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Letter

Field observation of wave damping by fluid mud

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ABSTRACT

Extensive mud deposits are found off Cassino Beach, Brazil. The wave damping over the muddy bottom was studied using field measurements. By applying a technique of spectral analysis we showed that the wave attenuation occurred differently throughout the wave spectra. Field measurements revealed that the maximum wave energy dissipation took place over the deposit's depocenter and that lutocline height varied significantly in the order of days. The results indicated that short waves (from 3.75 to 6.25 s) underwent the greatest damping due to the interaction with fluid mud. An idealized 1-D model helped to explain the observations.

1. Introduction

Field observation of wave–mud interaction has been long conducted in many muddy coastal areas over the world. The wave damping over the mudbanks of the Mississippi Delta was first quantified in the field by Tubman and Suhayda (1977). The authors observed that the energy loss resulting from the wave–mud interaction was at least one order of magnitude higher than that related to frictional effects that are typical from sandy environments. Wells and Kemp (1986) calculated the wave energy loss along a transect off the mud coast of Suriname. The authors reported that more than 90% of the spectral energy of the waves was damped out as they propagated over the muddy path from 8 to 1.5 m depth. More recently, the field observations by Mathew et al. (1995) showed that 75–80% of wave energy is attenuated as the waves travel 1.1 km over the mudbank off Kerala coast, India. Field measurements in the Persian Gulf presented in the work by Haghshenas and Soltanpour (2011) revealed that the wave energy is attenuated by 25 to 90% depending significantly on the period of incoming waves. The authors concluded that the maximum dissipation of the wave energy due to the presence of fluid mud occurred in the frequency band around 0.16 Hz (6 s) throughout the measurement period. In this paper, two distinct datasets are analyzed aiming at providing better insights on the wave damping phenomena at the Brazilian coast.

Extensive mud deposits are observed off Cassino Beach, Southern Brazil. According to Vinzon et al. (2008) this deposit mainly originates from the fine sediments flushed from the adjacent Patos Lagoon (Fig. 1) especially when northerly winds are persistent. This condition favors the deposit formation that is mostly located between 6 and 15 m depth.

During storms, the energetic incoming waves occasionally transport the mud deposit to the foreshore. In these situations, the typical sandy beach is covered with a substantial amount of mud. This is a unique process along the Brazilian coastline that jeopardizes recreation and endangers the fauna (Calliari et al., 2000; Pereira et al., 2011).

The extension of the mud deposit was determined by sediment sampling and combined acoustic methods such as single (210 Hz) and dual (33 – 200 kHz) frequency echo-sounding and also high-resolution seismic surveying (2 – 16 KHz) (Calliari et al., 2000, 2008; Dias and Alves, 2008). The observations showed that the onshore limit of the mud bank presents a relatively sharp transition between sand and mud, at depths varying from 3 to 6 m depth and the offshore limit is located about 17 m depth, from where the sand content gradually increases seaward. The grain size distribution of bottom sediment samples showed 75% to 100% of mud (silt + clay), with the clay size fraction comprising 25% to 59% of the sample. The clay fraction is mostly composed of smectite (40%) and illite (34%). The high content of smectite confers high cohesiveness to the material expressed by its high cation exchange capacity which ranged between 74.3 to 169.2 meq/100 g. Samples collected at depths deeper than 20 m, were classified as fine to very fine sands with D50 varying from 0.1 mm to 0.138 mm. Such samples contain from 3% to 21% of mud with a maximum of 6.2% of clay size particles.

The action of water waves over a soft marine mud bottom can rework the mud layer, elevating this interface to a height that depends on the balance between both mechanical energy imparted to raise the potential energy of the suspension and the negative buoyancy of the suspension beneath the interface (Vinzon and Mehta, 1998). In a feedback way, this mud layer plays an important role in the wave damping

