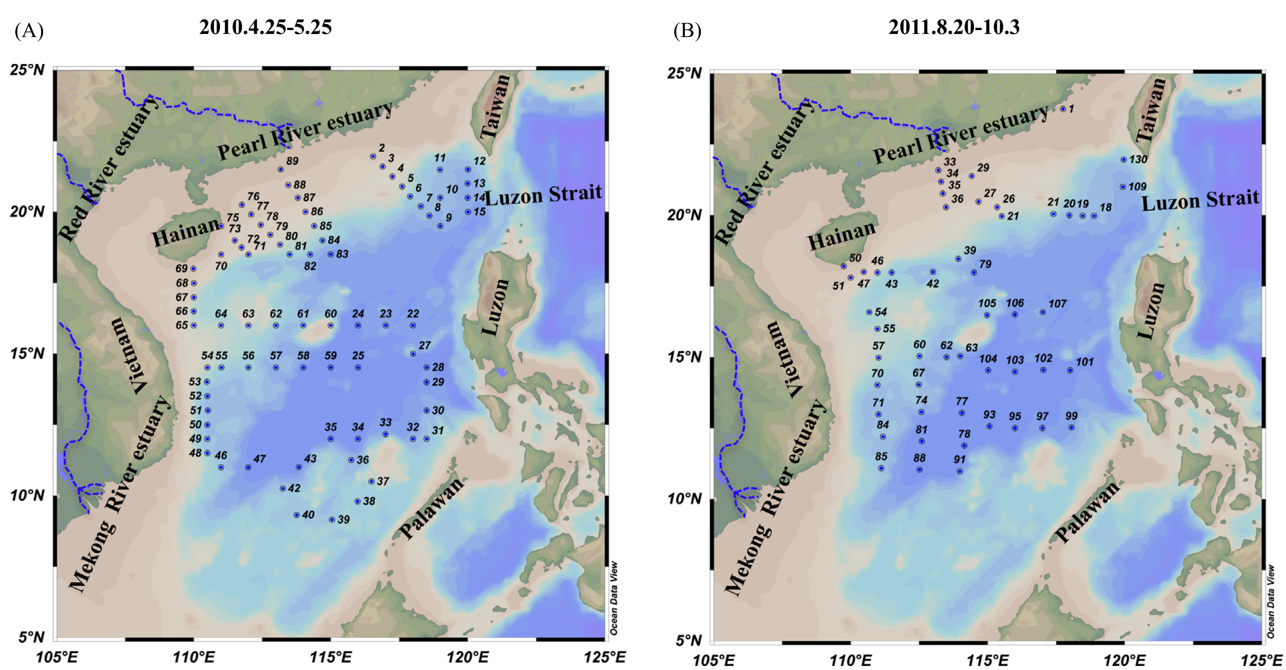

Fig. 1. Sampling stations in the SCS during (A) spring 2010, and (B) autumn 2011.