Predicting the Evolution of Tidal Channels in Muddy Coastlines

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LONG-TERM GOALS

- To quantify the relationships between resuspension of fine material in the shelf by wind waves, tidal channels hydrodynamics, and sediment supply to coastal marshes.
- To develop predictive, high-resolution models for the hydrodynamics and sediment dynamics of tidal channels in muddy coastal environments
- To develop methods to predict the long-term evolution of tidal channels in muddy coastlines as a function of sediment availability, hydrodynamics, and climate change.

OBJECTIVES

- Measure the supply of sediments to a Louisiana salt marsh as a function of wind waves.
- Determine the hydrodynamics of the tidal channels dissecting the mudflats of Willapa Bay, WA.
- Apply, test, and validate a high resolution hydrodynamic-sediment transport model in tidal channels and determine the short-term evolution of the channels and the supply of sediments from the shelf.
- Integrate the short-term results of high resolution numerical models in long-term models of tidal channels and mudflat evolution.
- Link the transport of sediments to salt marshes via tidal channels to the resuspension of fine sediments in the adjacent shelf.
- Compare the results of the MURI project "Mechanisms of Fluid Mud Interactions under Waves" to measurements of sediment concentration in a nearby marsh channel.
- Integrate high resolution hydrodynamic measurements in tidal channels with ongoing research activities at the Willapa Bay "Tidal Flats" DRI location

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APPROACH

Field component

We have focused our studies on two different channels dissecting muddy coastlines. The first channel is Little Constance Bayou, a creek in the Rockefeller State Wildlife Refuge, and it was chosen to study the interplay between waves and sediment fluxes in muddy coastlines. The second channel dissects the tidal flats of Willapa Bay, and it was selected in order to understand the hydrodynamics of tidal flats and the connections between sediment characteristics, tidal flows and channel morphology. At both sited we deployed in the last two years Nortek acoustic doppler current profilers, Sontek acoustic doppler velocimeters, and RBR wave recorders to measure wave climate, tidal currents and sediment concentration in the water column.

High resolution modeling component

In order to integrate field measurements with long-term evolution models we are using the high resolution model WWTM2D at the Willapa Bay site. The hydrodynamic model WWTM2D solves the shallow water equations with a triangular finite-elements mesh (Defina et al. 1994) and it has been extensively tested in the tidal channels in the Venice lagoon, Italy (D'Alpaos and Defina 1995, Defina 2000).

Figure 1 Wave-cut gullies along the coastline at the Rockefeller National Wildlife Refuge. Two Nortek ADCP were deployed in gully #3 for three days.

Integration of short-term high-resolution models with long-term simplified models

In recent years we have developed a suite of morphological models that quantify the response of salt marshes to changes in sea level, sediment supply, vegetation, and substrate characteristics. The models are able to simulate the feedbacks between morphology and wave propagation in salt marshes (Fagherazzi et al. 2003, Rinaldo et al. 1999), the long-term variations in channel cross section (Fagherazzi and Furbish 2001, D'Alpaos et al. 2006) The development of the channel network (Fagherazzi and Sun 2004, D'Alpaos et al. 2005), the feedbacks between vegetation and sedimentation (Mudd et al. 2004) and the repartition of intertidal areas between tidal flats and salt marshes (Fagherazzi et al. 2006a; Fagherazzi et al. 2006b).

In this current project we have developed a one-dimensional numerical model for the coupled long-term evolution of salt marshes and tidal flats is muddy coastlines. The model framework includes tidal currents, wind waves, sediment erosion and deposition, as well as the effect of vegetation on sediment dynamics. The model is used to explore the evolution of the boundary between the salt marsh and the tidal flats under different scenarios of sediment supply and sea-level rise (Mariotti and Fagherazzi 2009).

Describe your proposed technical approach. Briefly identify the key individuals participating in this work at your own or other organizations and the roles they play.

WORK COMPLETED

Interplay between waves and sediment fluxes in tidal channels

We terminated the analysis of the data collected in Little Constance Bayou, at the Rockefeller State Wildlife Refuge, Louisiana USA, from December 2007 to March 2008. The tidal measurements were compared to measurements of wave activity in the bay near the mouth of the channel, thus allowing the quantification of feedbacks between waves and sediment fluxes (see Fagherazzi and Priestas 2009 for the full results).

