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Eddy-entrained Pearl River plume into the oligotrophic basin of the South China Sea

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ABSTRACT

The South China Sea (SCS) is the world's largest tropical marginal sea with an oligotrophic basin. In June 2015, a rare large phytoplankton bloom, which is ~500 km long, 100 km wide and lasting more than 19 days, was captured in the northern SCS basin by satellite daily chlorophyll images. Water within the bloom area had a feature of low salinity and high temperature measured by an accidental-passing cruise. Meanwhile, satellite sea level anomaly images and drifter trajectory proved there was a cyclonic eddy nearby. No typhoon and heavy rain happened in this period, so we believed the bloom was triggered by the injection of nutrient-rich Pearl River plume driven by eddy. This is the first report on eddy-entrained Pearl River plume into the SCS, which would raise a new view on irregular transportation of nutrient and carbon and its related biogeochemical influence on the oligotrophic ocean.

1. Introduction

The South China Sea (SCS) is the world's largest tropical marginal sea with an average depth of over 2000 m (Xiu et al., 2010; Zhai et al., 2013). The Pearl River, the thirteenth largest river in the world in terms of discharge (Huang et al., 2003), flows into the shelf of the northern SCS (Fig. 1a) and delivers about 3.5×10^{11} m^3 of fresh water and 85×10^6 t of sediment per year (Zhang et al., 1999), with 80% of total discharge occurring in the wet season (April-September) (Zhao, 1990). With an average discharge of 16,000 m^3/s in the wet season, the nutrients in the Pearl River plume (PRP) contribute about 70% of the total annual nutrient load and 80% of the total annual biomass in the shelf waters (Gan et al., 2010). Thus, extension of the PRP can have profound impacts on the biogeochemical processes in the northern SCS, Taiwan Strait and East China Sea (Bai et al., 2015). The general pathways of the PRP are well defined and mainly controlled by the East Asia monsoon (Dong et al., 2004; Bai et al., 2015). In summers with a high discharge, previous studies have shown that the PRP advects eastward along the coast, inputting into the Taiwan Strait and further transporting to the East China Sea (Fig. 1a) (Hong et al., 2009, 2011; Gan et al., 2009; Shu et al., 2011; Bai et al., 2015).

The basin-scale circulations in the SCS are mainly driven by the East Asian monsoon with anti-cyclonic circulation in summer and cyclonic circulation in winter (Morimoto et al., 2000; Gan and Qu, 2008). In contrast to the nutrient-rich northern shelf of the SCS, a typical river-dominant marginal sea (RioMar), the wide basin of the SCS is an oligotrophic ocean-dominated marginal sea (OceMar) (Dai et al., 2013). Thus, the interaction between the shelf and the basin is a key process controlling the biogeochemical variation in the north SCS. In addition, mesoscale eddies are highly active in the SCS, with an annual mean number of around 32 and cyclonic eddies occurring slightly more frequently than anti-cyclonic eddies (Wang et al., 2003; Hu and Chiang, 2007; Xiu et al., 2010). Generally, it is regarded that the PRP cannot cross the shelf, and has negligible impacts on the oligotrophic SCS basin (Hu et al., 2000) due to the obstruction by the northeastward Guangdong Coastal Current on the shelf (Fig. 1a). Furthermore, in the northern SCS basin, the influences from terrestrial input and coastal upwelling are considered negligible because nutrients are usually depleted after a long distance (Chen et al., 2001; Liu et al., 2002; Xie et al., 2003; Tang et al., 2004; Wong et al., 2007). As a result, surface layer waters in the basin are oligotrophic with low chlorophyll concentrations of around 0.05–0.08 μg/l in summertime (Lin et al., 2010), except for the occasional passing of cold eddies or typhoons, which trigger high phytoplankton biomass (Lin et al.,

