Journal of Marine Systems xxx (2014) xxx–xxx

Contents lists available at ScienceDirect

Journal of Marine Systems

journal homepage: www.elsevier.com/locate/jmarsys

The impact of wind mixing on the variation of bottom dissolved oxygen off the Changjiang Estuary during summer

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ARTICLE INFO

Article history:
Received 30 June 2014
Received in revised form 15 September 2014
Accepted 24 November 2014
Available online xxxx

Keywords:
Dissolved oxygen
Hypoxia
Wind mixing
Stratification
Changjiang Estuary

ABSTRACT

Hypoxia off the Changjiang Estuary has been frequently reported using short time duration field data. However, its evolution was unknown because of a lack of long-term data and its associated dominant factor. A 104-day long dataset was collected with a bottom mounted system off the Changjiang Estuary in summer 2009. The monitored parameters were bottom dissolved oxygen (DO), temperature, pressure and current. Two hypoxia events were identified, showing that hypoxia was severe and lasted for more than a half month. The first event appeared on July 18 and lasted 17 days. During this hypoxia period, the minimum DO was down to 0.17 mg/L, which broke the historical record. The second hypoxia event appeared on August 30 and lasted 18 days with a minimum DO of 1.29 mg/L. The variation of bottom DO was closely related to that of stratification. The monitored data showed that almost every increase/decrease of DO was associated with a weakening/enhancing of stratification, which were recorded as many as 12 times during the monitoring period. Wind mixing modulated or broke the stratification, which affected the variation of bottom DO and hypoxia events. Using a lagged correlation analysis, the stratification and wind mixing were significantly correlated with a coefficient of determination $r^2 = 0.72$, and stratification lagged wind by 35 h. The bottom DO and wind mixing were significantly correlated with a coefficient of determination $r^2 = 0.65$, and DO lagged wind by 33 h. The formation periods of two hypoxia events estimated from monitored data were 20 and 15 days, which were much shorter than that from on-board experiments. Strong wind mixing played a dual role on hypoxia. It could relieve hypoxia conditions by supplying DO through mixing. It accelerated the formation of hypoxia afterward as a result of the enhanced phytoplankton bloom induced by wind mixing and high organic decomposition rates consuming more DO.

1. Introduction

Dissolved oxygen (DO) threatens marine animals when its concentration is lower than 2 mg/L or 62.5 μmol/L (Boesch and Rabalais, 1991; Diaz and Rosenberg, 1995), which is defined as hypoxia (Montgomery, 1969). Additionally, hypoxia could transform the community structure of zoo benthos (Ning et al., 2011) or damage the coastal ecosystem (Diaz and Rosenberg, 2008). Increasing coastal hypoxia was reported in the last few decades around the world because of enhanced anthropogenic nutrient loading. The seasonal hypoxia off the Changjiang Estuary is one of the most focused targets and has been a hot spot for interdisciplinary studies in recent years (Zhang et al., 2010).

Although the seasonal hypoxia off the Changjiang Estuary has been frequently reported using data observed by ship based field surveys, which are generally performed annually, seasonally and monthly, we were still unclear how it forms, maintains and disappears because of a lack of continuous observations (Wang et al., 2012; Zhu et al., 2011). The hypoxia area expanded fast and became one of the world's largest coastal hypoxia (Li et al., 2002; Wang, 2009; Wang et al., 2013; Zhou et al., 2009) when it was first reported in the 1950s (Gu, 1980). The formation and evolution of hypoxia were closely related to complicated physical processes from the interaction of the Changjiang Diluted Water (CDW), Taiwan Warm Current (TWC) and Kuroshio water masses, in addition to chemical and biological processes and bottom topography (Li et al., 2011; Ning et al., 2011; Wang, 2009; Wei et al., 2007; Zhou et al., 2010). The stratification of the water column and oxygen consumption through organic decomposition were two essential factors for the formation of hypoxia off the Changjiang Estuary (Wang et al., 2012). Typhoons, monsoons, cold air and tides are important factors to mediate hypoxia through weakening or breaking stratification, resulting in bottom oxygen supplement from the surface (Chen et al., 2007; Wei et al., 2007). However, there was no direct evidence to demonstrate this hypothesis because of a lack of continuous data; the

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http://dx.doi.org/10.1016/j.jmarsys.2014.11.010
0924-7963/

Please cite this article as: Ni, X., et al., The impact of wind mixing on the variation of bottom dissolved oxygen off the Changjiang Estuary during summer, J. Mar. Syst. (2014), http://dx.doi.org/10.1016/j.jmarsys.2014.11.010

key obstacle was that it was hard to make long-term observations because of heavy fishery activities off the Changjiang Estuary.

In this paper, we analyze the relationship between bottom DO and sea surface wind (SSW) with a 104-day time-series of bottom DO, temperature, depth and current at a station in the northern Changjiang Estuary. The evolution process of formation, maintenance and disappearance of hypoxia are shown along with the variation of stratification. The role of wind mixing and Chlorophyll-a (Chl-a) on the evolution of hypoxia is also discussed.

