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Signals of typhoon induced hydrologic alteration in particulate organic matter from largest tropical river system of Hainan Island, South China Sea

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SUMMARY

Tropical river systems affected by climatic extremes (typhoon) are recognized as significant source of particulate organic matter (POM) delivered to their adjacent seas. Studies on POM composition in typhoon affected rivers of tropical Hainan Island are limited. The Nandu River-Estuary (NRE) is the largest river system on Hainan Island in the South China Sea, affected by frequent typhoons every year. We used elemental contents, stable isotope ratios of organic carbon and lignin phenols to characterize POM compositions in NRE during typhoon affected wet season (August, 2011) vs. normal wet season (October, 2012). Short term and heavy precipitation during typhoon in August, 2011 was evidenced with a significant hydrologic change as well as change in POM composition along the NRE. The multi-proxy results suggest that POM was degraded and their sources significantly changed along the NRE hydrograph. Results from an end member mixing model indicated that POM constituted nearly similar OM input from soil (35%) and freshwater plankton (32%) during August, 2011, in contrast POM dominated with OM from freshwater plankton (51%) during October 2012 in riverine regions of NRE. In the estuarine region, POM constituted dominant inputs from marine plankton during August, 2011 (44%) and October, 2012 (56%) as compared to other sources. Collectively, the nature of POM composition change in the vicinity of typhoon induced copious precipitation, with potential land-use intervention across the Hainan Island are key factors affecting the carbon cycling in NRE and adjacent South China Sea.

1. Introduction

River transport of particulate organic matter (POM) is an important component of marine carbon cycle, in addition, their composition is extremely sensitive to local and global environmental perturbations, and therefore it represents an important linkage with global carbon cycle. River borne POM preserved in the estuaries, deltas and continental shelves strongly influence the global biogeochemical cycles and ocean's ability towards atmospheric CO_2 sequestration (Bianchi et al., 2013). Rivers across the tropical region (30°N–30°S) importantly contributes ~25×10^{12} m^3 yr^{-1} freshwater, 8.96×10^{12} kg yr^{-1} sediment and 0.13×10^{12} kg yr^{-1} particulate organic carbon (POC) to the global ocean. This is equivalent to ~66%, ~50% and ~70% of total annual freshwater discharge, sediment load and POC delivery from global rivers respectively (Huang et al., 2012). However, yet the global understanding of land-ocean carbon composition change and factors influencing along their dispersal pathways (rivers–estuary–sea), are hampered by complexities of natural climate change (excess/less precipitation) and anthropogenic activities (dam building, excessive agriculture, deforestation) in many tropical regions of the world.

Studies related to the POM compositions in typhoon affected tropical river–estuary systems are sparse (Liu et al., 2007a; Herbeck et al., 2011), despite the fact that typhoon affected tropical rivers are recognized as significant source of POM delivered to the adjacent seas and plays important role in global carbon cycling (Hilton et al., 2008). The varying source of POM delivered during typhoon-induced hydrologic change in tropical river–estuary systems is mainly related to the rainfall intensity (Jung et al., 2012). Besides, the human induced land-use changes (deforestation, excessive agriculture, dam building, increased industrial and domestic pollutants, etc.) largely corresponds to alteration in POM composition within the tropical river catchments, which is then delivered to near shore marine environments (Goldsmith

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et al., 2008; Hilton et al., 2008; Wu et al., 2013). Tracking above processes in typhoon affected small and large tropical rivers are evenly essential considering the fact that POM biogeochemistry has remained a bottleneck for clear understanding in many tropical regions of world.

One of such region remain understudied is the Hainan Island in South China Sea (SCS), which gets affected by frequent tropical storms (typhoon) during boreal summer. The combined effects of heavy precipitation during typhoon and prevailing anthropogenic activities (rising population, agriculture and aquaculture) have caused excessive nutrient and OM discharge from the rivers of Hainan Island and thereby affected the marine ecosystem of SCS (Liu et al., 2011; Herbeck et al., 2011; Unger et al., 2013; Wu et al., 2013). Rivers draining the high standing islands (e.g. Eel (USA); Blair et al., 2004, Santa Clara (USA); Komada et al., 2004, Strickland and Fly (Papua New Guinea); Alin et al., 2008, Rio Loco (Puerto Rico); Moyer et al., 2013 and Lanyang-Hsi (Taiwan); Kao and Liu, 2000) often delivered POM, with a greater input from the geological OM sources, especially during their flooding season. However, the less steep Hainan Rivers are hypothesized to deliver POM, with altered in composition mainly due to the typhoon related heavy precipitation and anthropogenic activities that will further influence the carbon cycling of SCS. To our knowledge, so far a complete understanding of POM composition across the river–estuary systems of Hainan Island is lacking. This study attempts to fulfill this gap by understanding the POM composition in Nandujiang (or Nandu River system; 'jiang' refers to River in Chinese), the largest river system of Hainan Island. We present the POM biogeochemistry along the Nandu River-Estuary (herein after NRE) during August, 2011 (typhoon affected wet season) and October, 2012 (normal wet seasons), by examining the results of multiple organic geochemical analyses such as molar ratio of organic carbon to total nitrogen (C/N), stable isotopic ratios of organic carbon ($\delta^{13}C_{org}$) and lignin phenols (biopolymers, synthesized by terrestrial vascular plants) composition. The main objectives of this study are to provide information on (i) spatio-temporal distribution of POM, (ii) sources of POM and (iii) factors influencing POM compositions in NRE. The combined use of lignin phenols along with C/N and $\delta^{13}C_{org}$ will help to obtain robust information about POM sources; also the information about diagenetic change can be acquired by observing specific phenol monomers (Bianchi et al., 2011; Dittmar and Lara, 2001). Collectively, the results from present investigation will provide useful background information to the fact that the river basins of tropical Hainan Island would inevitably be developed in near future owing to ongoing global population rise.