Wave-cut gullies in muddy shorelines

We identified a new mechanism responsible for the erosion muddy coastlines and salt marshes. Wind generated waves concentrate their energy in selected locations eroding the coastline and producing elongated wave-cut gullies (Fig 1). We studied ten wave-cut gullies at the Rockefeller State Wildlife Refuge each at a different stage of evolution (Fig. 1). We determined short-term headward and lateral erosion rates with erosion pins. Gully geometry and morphology was measured using a Topcon surveying total station. We measured gully width, spacing and slope. To capture the gully morphology, we focused our surveying measurements to a single gully (#3). The first survey was completed 1/14/2008 while the subsequent survey was completed 03/14/2008. Within gully 3 we deployed two 2 MHz Nortek ADCPs separated by approximately 8 m (ADCP-1 near the headward tip and ADCP-2 shoreward) and measured tidal elevations and water velocity from 03/11/08 at 2 pm until 03/14/08 at 2 pm.

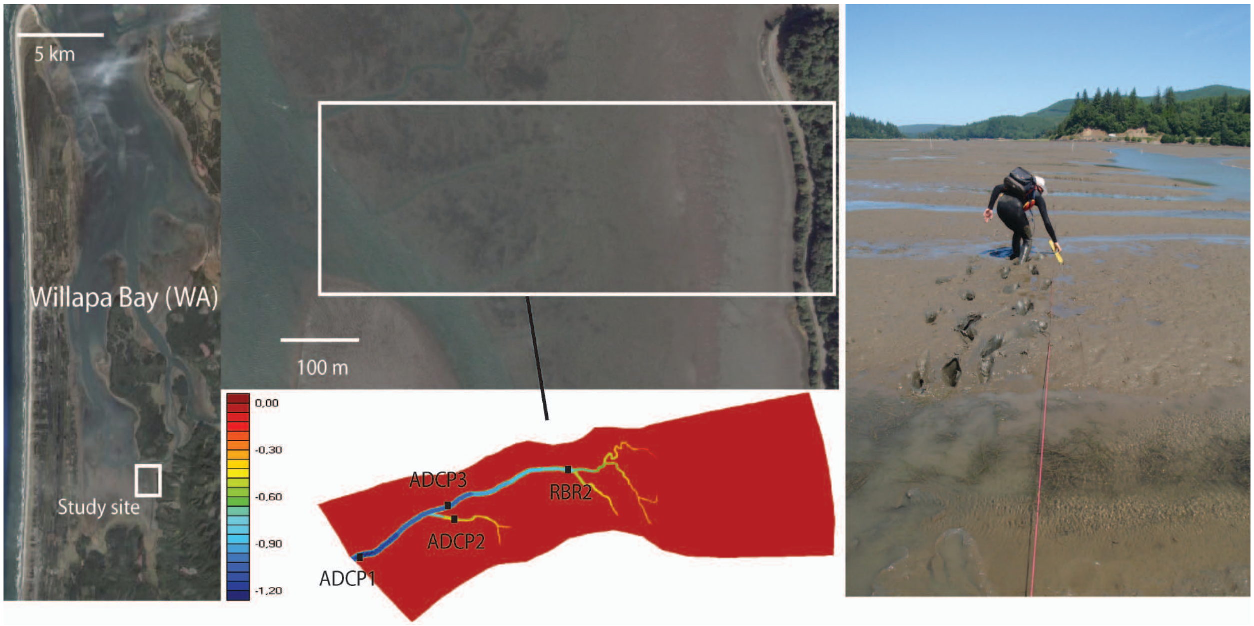

Figure 2 Studied tidal channel in Willapa Bay, WA. Three Nortek ADCP and one RBR were deployed in the tidal channel for two weeks in July 2009. A topographic survey produced the DEM indicated in red.

Hydrodynamics of tidal flat channels

In July 2009 we conducted a geomorphic study of a tidal channel in the mud flats of Willapa Bay (see Fig. 2). We deployed three ADCPs and one RBR for two weeks in a channel dissecting the mudflats, measuring tidal fluxes and sediment concentration every 15 minutes during spring tides. We have also conducted a topographic survey of the channel watershed with a Topcon total station, which will be used to implement the high resolution finite elements model WWTM2D in Willapa Bay.

RESULTS

Interplay between waves and sediment fluxes in tidal channels

Our results in Little Constance Bayou indicate that sediment fluxes in a tidal channel during flood are determined by wave climate. During storms, waves resuspend sediment in the nearshore area. These sediments are then funneled in marsh channels by the tide. Sediment concentration in the channel is linearly proportional to significant wave heights in the ocean. Storm surges carry large volumes of sediment to the marsh, but most of the material is returned to the ocean during the subsequent tidal cycle. On the contrary, long periods of wave activity, even of mild intensity and not necessary linked to storm surges, produce a net accumulation of sediments in the marsh. Meteorological low tides during fair weather conditions result in large ebb velocities which export sediments to the ocean. This sediment is not replaced in subsequent tidal cycles, giving rise to a net negative budget for the system.

