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Impact of Typhoon Morakot on suspended matter size distributions on the East China Sea inner shelf

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ABSTRACT

Two surveys were conducted on the East China Sea inner shelf before and after the passage of Typhoon Morakot in 2009. The typhoon-induced variations in the size distributions of suspended matters were studied based on the data collected by a Laser *In Situ* Scattering Transmissometer (LISST). A comparison of the measurements from the two surveys revealed significant changes in seafloor sediment grain size, suspended matter volume concentration and size distribution due to Typhoon Morakot. The mean seafloor sediment grain size increased generally, while the sorting coefficient decreased after the typhoon. Before the typhoon, suspended matter size was generally >100 μm, which was significantly reduced to between 20–50 μm after the typhoon. The single-grain fraction with sizes <36 μm and microflocs with sizes between 36–133 μm significantly increased in volume concentrations and percentage after the typhoon. On the other hand, the volume concentration of macroflocs (with sizes >133 μm) were largely reduced from $>40\%$ before the typhoon to $<20\%$ after the typhoon in the entire water body.

Our analyzes suggest that the dynamic process of the typhoon caused the seafloor sediment resuspension, which significantly increased the suspended matter volume concentration in addition to the increase of terrigenous materials due to high-intensity rainfall accompanying the typhoon. The typhoon process also decreased the suspended matter size and macrofloc (>133 μm) concentration by strong disturbance of water column and the temporary demise of plankton under heavy cloudy condition.

1. Introduction

Suspended matters, mainly consisting of sediments and seston, control the reactivity, transport and biological impacts of materials and provide a crucial link for chemical constituents among the water column, bed sediment and food chain (Baskaran and Santschi, 1993; Turner and Millward, 2002; Hsu and Liu, 2010; Safak et al., 2013). Suspended matter volume concentration and size distribution affect several aspects of the fate, transport, deposition and interactions of the particles in the water column (Kranck and Milligan, 1992; Agrawal and Traykovski, 2001; Turner and Millward, 2002; Ahn and Grant, 2007; Safak et al., 2010; Bian et al., 2013) and are in turn affected by the supply of suspended matter, the hydrodynamic environment and physicochemical (resuspension, deposition, coagulation, and fragmentation) and biological (production, mineralization, and repackaging) processes (Eisma, 1986; Milligan and Loring, 1997; Benoit and Rozan, 1999; Hill et al., 2001; Kumar et al., 2010; Ahn, 2012).

Typhoons may, although on a short time scale, profoundly alter the oceanic water structure (Price, 1981; Dickey et al., 1998; Lin et al., 2003; Li et al., 2012), seafloor topography and coastal landforms (Milliman et al., 2007; Goff et al., 2010), particle transport and distribution (Chang et al., 2001; Bian et al., 2010; Liu et al., 2011), nutrient distribution and primary production (Goñi et al., 2006; Herbeck et al., 2011; Li et al., 2013) in the affected marine area. During a typhoon, the strong cyclonic wind-stress accelerates the air-sea heat exchange and strengthens the upwelling (downwelling) of deep (surface) water, significantly altering the water structure and particle distribution in the water column, through waves and currents and the resuspension of bed sediment (Lin et al., 2003; Rao et al., 2010; Safak et al., 2010; Li et al., 2012). Meanwhile, heavy precipitation accelerates terrigenous particle supply through enhanced runoff in the coastal areas.

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These increases in water mixing, sediment resuspension and particle supply can be reflected by the suspended matter volume concentration and size distribution in the water column, which might control the distribution, transport and deposition of materials (including sediment, nutrients, pollutants, etc.) and completely change the overall marine environment (Babin et al., 2004; Goñi et al., 2006; Mead and Goñi, 2006; Zheng et al., 2010; Li et al., 2012).

Due to the insufficient capability of typhoon forecast and the shipboard operational difficulties under severe weather conditions, *in situ* observation of typhoons is an extremely difficult task. As for suspended matter distribution studies, the previous *in situ* observations are very rare and generally performed through mooring (Agrawal and Traykovski, 2001). The mooring-point observations have confirmed that the typhoon (or hurricane) process has significant impacts on suspended matter concentrations and distributions (Dickey et al., 1998), and emphasize the necessity of further studies with advanced measurement techniques. Shipboard measurements can remedy the lack of mobility of mooring observations, but they are also strongly restrained by severe weather and sea conditions.

We conducted two surveys in the Zhejiang–Fujian coastal mud area on the inner shelf of the East China Sea (ECS) in 2009. The first survey was conducted in normal sea condition and about one week before Typhoon Morakot's landfall and the second one was conducted 2.5 days after the landfall of Typhoon Morakot near the study area. The surveys provided a unique opportunity to study the typhoon-induced variations in the volume and size distributions of suspended matter.