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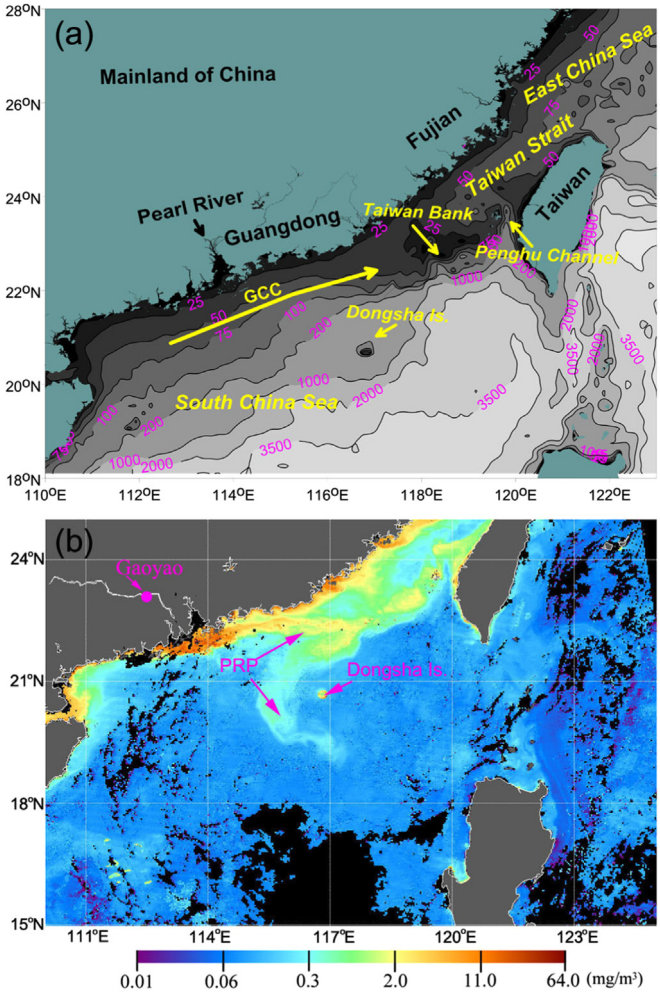

Fig. 1. (a) Location and bathymetry (isobaths in meters) of the study site, with GCC representing the Guangdong Coastal Current. (b) Daily satellite Chla image on 17 June 2015 with the black areas covered by clouds.

2003, 2010; Chen et al., 2012).

However, from 15 June to 3 July 2015, with no typhoon passing through the northern SCS, a special semicircle belt-shaped phytoplankton bloom occurred in the oligotrophic SCS basin through the western side of Dongsha Island (Fig. 1b). This bloom belt was approximately 500 km long and 100 km wide, southward approaching to 19°N, and lasted for about three weeks, as inferred from the time-series satellite-derived chlorophyll concentration (Chla) images (Fig. 2). Thus, it was of great interest to explore the nutrient source supporting such a large spatiotemporal scale bloom in the oligotrophic SCS basin. We speculated it may be intrusion of the PRP, which has never been observed before.

In this study, we used independent observations by satellite remote sensing (ocean color, temperature and altimetry) and *in situ* measurements by cruise and drifter to diagnose the episodic nutrient supplement into the SCS basin and the mechanism behind it.

2. Data and methods

2.1. Satellite data

The orbital level-2 ocean color data (embedding Chla) from the Moderate Resolution Imaging Spectroradiometer (MODIS) with orbits passing the SCS were obtained from the NASA ocean color website (http://oceancolor.gsfc.nasa.gov) from 1 June to 3 July 2015. The level-2 data maintained the original spatial resolution of about 1 km at the nadir of the orbit. Both the MODIS data onboard the Aqua and Terra satellites were acquired to obtain more valid data coverage. All orbits of the MODIS level-2 ocean color data within the same day were merged to get the daily composite Chla images. In addition, the 8-day composited sea surface temperature (SST) retrieved by Aqua/MODIS at nighttime were also obtained from the NASA ocean color website with a spatial resolution about 4 km.

We obtained the weekly composited sea level anomalies and daily geostrophic currents corresponding to the same period as the ocean color data from AVISO (www.avisio.altimetry.fr) with a spatial resolution of 0.25°. In addition, the weekly composite rain rate data retrieved by the Special Sensor Microwave Imager (SSMI) were also obtained from Remote Sensing Systems (www.remss.com) with a spatial resolution of 0.25°.

2.2. In situ data

A cruise onboard the "Nan Feng" fishery research vessel was carried out in the region southwest of Dongsha Island from 13 to 25 June 2015. The cruise had 16 sampling stations, and the profiles of water salinity, temperature and chlorophyll fluorescence at each