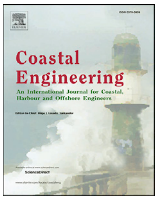
Coastal Engineering 130 (2017) 52–64

Contents lists available at ScienceDirect

Coastal Engineering

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



Nonlinear wave dynamics in the presence of mud-induced dissipation on Atchafalaya Shelf, Louisiana, USA

Ilgar Safak [a,*], Alex Sheremet [b], Justin Davis [b], James M. Kaihatu [c]

[a] *United States Geological Survey, Woods Hole Coastal and Marine Science Center, 384 Woods Hole Rd, Woods Hole, MA 02543, USA*
[b] *Department of Civil and Coastal Engineering, University of Florida, 365 Weil Hall, P.O. Box 116590, Gainesville, FL 32611, USA*
[c] *Zachry Department of Civil Engineering, Texas A&M University, 3136 TAMU, College Station, TX 77843, USA*

ARTICLE INFO

Keywords:
Wave modeling
Nonlinear waves
Directional waves
Wave dissipation
Triad interactions
Mud

ABSTRACT

The interplay between wave nonlinearity and mud-induced dissipation is studied here using wave and sediment transport measurements collected in winter 2008, on the Atchafalaya Shelf, Louisiana, between the 8-m and the 4-m isobaths. This study focuses on the relatively energetic storm that occurred on March 4th (2-m wave height in 8-m water depth), which caused significant bed reworking and left in its wake a 20-cm layer of hindered-settling fluid mud. While the net wave dissipation rate was maximal during the hindered-settling phase after the storm, consistent with previous observations, significant dissipation was observed throughout the storm duration, with a secondary maximum associated with the peak of the storm and the maximum bed-reworking effects. The effects of mud-induced dissipation on the nonlinear shoaling process are investigated here using TRIADS, a newly-developed spectral model for nonlinear shoaling of waves. With mud-parameter values estimated using a crude inverse modeling approach, the model was used to separate the effects of mud-induced dissipation from nonlinear transfers, during both the erosion and deposition phases of bed reworking. Numerical simulations show that nonlinear transfers are always active, even under strong dissipation regimes. Remarkably, they also suggest that heavy mud-induced dissipation causes the nonlinear energy cascade to revert direction, with bulk transfers occurring from high-frequency to low-frequency spectral bands. This supports the hypothesis that the interplay between mud-induced dissipation, which is much more significant than the bottom dissipation over sandy beds, and wave nonlinearity can drain energy from the entire spectrum, and not just from the frequency bands that interact directly with the seafloor. The decay of high-frequency variance induced by the reversal of spectral flux in effect reduces the nonlinearity of the wave field.

1. Introduction

The interplay between mud-induced wave energy dissipation (e.g., Gade, 1958; Wells and Coleman, 1981; Sheremet et al., 2005a; Kaihatu et al., 2007; Elgar and Raubenheimer, 2008; Safak et al., 2013a) and nonlinear wave propagation in shallow water is not fully understood. It has been hypothesized that, due to nonlinear interactions, mud-induced dissipation affects not only long waves that interact directly with the bottom, but also high-frequency waves, in effect draining the energy from the entire spectrum (Sheremet and Stone, 2003). Such a generalized interaction could affect wave propagation in unexpected ways, for example, by suppressing the development of steep wave fronts and associated wave breaking, or generating diffraction through non-uniform mud distribution (Kaihatu et al., 2007). Mud-induced dissipation is the response of waves to a muddy bed, whether through the formation of wave-supported fluid mud layers in the waning phase of a storm, or through phase changes of the muddy bed state such as liquefaction during the storm. Wave-supported fluid mud layers are routinely observed when high-concentration fluid mud layers are formed due to hindered settling of initially suspended cohesive sediment (Traykovski et al., 2000; Wright et al., 2001; Sheremet et al., 2011a; Safak et al., 2013a), eventually decaying to laminar flows with high viscosity and small velocities. The processes associated with bed reworking at the peak of a storm are less studied. The term “bed reworking” is used here as a generic name subsuming processes such as expansion, liquefaction, and fluidization (see discussion in Sahin et al., 2012). It excludes the formation of fluid mud layers through hindered settling, a process that typically occurs during the waning phase of a storm.