2. Data and methods

The long-term time-series data of interdisciplinary parameters at mooring station B in the northern Changjiang Estuary during summer 2009 were collected by a Trawl Resistant Bottom Mount (TRBM) (Ni et al., 2014). Mooring station B is shown in Fig. 1 and is located at 31.5°N/123°E. It was deployed on June 6 and recovered on September 17, lasting 104 days. The bottom DO was measured with an Aanderaa Oxygen Optode 3835 sensor. The sea bottom temperature (SBT), salinity and pressure were measured with a RBR Conductivity-Temperature-Depth (CTD). The current profile was measured using a RDI-WHS Acoustic Doppler Current Profiler (ADCP). All of the instruments were mounted on the TRBM, with a sampling interval of 30 min. The DO and CTD sensors were calibrated before deployment and after recovery. They were reclaimed once for maintenance and calibration during a cruise on August 4.

During the observation period at mooring, an interdisciplinary survey was performed from August 17 to 18 in section C at 31°N during 2009 (Fig. 1). During this survey, temperature and salinity profile data were collected at nine stations using a SBE917plus CTD.

The Level 4 sea surface temperature (SST) data produced by NOAA's National Oceanographic Data Center were used in this study. The SST data had a spatial resolution of 5 km × 5 km with a time interval of one day. The SST data that covered the study area from June 6 to September 17 in 2009 were downloaded from their website at http://ghrsst.nodc.noaa.gov. The SST at station B was calculated using the spatial average of the four nearby SST points.

Sea surface wind (SSW) data produced by NOAA's National Climatic Data Center were used in this study. The 6-h data had a spatial resolution of a 0.25-degree grid. The SSW data covering the study area from June 1 to September 17 in 2009 were acquired from their website at http://www.ncdc.noaa.gov. The east and north components of the SSW at station B were calculated using the spatial average of the four nearby SSW points.

Sea surface Chl-a concentration data derived using MODIS-Terra and -Aqua from June 1st to 13th, 2009 were used in this study. The Level 3 mapped data with a spatial resolution of 4 km × 4 km were acquired from the U.S. National Aeronautics and Space Administration (NASA) website at http://oceancolor.gsfc.nasa.gov.

The main acronyms used in this paper are listed in Table 1.

3. Results

3.1. Temporal variation of bottom DO

The data at mooring station B was monitored from June 6 to September 17, which almost covered the whole summer in 2009.

Fig. 2a shows that the bottom DO fluctuated with multiple time scales ranging from a tidal period of 12-h to a 20-day period. The tidal scale variation of DO was caused by the tidal current advection of DO. In this paper, we focused on the synoptic and seasonal variation of DO. Therefore, the daily mean DO (Fig. 3) was used in the following text, which removed the tidal variation. The most apparent features in the temporal variation of the daily mean DO were that there were two decreasing processes of DO. The first was from early June to the end of July, and the second occurred from mid-August to mid-September. Additionally, there was one increasing process of DO from early August to mid-August after Typhoon Morakot. The other noticeable characteristics were the 12 DO increasing-decreasing events. The timing of the DO increasing events were on June 6th, June 18th, June 24th, July 6th, July 14th, July 22nd, July 28th, August 2nd, August 19th, August 30th, September 6th, and September 15th. In general, the longer the time of an increasing event, the higher its corresponding DO peak. In particular, the DO increased from 0.17 mg/L to 5.86 mg/L in a 13-day increasing event starting on August 2nd. The decreasing rate of DO following each increasing event was proportional to that of the increasing rate.

Two episodes of hypoxia were observed during summer 2009. The first hypoxia formed on July 18. Two mild increasing events occurred within this hypoxia period, with a minimum DO of 0.17 mg/L. This

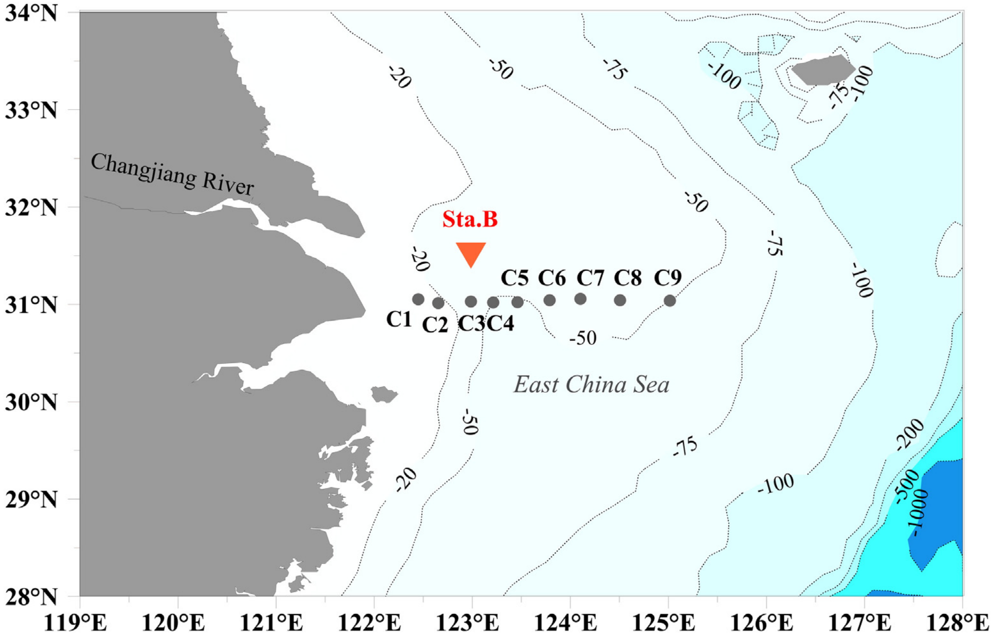

Fig. 1. The location of mooring station B and section C off the Changjiang Estuary.

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