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ScienceDirect
Continental Shelf Research 27 (2007) 542–559
CONTINENTAL SHELF RESEARCH
www.elsevier.com/locate/csr

The impact of floods and storms on the acoustic reflectivity of the inner continental shelf: A modeling assessment

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Received 6 December 2004; received in revised form 19 December 2005; accepted 19 December 2005
Available online 18 January 2007

Abstract

Flood deposition and storm reworking of sediments on the inner shelf can change the mixture of grain sizes on the seabed and thus its porosity, bulk density, bulk compressional velocity and reflectivity. Whether these changes are significant enough to be detectable by repeat sub-bottom sonar surveys, however, is uncertain. Here the question is addressed through numerical modeling. Episodic flooding of a large versus small river over the course of a century are modeled with *HYDROTREND* using the drainage basin characteristics of the Po and Pescara Rivers (respectively). A similarly long stochastic record of storms offshore of both rivers is simulated from the statistics of a long-term mooring recording of waves in the western Adriatic Sea. These time series are then input to the stratigraphic model *SEDFLUX2D*, which simulates flood deposition and storm reworking on the inner shelf beyond the river mouths. Finally, annual changes in seabed reflectivity across these shelf regions are computed from bulk densities output by *SEDFLUX2D* and compressional sound speeds computed from mean seafloor grain size using the analytical model of Buckingham [1997. Theory of acoustic attenuation, dispersion, and pulse propagation in unconsolidated granular materials including marine sediments. Journal of the Acoustical Society of America 102, 2579–2596; 1998. Theory of compressional and shear waves in fluidlike marine sediments. Journal of the Acoustical Society of America 103, 288–299; 2000. Wave propagation, stress relaxation, and grain-tograin shearing in saturated, unconsolidated marine sediments. Journal of the Acoustical Society of America 108, 2796–2815]. The modeling predicts reflectivities that change from <12 dB for sands on the innermost shelf to >9 dB for muds farther offshore, values that agree with reflectivity measurements for these sediment types. On local scales of $\sim$100 m, however, maximum changes in reflectivity are <0.5 dB. So are most annual changes in reflectivity over all water depths modeled (i.e., 0–35 m). Given that signal differences need to be $\geqslant$2–3 dB to be resolved, the results suggest that grain-size induced changes in reflectivity caused by floods and storms will rarely be detectable by most current sub-bottom sonars.

Keywords: Floods; Storms; Ocean floor; Grain size; Sonar; Reflectance

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doi:10.1016/j.csr.2005.12.018

1. Introduction

Grain size distributions on continental shelves are a governing influence on the response of the shelf surface to acoustic imaging. The speed of sound through unconsolidated sediments correlates with grain size, as does the bulk density and thus reflectivity of the sediments through the control of grain size on porosity (Hamilton, 1970a, b, 1980; Hamilton and Bachman, 1982).

Two common processes capable of changing grain size distributions on the inner shelf are river floods and storms. Floods that succeed in discharging sediments to the shelf through plume sedimentation tend to fine the seabed (Wheatcroft et al., 1997; Sommerfield et al., 2002), while storms often coarsen the seabed through waves that resuspend fines and (e.g., downwelling) currents that then move the fines into deeper water (Wiberg et al., 1996; Wiberg, 2000).

Topographic changes to the shelf surface by floods and storms offshore the Eel (northern California, US) and Po Rivers (Italy) are $\leqslant 15$ cm (Wheatcroft et al., 1997; Wheatcroft and Drake, 2003; Palinkas et al., in review) and so appear to be near or below the resolving powers of commonly used sub-bottom sonar frequencies (minimum resolution is given by 1/4 of the signal wavelength, so in ocean waters (sound speed $= 1500\,\mathrm{m\,s^{-1}}$) a 10 kHz sonar can only resolve changes of $\geqslant 4$ cm, while for a 1 kHz sonar the minimum is $\geqslant 40$ cm). However, if floods and storms affect grain size distributions, then they also alter the porosity, bulk density, sound speed, and thus reflectivity of the seafloor. Whether these changes are significant enough to be resolved has, to our knowledge, never been systematically addressed. This may be because such an assessment would be difficult to accomplish using field measurements. It would require repeat soundings using calibrated sonar systems re-occupying the exact same location(s) following well-recorded changes in the seabed brought about by equally well-documented floods and/or storms of varying magnitude. Furthermore, the measurements would ideally need to encompass more than a handful of events to adequately capture the range of possible discharges and wave activity.

In this study, we use numerical modeling as a means of placing first-order constraints on how much the reflectivity of the seabed may be altered by flood and storm induced changes in grain size. Grain size distributions resulting from plume sedimentation and wave reworking are simulated using *SEDFLUX2D* (Fig. 1), a two-dimensional, process-based stratigraphic model (Syvitski and Hutton, 2001). Seabed reflectivities are then calculated for each year in the simulations using an analytical model developed by Buckingham (1997, 1998, 2000) for estimating sediment velocity from mean grain size.

The flood input to this modeling sequence consists of 100-yr long records of daily sediment discharge from a large versus small river that are derived from the hydrologic model *HYDROTREND* (Fig. 1) using as input the drainage-basin characteristics of the modern Po and Pescara Rivers (Fig. 2). An equivalent 100-yr long model of daily wave climate is developed from statistics of wave measurements made in the western Adriatic Sea. We note that these simulations are not meant to reproduce the shelf strata that presently exist offshore of the Po and Pescara Rivers. Instead, the simulations are designed to theoretically assess the relative impacts of floods and storms on the seabed using realistic inputs and boundary conditions for the modeling. The simulations provide an indication of how much floods and storms can change seabed reflectivities both over time and with distance offshore.

2. Numerical modeling

2.1. Simulations of seabed grain size and bulk density distributions from SEDFLUX2D

SEDFLUX2D simulates the evolution of grain size and bulk density distributions across a basin through event-based deposits that are created by a series of interacting sub-models for sediment erosion, transport, deposition and compaction from the coastal plain to the abyssal plain (Syvitski and Hutton, 2001; Kraft et al., in review). In this study, only the subaerial and shelf modules are used (Fig. 1). All but one of these modules are documented elsewhere, so we limit our description of them to brief summaries of their governing equations supported by pertinent references.

2.1.1. River discharge and sediment load (HYDROTREND)

A set of empirical relationships predicts the discharge, suspended sediment load and bedload for a river based on key properties of its drainage basin (Fig. 1) (Syvitski et al., 1998a; Morehead