Remote Sensing of Environment 173 (2016) 133–144

Contents lists available at ScienceDirect

Remote Sensing of Environment

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

The role of Mississippi River discharge in offshore phytoplankton blooming in the northeastern Gulf of Mexico during August 2010

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ARTICLE INFO

Article history:
Received 30 April 2014
Received in revised form 25 October 2015
Accepted 10 November 2015
Available online xxxx

Keywords:
MODIS
Mississippi River
Deepwater Horizon
Phytoplankton bloom
Fluorescence line height
Nutrients
northeastern Gulf of Mexico
Oil spill

ABSTRACT

A phytoplankton bloom covering an area >11,000 km^2 has been reported in the northeastern Gulf of Mexico east of the Mississippi River Delta in August 2010 (30°–28° N, 90°–86° W) based on NASA Moderate Resolution Imaging Spectrometer (MODIS) chlorophyll fluorescence line height (FLH) images. The bloom appeared to be anomalous relative to a historical monthly chlorophyll FLH mean (August 2002 to 2010), and was attributed by others to the *Deepwater Horizon* (*DWH*) oil spill accident. Here we tested an alternative hypothesis that the eastward dispersal of the Mississippi River plume entrained in wind-driven currents contributed to the development of this phytoplankton bloom. We examined Mississippi River discharge and nutrient records, ship-based surface salinity data, and the time-series of MODIS ocean color and FLH images. Wind measurements from buoys showed winds >6 m s^{-1} first in a southerly (northward) direction August 8–10, and then in a northerly (southward) direction until August 26. Results from the American Seas-Navy Coastal Ocean Model (AmSeas-NCOM) show how coastal water was advected in wind-driven currents into the area of the northeastern Gulf of Mexico where the bloom was documented.

Between July 9 and September 8, 2010, the discharge of the Mississippi River exceeded the 20-year mean. During this time, the northeastern Gulf received an estimated excess volume of approximately 8.3 × 10^9 m^3 relative to the 20-year mean. Together with findings from a particle trajectory model, we conclude that nutrients and other materials (e.g., sediments) from the excessive discharge of the Mississippi River and adjacent marshes and wind-driven currents likely contributed to the anomalous bloom observed during August 2010 and to the anomalously high organic matter sedimentation rates observed in the northeastern Gulf of Mexico in the aftermath of the *Deepwater Horizon* oil spill.

1. Introduction

On April 20, 2010, an explosion occurred on the *Deepwater Horizon* (*DWH*) drilling rig operating in the northern Gulf of Mexico, 90 km southeast off the Mississippi River Delta off the Louisiana coast (Fig. 1). This event marked the beginning of one of the worst environmental disasters in history. For an unprecedented 87 days, crude oil and natural gas flowed into the Gulf of Mexico from a wellhead located at a depth of 1500 m (US Department of Interior, 2010; Mc Nutt et al., 2011). The introduction of oil into the marine environment poses significant ecological and economic impacts (National Research Council, 1985), and the large volume of oil discharged by the *DWH* spill led to one of the largest coordinated efforts to assess impacts to the environment, and plan for restoration of the Gulf of Mexico ecosystem (see Goni et al., 2015 and references therein).

In an effort to evaluate oceanographic conditions in the aftermath of the *Deepwater Horizon* event, Hu et al. (2011) identified a chlorophyll fluorescence anomaly in satellite imagery collected over the northeastern Gulf of Mexico during August 2010. This anomaly signified that an unusual phytoplankton bloom had occurred relative to observations in the months of August over the previous decade. Hu et al. (2011) examined ocean circulation and historical data in combination with the location, duration, and timing of the anomaly, and speculated that the bloom may have been related to the *DWH* spill.

Given the known influence of river plumes on coastal ocean properties, the primary objective of the present study is to test an alternative hypothesis that the eastward advection of the Mississippi River plume water contributed to the bloom observed in the northeastern Gulf of Mexico in August 2010. As part of our approach, we examined the role of freshwater discharge from the Mississippi River and adjacent marshlands in June and July 2010. Many actions in response to the *DWH* event were undertaken without the luxury of time to assess associated environmental tradeoffs.