2. Background and data

2.1. Study area and surveys

The study area is located in the mud deposition center off the Zhejiang–Fujian coast, which acts as a sink for sediment discharged by the Yangtze River. Surface sediment in the study area is dominated by clayey silt (Hu and Yang, 2001; Liu et al., 2006; Xu et al., 2012). In the study area, the tide type is regular semidiurnal, the M_2 constituent is dominant and the tidal current was about 10–30 cm/s in summer. The winds in summer are mainly southeastward with speed less than 10 cm/s in the study area (Su, 2005). The circulation system in the mud deposition center includes the coastal current, which is relatively weak and flows northward in summer and is relatively strong and flows southward in the winter due to monsoons, and the Taiwan Warm Current (TWC), which perennially flows northward and strong in summer and weak in winter (Su, 2005) (Fig. 1b). The sediment discharged from the Yangtze River are generally rapidly deposited in the Yangtze River estuary in summer due to the obstruction by the northward monsoon and the marine circulations (Hu and Yang, 2001; Liu et al., 2006; Xu et al., 2012). The deposited sediment in the estuary can be resuspended by extreme storms and transported southward along the coast in winter (Liu et al., 2006). According to long-term records, on average, four typhoons pass over the ECS shelf annually (Su, 2005), which significantly impact sediment transport and the modern sedimentary environment.

Two surveys were carried out at the study area (Fig. 1). The first survey was conducted from August 1st to 3rd, 2009, collected data at 29 stations (blue triangle in Fig. 1b) in five east–west transects (labeled as A, D, B, E, and C in Fig. 1b), followed by a second survey conducted from August 12th to 14th, collected data at 23 stations (red dot in Fig. 1b) in four east–west transects (labeled as transects D, B, E, and C in Fig. 1b) which was 2.5 days after Typhoon Morakot made landfall near the study area on August 9th. Each observation and sampling time at each station was about half an hour and a whole section's observation cost about 9–10 h. During all the first survey, the weather was calm, with southern wind speeds of less than 10.7 m/s and wave heights less than 1.6 m. The weather and sea conditions became unfavorable during the second survey due to the typhoon impact, with wave heights of 2.0–2.5 m and wind speeds greater than 13.0 m/s (Ocean Monitoring and Forecasting Center of Zhejiang Providence, www.zjhy.net.cn). As our cruise moved northward, the sea conditions deteriorated so considerably that we were forced to abandon the survey for the northernmost portion of transect A.

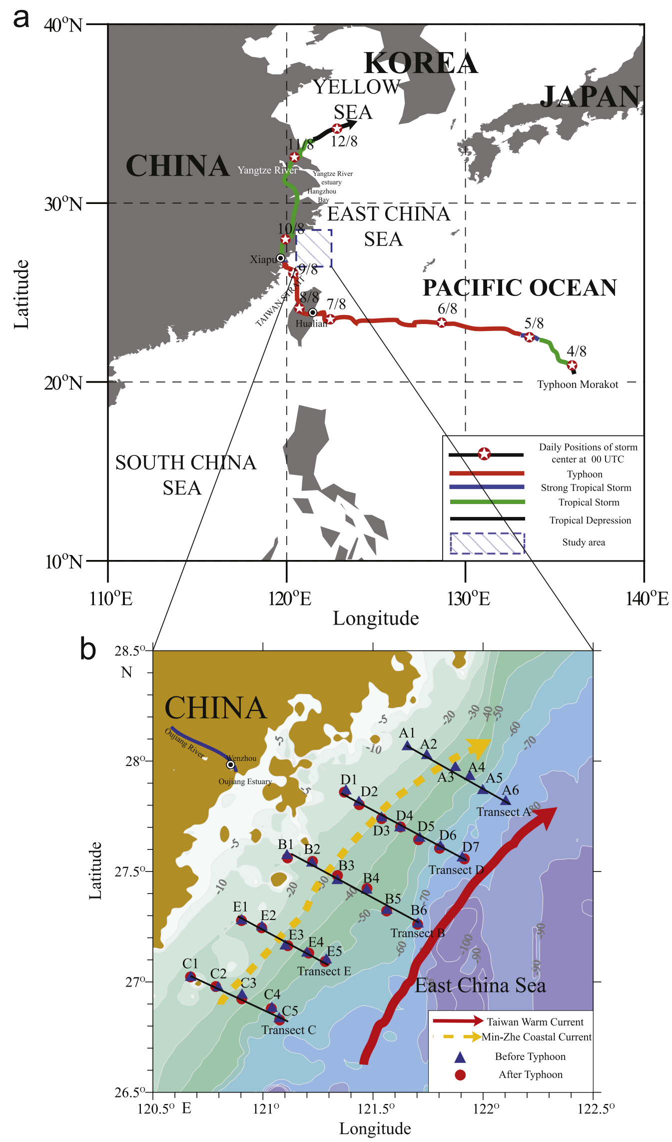

Fig. 1. (a) Track of Typhoon Morakot in 2009 (modified from the typhoon track data at http://map.weather.gov.cn/). (b) The station locations and survey transects. (Li et al., 2012, 2013 with stations names adjusted) blue triangle and red dot correspond to pre- and post-typhoon stations, respectively. (For interpretation of references to color in this figure legend, the reader is referred to the web version of this article.)

2.2. Typhoon Morakot and its impacts on water structure

The Morakot, as a severe tropical storm, was making a second landfall in mainland China on August 9th after first landfall in central Taiwan and cross through the Taiwan Strait. The wind speed was approximately 33 m/s at landfall, which is