---

* Corresponding author.
E-mail address: isafak@usgs.gov (I. Safak).

https://doi.org/10.1016/j.coastaleng.2017.09.014
Received 13 May 2016; Received in revised form 11 June 2017; Accepted 26 September 2017

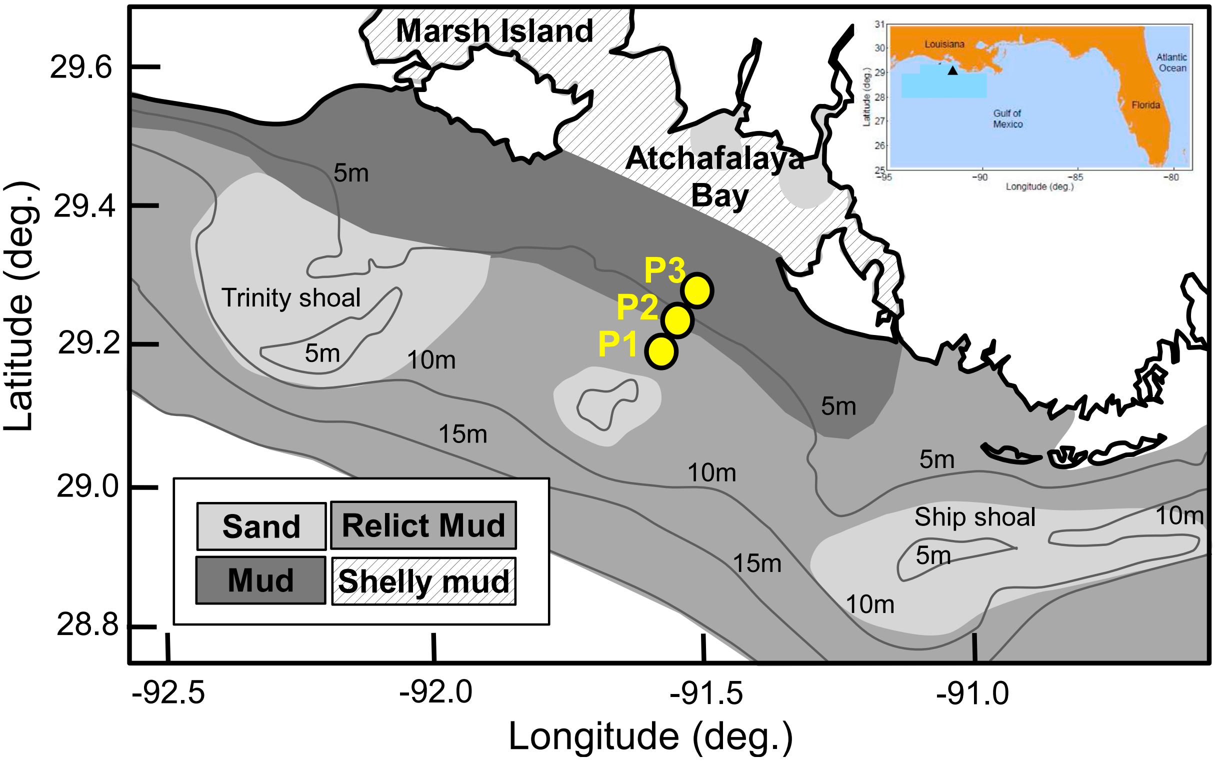


Fig. 1. Map of the Atchafalaya Shelf. The instrumented platforms (Table 1) were located near the 7.4-m, 5.0-m, and 3.8-m isobaths. The transect spanned approximately 8 km. The triangle in the inset shows the location of the transect in the northern Gulf of Mexico.