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http://dx.doi.org/10.1016/j.rse.2015.11.004
0034-4257/

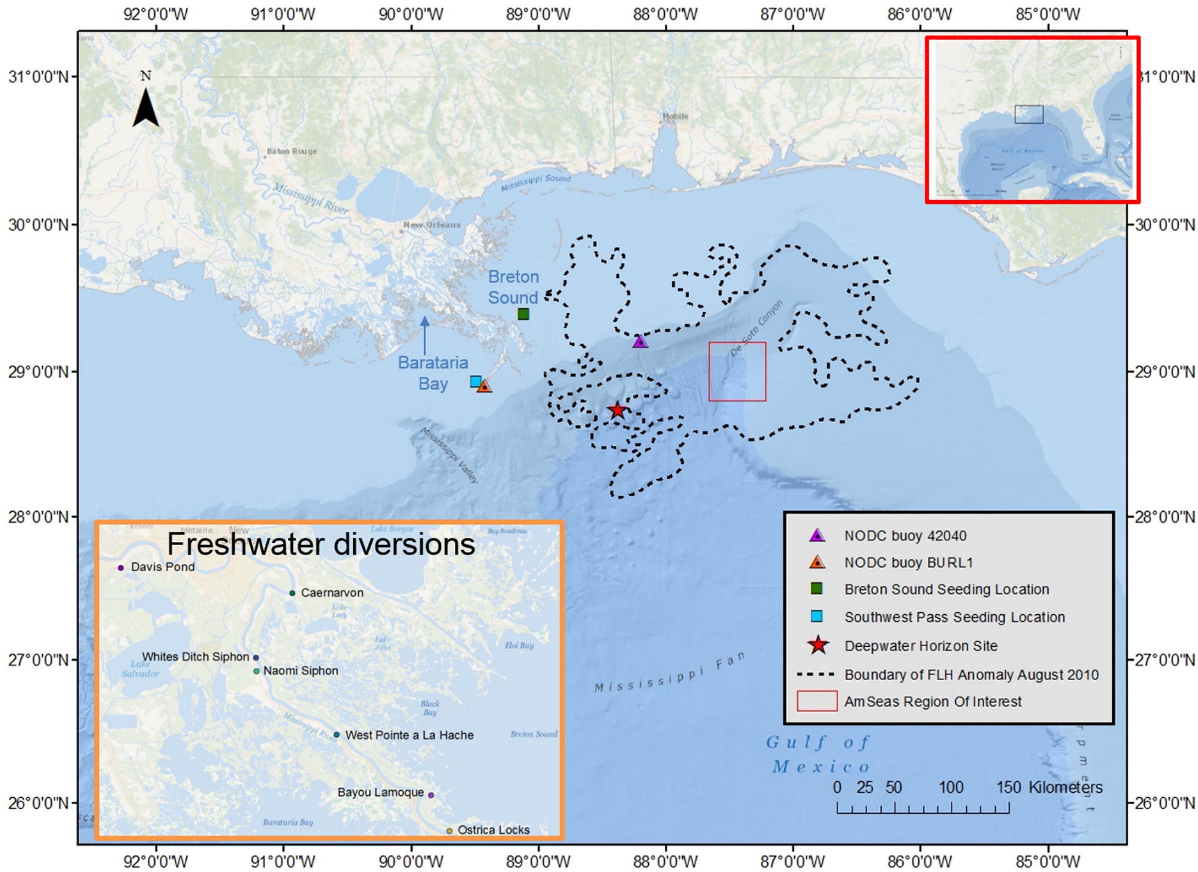

Fig. 1. Chart of the northeastern Gulf of Mexico showing the location of the *Deepwater Horizon* site, the boundary of the phytoplankton bloom anomaly traced from satellite-derived Fluorescence Line Height observations, and the position of the freshwater diversion and lock systems (lower left inset). The locations of seeding of virtual particle tracers for the AmSeas simulation are shown as small filled squares on the Mississippi River Delta. The Region of Interest used to count the number of tracer particles moving from the Mississippi River Delta into the area of the bloom is shown as a red box. The locations of the two wind buoys are shown as triangles.