2. Materials and methods

2.1. Study area description

The Nandujiang originates from Bawang hills in the central Hainan Island and meander north-east–north direction about 320 km before draining into the Qiongzhou Strait in SCS (Fig. 1). The entire catchment of NRE (7022 km^2) occupy 21% of total geographical area of Hainan Island and its estuarine region is located in densely populated Haikou district (population density; 910 km^{-2}). The NRE bifurcates into three channels (Haidianxi, Henggou and Beiganliu) in the estuarine region, amongst Beiganliu act as major freshwater discharge outlet to Qiongzhou Strait. Climatologically, the average annual precipitation on Hainan Island is about 1774 mm, which oscillates between 1200 mm and 2200 mm. Distinct wet (May–October) and dry (November–April) seasons are prevalent over the Island, with 80% of total annual precipitation occur during wet season. Tropical cyclones cross over the Island during July–October, causing copious precipitation (highest during August), which equals to ~30% to the total annual precipitation over Hainan Island (Wu et al., 2007). Average freshwater discharge and sediment load for a period from 1957 to 2008 in NRE are 5.7×10^9 m^3 yr^{-1} and 0.4×10^9 kg yr^{-1} respectively, which equals to ~20% and 10% of total freshwater discharge (31×10^9 m^3 yr^{-1}) and sediment load (4×10^9 kg yr^{-1}) respectively, from all the rivers of Hainan Island (Yang et al., 2013; Zhang et al., 2013). The Songtao reservoir exists in the upper reaches of NRE, with an annual water storage capacity of 3.3×10^9 m^3 that equals to ~60% of the total river runoff.

The land-use pattern over NRE varies from upland forest cover to lowland urbanized areas, which is due to a massive deforestation that caused significant reduction in forest cover from 169×10^3 km^2 to 5.8×10^3 km^2 between 1933 and 2008 (Zhang and Zhu, 2012). In the estuarine water, diurnal tidal currents (amplitude: 1.1 m) oscillate in a north-east–north direction across the Qiongzhou Strait (Wang and Ou, 1986). Also, year-round water mass with strong riverine character and high suspended sediment transport from north-east region of SCS and enter into the Beibu Gulf through Qiongzhou Strait off NRE (Su and Weng, 1994; Tang et al., 2003).

2.2. Sample collection

Water samples were collected from eighteen locations in NRE, during August, 2011 and October, 2012 (Fig. 1). A bucket was lowered from the bridge to collect water in the riverine region, whereas sampling in the estuarine waters were done by using a 5 L Niskin water sampler lowered from a mechanized boat. Estuarine stations were chosen along a salinity gradient from 0 to 35 psu (psu: practical salinity unit) during the neap low tide period (tidal height: 1.3–2.2 m). The stations were selected according to the observed spatial distribution of salinity in NRE and to cover a wide range of salinities. A series of typhoons cross over the Island during this study period (Fig. 1). Typhoons during 2011 were strong and crossed closely over the NRE, whereas typhoons in 2012 affected Leizhou Peninsula and marine regions off Hainan Island (Fig. 1). The typhoon Nock-ten (developed in coastal Philippine) with strongest wind speed (40 knots h^{-1}), crossed over the Hainan Island on July 29, 2011 and caused heavy rainfall (~220 mm within 12 h). This was the closest typhoon event occurred during August, 2011 campaign of this study, which was carried out after 3 days and during peak discharge (567 ± 45 m^3 s^{-1}) condition of NRE. The hydrographic parameters (temperature, salinity and pH) were measured directly with a multi-parameter probe (WTW MultiLine F/sets3) and the precision for temperature, salinity and pH measurement was 0.01 °C, 0.01 psu and 0.001 pH units respectively. Suspended particulate matter (SPM) was collected by filtering known volume of water through pre-weighed 47 mm GF/F filter papers (pre-combusted at 450 °C for 5 h) and later the filters were used for the analysis of POC, PN (refers to organic carbon and total nitrogen content of SPM respectively) and $\delta^{13}C_{org}$ (refers to stable carbon isotopic ratio of POC). About 10–15 L of water was separately filtered through 142 mm GF/F filters by using a pressure (N_2) filtration system, and then the filter was dried at 45 °C and used for lignin phenol analysis.

2.3. Bulk chemical analyses

The contents of POC and PN (relative precision ±5%) were determined using an Elemental Analyzer (Model: Vario EL III; Elementar Co.). The weight percentages of POC were analyzed after removing the carbonate fraction in vapour phase acidification (i.e. exposing the filters with concentrated hydrochloric acid (HCl) in desiccators for 24 h and then oven-dried at 45 °C). Weight percentages of PN