Although the problem of the interplay between nonlinear wave-wave interactions and band-limited mud-induced dissipation has been considered before (Sheremet et al., 2005b, 2011a; Alam et al., 2011), its details are yet to be resolved, in part because of incompleteness of data, but also in part due to nonlinear model limitations such as unidirectional representation (Sheremet et al., 2011a; Safak et al., 2013a). Here, we revisit the problem using new data and new modeling technology.

Muddy-bed reworking by waves has been the focus of several large-scale field experiments conducted in 2008 and 2010 on the Atchafalaya Shelf and the Louisiana Chenier Plain. These experiments produced comprehensive data sets discussed since in a number of papers (e.g., Elgar and Raubenheimer, 2008; Safak et al., 2010, 2013b; Sahin et al., 2013; Traykovski et al., 2015; Safak, 2016). The data set used here contains detailed information about directional characteristics of surface waves, as well as muddy bed transformation. In particular, the data set used here contains information not only about the dissipation effects of the waning-stage fluid mud layers, but also about bed reworking effects during the peak of the storm. Therefore, wave-mud interaction throughout the entire storm duration is examined. The main goal of the paper is to investigate wave dissipation induced by mud-reworking stages of a storm other than the fluid-mud stage, which occurs at the end of the storm. Such an investigation requires a numerical tool to separate the contribution of nonlinearity and dissipation, as their effects on wave propagation have similar order of magnitude (e.g., Sheremet et al., 2011a) and can be separated only locally (as rates of change, derivatives) and not globally (as global contributions).

Accurate modeling of wave transformation on the Atchafalaya Shelf is difficult, due to the large-scale, shallow-water environment (the 10-m isobath can be as far as 50 km offshore). Such efforts are few (e.g., Winterwerp et al., 2007; Rogers and Holland, 2009) and typically use directional phase-averaged models and thus are not adequate for the Atchafalaya shallow shelf. Alternatively, attempts to account for the triad interactions (Sheremet et al., 2005b, 2011a; Elgar and Raubenheimer, 2008; Safak et al., 2013a), which dominate nonlinear shallow water wave transformation, have been hampered by the use of unidirectional models. Unidirectional models previously showed skill in reproducing observed mud-induced dissipation (Sheremet et al., 2011a; Safak et al., 2013a), a feature useful, for example, for the development of fast numerical procedures for estimating mud characteristics. However, the natural wave-shoaling process is fundamentally directional, and although directional numerical simulations bring additional complexity and numerical effort, they provide a more realistic framework for the description of nonlinear effects. In a recent application of a phase-resolving model based on idealized directionality with zero and oblique incidence angles, a zero initial angle in the model never returned the best comparison with the data which showed that wave directionality may help to capture some of the missing features of wave propagation over muddy shelves (Liao et al., 2015). A secondary goal of the paper is to take a further step in the complexity of the numerical representation, by using a directional triad interaction model. Recently, a phase-resolving, directional triad interaction model was developed by Davis et al. (2014) and Sheremet et al. (2016), which has the potential of eliminating the unidirectional wave constraint. The development of the TRIADS model engine provides the opportunity to examine the problem under the assumptions of alongshore uniform bathymetry, but with broad directional spectra.

Brief descriptions of the experiment setup and instrumentation, and of the numerical model used here are given in Sections 2 and 3, respectively. Sections 4 and 5 present the analysis of the observations and numerical simulations. Section 6 summarizes our findings.

2. Experiment site and instrumentation

The field observations discussed here were collected on the muddy Atchafalaya Shelf at the northern Gulf of Mexico (Fig. 1) between February 23rd and March 7th, 2008. This time interval typically coincides with high discharge of the Atchafalaya River and energetic waves on the Atchafalaya Shelf, both processes driven by frequent cold atmospheric fronts passing over the region (Walker and Hammack, 2000). The Atchafalaya Shelf is a large-scale, shallow basin with a slope of