2. Study site

Ranked as the seventh largest river in the world in terms of freshwater discharge (Walker & Rabalais, 2006), the Mississippi River drains approximately 3.24 million square kilometers of land (USACE, 2011) from 41% of the contiguous United States (Lohrenz, Redalje, Cai, Acker, & Dagg, 2008). The Mississippi River contributes approximately 80% of the fresh water from land that enters the Gulf of Mexico. This flow has a seasonal pattern (range $= 0.81 \times 10^4$ m^3 s^{-1} in September to 2.81×10^4 m^3 s^{-1} in April, with an average about 1.7×10^4 m^3 s^{-1}). It also exhibits interannual variation, with changes in flow varying by a factor of 3 from one year to the next (Muller-Karger, 1993; Lohrenz et al., 2008).

The Louisiana coastal wetland system, including the Mississippi River Delta, loses over 40 km^2 per year (CPRA, 2007). This accounts for 80% to 90% of the coastal marsh wetlands lost throughout the contiguous United States (USACE, 2011). The causes of this erosion are multiple, and include sea level rise, land subsidence due to oxidation of organics in soil, sediment compaction, human alterations to the environment, oil and gas activities, and dredging to improve navigation (CPRA, 2007). Reductions in the amount of sediment delivered to coastal Louisiana wetlands caused by the redirection of Mississippi River waters to mitigate flooding also contribute to the wetland loss (USACE, 2011).

2.1. The Mississippi River plume

The fate of the water of the Mississippi River entering the Gulf of Mexico is complex (Muller-Karger, Walsh, Evans, & Meyers, 1991; Muller-Karger, 1993; Del Castillo, Gilbes, Coble, & Muller-Karger, 2000; Yuan, Miller, Powell, & Dagg, 2004; Hu et al., 2003; Hu, Nelson, et al., 2005; Bianchi et al., 2010). This river plume and other coastal discharges in this region are largely controlled by wind (Muller-Karger, 2000; Walker & Rabalais, 2006; D'Sa & Korobkin, 2009). Walker and Hammack (2000) showed that southeasterly (northwestward) winds, which dominate much of the year off the Mississippi River Delta (Walker, Wiseman, & Babin, 2005), lead to an east-to-west current that transports the Mississippi plume towards the Louisiana-Texas border (Schiller, Kourafalou, Hogan, & Walker, 2011; Kourafalou & Androulidakis, 2013). There typically is a change in the summer to more southerly (northward) winds, which transport the Mississippi River plume eastward and towards the DeSoto Canyon along the northeastern Gulf of Mexico coast and over the continental shelf (Muller-Karger, 2000; Schiller et al., 2011).

The Mississippi River and Delta are the predominant land sources of nutrient, organic matter, and sediment loading for the northern Gulf of Mexico (Dagg & Breed, 2003). The fluctuations over time in Mississippi River discharge contribute to large variability in primary productivity by phytoplankton in the northern Gulf of Mexico (Lohrenz et al., 2008). Nitrogen and phosphorus are considered the limiting nutrients to phytoplankton productivity in the northern Gulf region (Lohrenz et al., 1997; Dagg & Breed, 2003; Lohrenz et al., 2008; Lehrter, Murrell, & Kurtz, 2009). The input of these nutrients into the Gulf varies with season, leading to marked changes in the size of phytoplankton blooms associated with the river plume (Muller-Karger et al., 1991; Muller-Karger, 2000; Lohrenz et al., 2008; D'Sa & Korobkin, 2009; Nababan, Muller-Karger, Hu, & Biggs, 2011).