CHAPMAN
CONFERENCE

AGU CHAPMAN CONFERENCE ON
PHYSICS OF WAVE-MUD INTERACTION

Amelia Island, Florida, USA
17–20 November 2008

AGU Chapman Conference on Physics of Wave-Mud Interaction

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Conveners

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Sponsors

The conveners and planning committee wish to thank NortekUSA, Nortek Scientific for their cooperation in sponsoring the Welcoming Ice-Breaker Reception on Sunday 16 November. www.nortekusa.com, as well as the University of Florida's College of Engineering for supporting this conference.

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AQUATEC GROUP

MEETING AT A GLANCE
(Revised 11/13/08)

Monday, 17 November 2008

1100h – 1130h	Registration
1215h – 1445h	Oral Discussions
1445h – 1515h	Coffee Break
1515h – 1615h	Oral Discussions
1615h – 1645h	Panel Discussion I
1700h – 1900h	Ice Breaker Reception

Tuesday, 18 November 2008

800h – 1015h	Oral Discussions
1015h – 1045h	Coffee Break
1045h – 1215h	Oral Discussions
1215h – 1315h	Lunch
1315h – 1445h	Oral Discussions
1445h – 1515h	Coffee Break
1515h – 1645h	Oral Discussions
1645h – 1730h	Panel Discussion II
1730h	Dinner (On your own)

Wednesday, 19 November 2008

800h – 1015h	Oral Discussions
1015h – 1045h	Coffee Break
1045h – 1215h	Oral Discussions
1215h – 1315h	Lunch
1315h – 1445h	Oral Discussions
1445h – 1515h	Coffee Break
1515h – 1645h	Oral Discussions
1645h – 1730h	Panel Discussion III
1800h – 2000h	Banquet

Thursday, 20 November 2008

800h – 1015h	Oral Discussions
1015h – 1045h	Coffee Break
1045h – 1145h	Oral Discussions
1145h – 1245h	Summary
1245h – 1400h	Lunch (Boxed lunch available)

Sessions and events will take place at Amelia Island Plantation, Racquet Park Conference Center. The Registration/Information Desk will be in the Heron Room foyer throughout the conference.

MONDAY, 17 NOVEMBER

1100h – 1130h	**Registration** ♦ Heron Room Foyer
1445h – 1345h	**Session I – Sediment Characterization** ♦ Heron Room Chair: **S. Bentley**, Keynote: **C.C. Mei**
1345h – 1415h	**E. Toorman** *An investigation into thixotropic wave dissipation potential of fluid mud*
1415h – 1445h	**R. Faas, A. Reed** *Comparative analysis of two methods used to analyze the rheological properties of high density (fluid mud) suspensions*
1445h – 1515h	Coffee Break ♦ Heron Room
1515h – 1545h	**T. Holland, A. Reed, A. Sheremet** *Dynamic mud behavior in response to wave loading: observations, predictions and interpretations of seawave-seabed interaction*
1545h – 1615h	**S.-F. Su, A. Sheremet, M. Alison** *Mud rheology and wave dissipation on shallow muddy shelf*
1615h – 1645h	**Panel Discussion 1 -** *Advances in non-Newtonian rheology of marine muds* Moderator: **E. Toorman**
1700h – 1900h	**Ice Breaker Reception** ♦ **Egret Room** Sponsored by NortekUSA and Nortek Scientific

TUESDAY, 18 NOVEMBER

800h – 845h	**Session II – Dissipation Mechanisms** ♦ Heron Room Chair: **S. Vinzon**, Keynote: **R. Dalrymple**
845h – 915h	**N. Tahvildari, J. Kaihatu, A. Sheremet and S.-F. Su** *Predictability and invertibility of wave-mud interaction*
915h – 945h	**W. Kranenburg, J. Winterwerp, G. de Boer** *Modeling of fluid-mud induced wave damping within SWAN*

945h – 1015h	**J. Winterwerp, G. de Boer, G. Greeuw, D.S. van Maren** *Mud-induced wave damping in the Dutch Wadden Sea*
1015h – 1045h	Coffee Break ♦ Heron Room
1045h – 1115h	**J. Trowbridge** *Dynamics of interfacial waves in muds on the Louisiana shelf*
1115h – 1145h	**M. Alam, Y. Liu, D. Yue** *Numerical investigation of dissipation mechanisms for surface wave propagation over muddy seabed*
1145h – 1215h	**M. Jain, A. Mehta** *Problems in modeling mud rheology in a dynamic settling*
1215h – 1315h	**Lunch** ♦ Egret Room
	Session II – Dissipation Mechanisms (cont.) Chair: **J.M. Kaihatu**
1315h – 1345h	**E. Hayter, S. So** *Modeling wave-induced entrainment of mud in Lake Apopka, Florida*
1345h – 1415h	**J. Letter, A. Mehta** *A stochastic interpretation of cohesive bed-suspension particle exchange paradigm*
1415h – 1445h	**A. Torres-Freyermuth, T.-J. Hsu** *An integrated numerical model for the study of wave-mud interactions*
1445h – 1515h	Coffee Break ♦ Heron Room
1515h – 1545h	**H.S. Tang, T. Keen** *Coupled wave, current and morphology approach for accurate coastal flow simulation*
1545h – 1615h	**D. Robillard** *Stress-strain-behavior of cohesive seabeds*
1615h – 1645h	**A. Priestas and S. Fagherazzi** *Non-uniform Salt Marsh Boundary Erosion by Wave Impact in Costal Louisiana and Virginia: Implications for Sale Marsh Stability*
1645h – 1730h	**Panel Discussion II** – *Advances in modeling wave-mud interaction* Moderator: **J. Trowbridge**
1730h	Dinner (On your own)