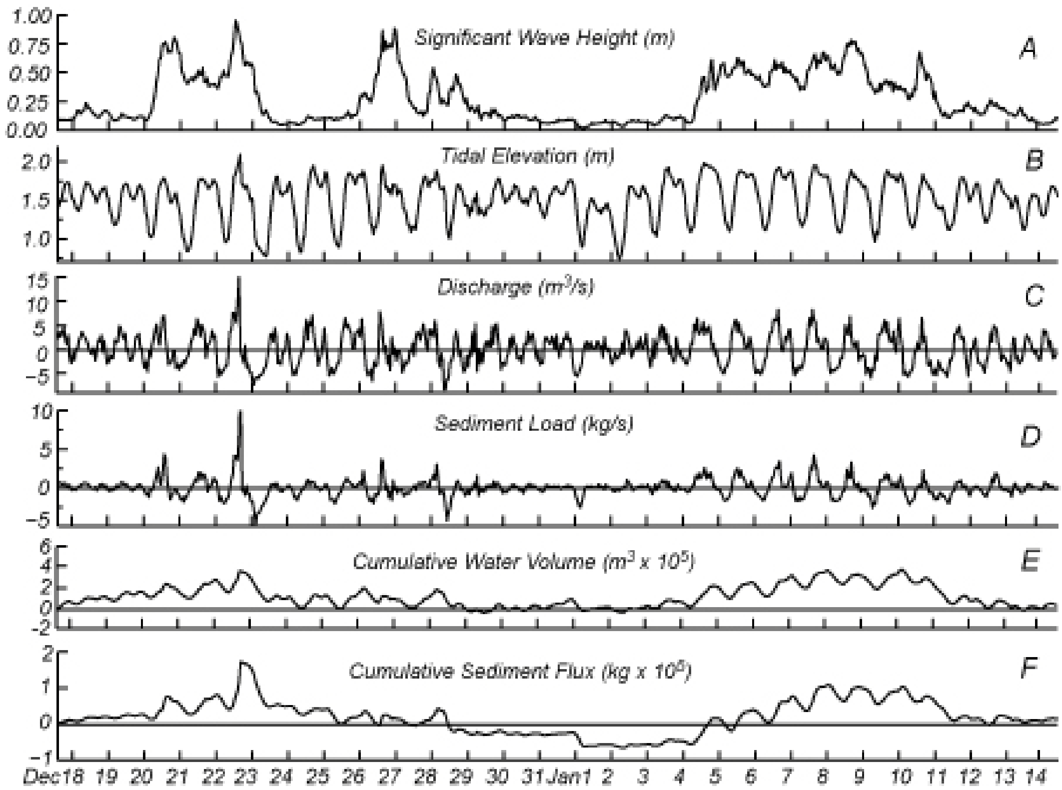

Figure 3. Time series of (a) wave height at the channel mouth, (b) tidal elevation in the channel (c) channel discharge and (d) sediment load in the channel for the entire study period; (e) cumulative water volume and (f) cumulative sediment mass that entered the chenier plain.

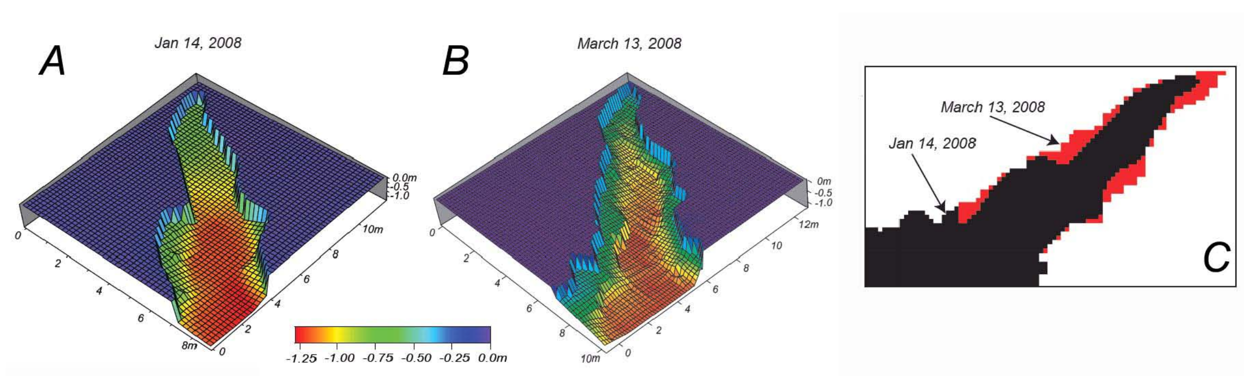

Figure 4. Wave gully erosion. The gully eroded deep in the marsh platform in the three months from Jan 14 to March 13 2008.

