MAPPING OF VERTICAL STRATIFICATIONS IN TURBIDITY CURRENTS THROUGH MEDICAL ULTRASOUND IMAGES

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Abstract

A vertical stratification of sedimentary gravity flows was identified through laboratorial recording and analysis of turbidity currents due to the increased sediment concentration near the botton and gradative dilution towards the mixture layer, caused by ambient water entrainment (incorporation of clean water) along the top of of the current. The application of medical ultrasound allows a clear visualization of the internal structures of the current, highligthing the stratification layers. With the experimental data obtained, it was possible to identify similarities between the different density layers measured by the medical ultrasound, and the velocity and concentration profiles measured during the experiments.

Introduction

The study of the sedimentary deposits present on the ocean floor has awaken a great interest in the last decades, being the main cause the analogy with exploration and production of petroleum targets around the world (Weimer & Slatt, 2004). A significative part of the research efforts are applied in the understanding of density flows characteristics, highlighting the importance of physical models, and the comprehension of transport and deposition mechanisms (Kneller, 1995). During the last two decades, there has also been progress in monitoring the seafloor, with the purpose of recording the density currents (Xu & Noble, 2009) and mapping the related deposits (Smith *et al.*, 2007).

An alternative for studying and obtaining data on natural phenomena is physical simulation, a robust tool used for many decades to study flows and sediment transport (Yalin, 1971). This work is based on a physical simulation study of density currents, aiming to perform an analysis of images acquired with a medical ultrasound, in order to improve the identification and interpretation of the internal structures and stratifications present in the simulated flows. This analysis aids the interpretation of mechanisms operating during the transport and deposition. It will also be evaluated the possibility of using ultrasound images to obtain quantitative data of turbidity currents.

Method

The analytical data were obtained from simulations performed in an experimental flume with 15 x 0.4 x 0.6 m in dimension. The simulated currents had volumetric concentrations ranging from 2 to 37%. The sedimentary material used was mineral coal (D_{50} = 55 µm) with mixing volumes between 200 and 400 liters and injection flow rates between 50 and 60 L/min. During the tests, velocity profiles (UVP - Ultrasound Doppler Velocity Profiling – Met-Flow) and concentration profiles (UHCM - Ultrasonic High Concentration Meter – Deltares) were obtained.

The imaging of the currents was produced by a medical ultrasound (Siemens - GM-6600A2A00), positioned at 4.5 m from the injection point, recording the data in a digital video file (30 fps).

The images obtained were processed with Matlab, for pixel color scale identification. Two different models of ultrasound sensors were tested, and the one that was best adapted for use was the linear transducer with 7.5 MHz (model 7.5L40), because it has a better definition and signal penetration, measuring depths up to 12 cm. The medical ultrasound was used to calibrate color scales for the mixtures with different concentrations, adjusting a law for image interpretation through the colors.

Results

Data from two experiments were selected for discussion. The first, with volumetric concentration of 11%, corresponds to the experiment in which it was observed the emergence of a more pronounced stratification, and data from all sensors could be analyzed. The second, with maximum concentration of 37%, aiming to illustrate the effects of strong stratification, presented limitations by the sensors for exceeding the acquisition range.

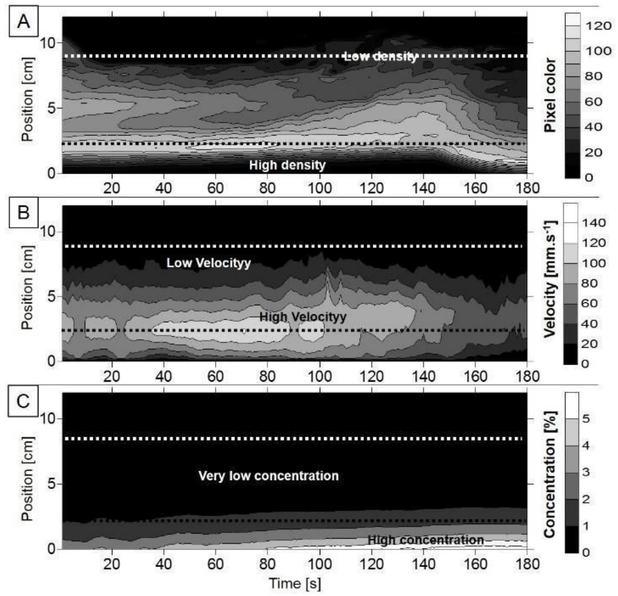

Figure 1. Surface map showing variations of (A) gray colors obtained by interpretation of ultrasound images; (B) velocity profile (UVP) and (C) concentration profile (UHCM). The dotted lines were identified in the images of ultrasound interpretation, being the white line the boundary of the mixing layer and the black line the top of the high density layer. (Setup: Flow concentration: 11%; record time: 50s after the front of flow pass by of sensors).