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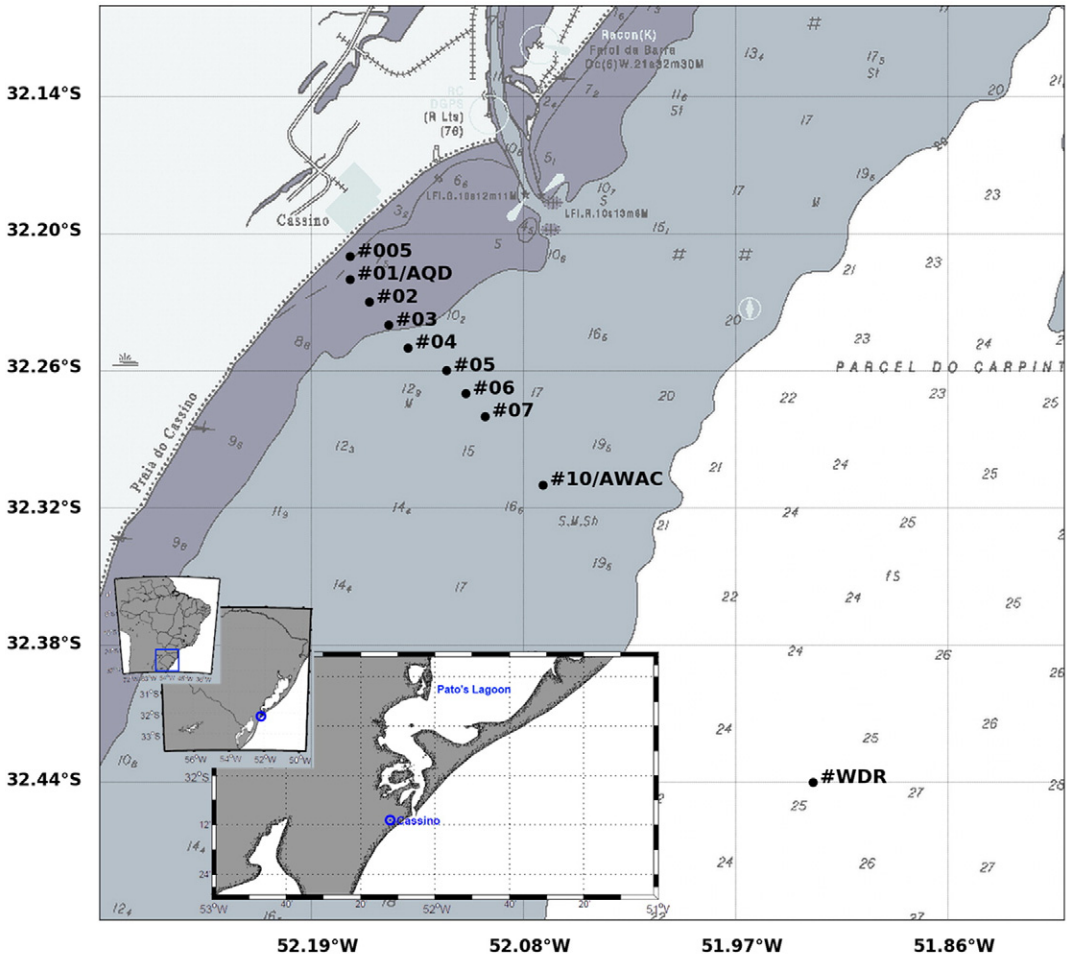

Fig. 1. Cassino Beach location and the measurement stations along a shore-perpendicular transect. During the 2005 campaign, a Waverider (WDR) was deployed at 25 m depth along with an Aquadopp (AQD) placed at 8 m. In 2008, an AWAC was deployed permanently at 18 m depth (#10) while the other instruments measured successively on the stations numbered from #07 to #005 along a transect towards the shore (see text for details).

by viscous dissipation (Darlrymple and Liu, 1978; Torres-Freyermuth and Hsu, 2010). The theoretical background of the wave attenuation due to fluid mud has been described under a number of frameworks but in all cases the damping rate varies as a function of the mud layer thickness, viscosity, density and the water depth (Gade, 1958; De Wit, 1995; Ng, 2000; Kranenburg et al., 2011).

Aiming to investigate the dynamic behavior of the mud deposit under wave action, a series of field experiments called Cassino Project, started in 2004. In Holland et al. (2009) the main aspects of the data collection of this project are summarized. Initially, the characteristics of the deposit were determined by using geo-acoustic methods and in situ sampling for laboratory analysis enabling to identify the extension, thickness and relevant aspects of the mud deposit. Wave measurement devices were deployed in a transect along the main direction of the incident waves so as to register the attenuation induced by the mud deposit. Rogers and Holland (2008) thoroughly analyzed the wave data collected in 2005 using different mud-wave damping modeling approaches. The authors showed that the extension, thickness, density and viscosity of the mud deposit are critical parameters for simulating the wave attenuation observed through the mud deposit. The deposit characteristics remained constant during the simulated time series as there was no sufficient information about its spatial and temporal variability. As a result, more detailed observations were recommended in order to fine-tune the validation of the dissipation mechanisms. The lack of information about the bed characteristics and its relation with the wave damping motivated a new set of experiments which were carried out in 2008.

The new measuring strategy considered the transient properties of the mud deposit as a function of the local wave regime. Therefore, data collection of the wave parameters and the mud characteristics was conducted concomitantly. Furthermore, the dataset of 2005 was further inspected so that the wave spectra were divided in four predetermined frequency bands that are representative of the wave climate (see Section 3 for details). The advantage of this technique is that it allowed the assessment of the wave energy dissipation for distinct sea states that are represented by each of the frequency bands.

2. Field work

In the fall 2005, wave measurements took place simultaneously at two locations. One offshore location, situated at 25 m depth, where a Waverider Datawell© (WRD) was deployed providing information about the undisturbed waves entering the system and a second location near the landward border of the mud patch at 7−8 m depth where an Aquadopp Nortek© (AQD) was installed (Fig. 1).

In 2008, simultaneous data collection of the wave field and the vertical structure of the mud layer was conducted (Fig. 1). The measurements covered the same transect of the 2005 measurements however with more cross-shore resolution such that the locations were approximately 1.5 km apart from each other. Wave parameters were measured continuously at 18 m depth with an AWAC Nortek©. At successive stations moving towards the coast waves were obtained with an ADV Nortek© at same time that density profiles were determined with a DensiTune Stema Sytem©. This density measuring probe is based on