Wave-cut gullies in muddy shorelines

The most remarkable result of our field measurements in wave-cut gullies is the amount of landward incision that occurred after a moderate storm. In only one day the gullies incised up to 19cm in the marsh platform (see Fig. 1). We also found that the gullies formed at regular intervals with constant spacing. The length and width of the gullies increases with gully age, while the marsh surface was locally eroded near the oldest gullies. Comparing the gully morphology after three months we see that the gully had retained its basic morphology but its dimensions have changed considerably. Moreover the combined effect of wave shoaling wave breaking, and oscillatory motion had caused erosion of the gully floor.

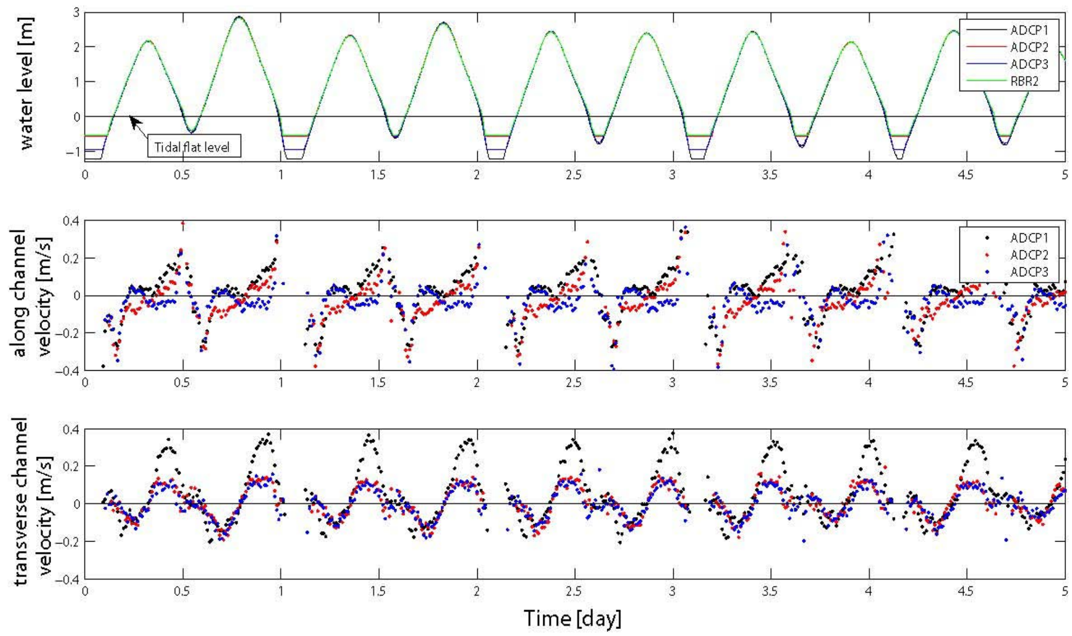

Figure 5. Hydrodynamics of a tidal channel in the mud flats of Willapa Bay. The locations of the three ADCPs is indicated in Figure 2. At location 1 the transverse channel velocity increases for high tidal elevations, indicating the presence of fast sheet flow on the tidal flat platform.

Hydrodynamics of a tidal flat channel

Preliminary results in a tidal channel dissecting the mudflats of Willapa Bay shed light on the hydrodynamics of channel networks. In particular, we were able to separate the confined flow in the channel during low tide and the sheet flow across the tidal flat platform during high tide. We also identified a mechanism for channel incision when the tidal flat platform emerges and the water in drained by the channel by gravity.

IMPACT/APPLICATIONS

The collected data will help assessing the navigability of tidal channels in denied areas. Moreover, the characterization of wave climate along a muddy coast will provide useful information for navigation in very shallow water and landing. Our project will also establish the connection between the geotechnical properties of sediment substrates and the spatial and hydrodynamic characteristics of tidal channels. Finally, the feedbacks between tidal channels and waves will provide information on the origin of marsh sediments and their characteristics.

RELATED PROJECTS

The proposed research is designed to synergistically complement the already funded MURI project "Mechanisms of Fluid Mud Interactions under Waves" (http://www.ce.jhu.edu/dalrymple/MURI/). The MURI project studies the interactions between waves and muddy bottomsets in the shelf in front of the Rockefeller State Wildlife Reserve. In this project we will measure the sediment concentration in nearby tidal channels during the same period, and use this information to tune a model for tidal channel evolution.

Our instrument deployment in Willapa Bay is also fully complementary with ongoing research activities of the "Tidal Flats" DRI project. In particular, we will provide high resolution measurements of tidal and sediment fluxes in the channels dissecting the mud flats at the Willapa Bay DRI location.

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