The images obtained by the ultrasound, after processed and analyzed, allowed to stablish numerical values for the variations in the gray scale colors. It was identified that the color variations are geometrically similar to the measured velocity and concentration profiles. The ultrasound images allow a better detailing and observation of internal flow structures (Fig. 1 - A) when compared to velocity (Fig. 1 - B) and concentration (Fig. 1 - C) profiles. The ultrasound images suggest a gradual density increase, *i.e.* stratification between the top of the mixing layer and the base of the simulated currents.

For more concentrated currents (C> 19%), the stratification is more pronounced, but the image interpretation suggests a false inversion of density at the base. The strong stratification, caused by the high concentration close to the bottom, impairs the sharpness of the layers in this region (Fig. 2 - A). A similar problem is also noted for sensors used to measure velocity and concentration. For the velocity profiler, the same zone presents low velocities or recorded errors, due to sediment deposition (Fig. 2 - B). For the concentration sensors, there is a maximum limit that can be measured (around 7% in volume), which produces uncertainty regarding the real value measured during the simulation (Fig. 2 - C).

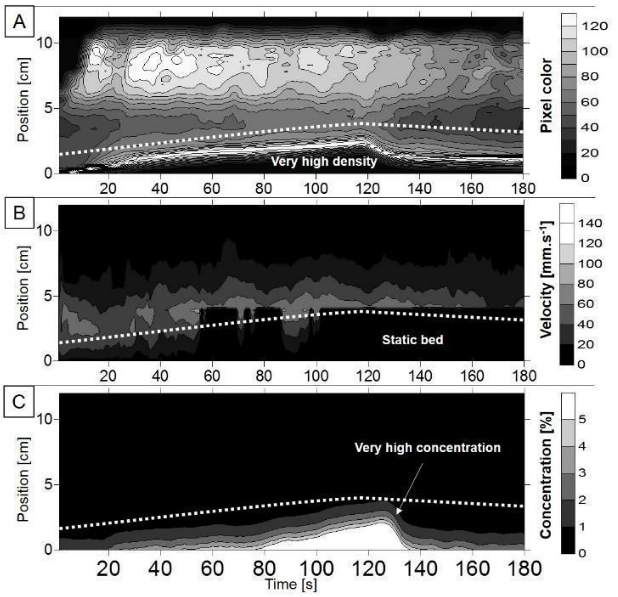

Figura 2. Surface map showing variations of (A) gray colors obtained by interpretation of ultrasound images; (B) velocity profile (UVP) and (C) concentration profile (UHCM). The dotted lines mark the beginning of a zone of uncertainty for the measured data, probably due to the strong stratification of the flow. (Setup: Flow concentration: 11%; record time: 50s after the front of flow pass by of sensors).

Discussion

Our effort was to test the application of a new tool for the acquisition of qualitative and quantitative data for simulated currents. It was possible to improve the details of more diluted regions, as well as to observe, through recorded videos, mechanisms of sediment transport and deposition. With low concentrations (up to 10% by volume), the basal layer of the currents evolve reaching lower concentrations, and turbulent mechanisms of transport and deposition predominates. Currents formed by concentrated mixtures (above 19%) have mechanisms that resembles mass transport, yet with some particularities, as they are not cohesive, and the deposition is mainly by frictional freezing.

However, the determination of more consistent quantitative data still depends on improvements in the calibration and adjustment of the algorithm, as better interpretation of the images obtained by the ultrasound will potentially be established. The adjustments this far allowed only the concentration determination for the mixing layer, but suggests that it is possible to expand the method to higher values, through the application of more sophisticated algorithms.

Considering the analyzed data, significant modifications for the transport and deposition mechanisms were identified, as a function of the increased concentration of the injected mixtures. In addition, the volumetric sediment transfer, and the displacement efficiency of these currents, presented a linear growth with the increase of the injected concentration (for flows with concentrations up to 30%). These data are very important because of the deposited volumes that are richer in coarser sediments such as sand fraction, which are the main targets for petroleum exploration and production.

On the other hand, there is an obstacle for simulating high concentration flows and also for measuring them in the natural environments (Xu *et al.*, 2014). The equipment currently available for data acquisition of velocity and concentration in simulation scales, presents limitations in the application for high concentration conditions. The reason is that it ends up decreasing the depth of reach for the acoustic signal, because of the high impedance generated within the flow. The profilers can also cause disturbance in the flow, generating resistance and inducing deposition in their surroundings, burying the sensors, and in turn, they may lose the ability to record data during the experiment.

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