WEDNESDAY, 19 NOVEMBER

800h – 845h	**Session III – Wave Processes** ♦ Heron Room Chair: **P. Traykovski,** Keynote**: S. Elgar**
845h – 915h	**J. Maa, H. Ha, Y.Y. Shao** *Using acoustic waves for identifying the change from fluid mud to solid bed*
915h – 945h	**S. Fagherazzi, M. Priestas** *Sediments and water fluxes in a muddy coastline: interplay between waves and tidal channels*
945h – 1015h	**I. Safak, A. Sheremet, T.J. Hsu, M. Allison** *Observations of waves and turbulence on a shelf*
1015h – 1045h	Coffee Break ♦ Heron Room
1045h – 1115h	**P. Pereira** *Video Observations of a Mud Deposition Event at the Surf Zone of Cassino Beach, Southern Brazil*
1115h – 1145h	**S. Vinzon, S. Rocha, G. de Boer** *Wave-mud interaction: some lessons from the Cassino project*
1145h – 1215h	**A. Smerdon** *Establishing limits on the applicability of acoustic backscatter techniques for the measurement of high concentrations of suspended sediment*
1215h – 1315h	Lunch ♦ Egret Room
	Session III – Wave Processes (cont.) Chair: **K.T. Holland**
1315h – 1345h	**P. Pratolongo, G. Perillo, Piccolo** *Short-wave effects on mud deposition at flat-marsh interface*
1345h – 1415h	**L. Shen** *Direct simulation of mud flow in bottom boundary layer*
1415-1445h	**P. Traykovski** *Observations of mechanisms of wave dissipation on the Louisiana shelf: the role of short wavelength lutocline internal mode waves*
1445h – 1515h	Coffee Break ♦ Heron Room
1515h – 1545h	**S. Bentley, K. Maas, S. Brandstatter, S. Johnson, G. Kineke, M. Lermon** *Depositional processes and sediment properties of fluid muds on the inner shelf: western Mississippi Delta, Louisiana, USA*

1545h – 1645h	**E. Siegel** *New acoustic measurements of currents, waves and sediment in the bottom boundary layer*
1645h – 1730h	**Panel Discussion III** – *Fluid Mud Properties* Moderator: **G. Kineke**
1800h – 2000h	Banquet ♦ Amelia Inn & Beach Club, Ocean View Terrace

THURSDAY, 20 NOVEMBER

800h – 845h	**Session IV –** Sediment Transport Chair: **S. Fagherazzi**, Keynote: **H. Winterwerp**
845h – 915h	**H. H. Hwung, W.Y. Hsu, R.Y. Yang, Y. Chang, I. Shugan, H.C. Hsu** *The settling process of cohesive sediment*
915h – 945h	**G. Kineke, S. Bentley, M. Lermon, S. Brandstatter, P. Traykovski , J. Trowbridge Waves** *Mud and buoyancy – positive feedbacks on a muddy coast*
945h – 1015h	**L. Sanford, A. Packman** *Interactions between bedload and mud transport in sand-mud mixtures subjected to wave forcing*
1015h – 1045h	Coffee Break ♦ Heron Room
1045h – 1115h	**G. Voulgaris, K. Kim** *Lateral circulation and sediment transport in a curved estuary*
1115h – 1145h	**K. Barry, G. Brown** *Wave-induced cohesive sediment transport in the South Bay salt pond restoration project*
1145h – 1215h	**S. Brandstatter, S. J. Bentley, S. Johnson, G. C. Kineke** *Be-7 Inventories as Tracer for Sediment Movements on the Inner Shelf: Western Atchafalaya River Delta, Louisiana, USA*
1145h – 1245h	Summary & Closing Remarks Moderator: **A Mehta**
1245h – 1400h	Lunch (Boxed lunch available)

Numerical Investigation of Dissipation Mechanisms for Surface Wave Propagation over Muddy Seabed

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Mechanisms of surface wave dissipation over a muddy sea floor are studied using direct numerical computations together with comparisons to available field measurements. The numerical computation is based on the primitive equations for the wave motion problem and accounts for effects of nonlinear surface wave interactions in a broadband spectrum, nonlinear surface-internal wave interactions associated with density stratification, nonlinear wave-bottom interactions, and viscous dissipation in the fluid and on the bottom. Among the various dissipation mechanisms, the following three are of special interest in this study: direct (linear) wave-mud interactions, indirect (nonlinear) wave-mud interactions with long waves generated from wave resonance or near-resonance, and resonant interactions of surface and interfacial (mud) waves. In the direct mechanism, the mud is modeled as a visco-elastic sea floor with its motion described by a simple mass-spring-damper system. The direct model is capable of predicting the attenuation of long waves with good agreement with field measurement, but is not robust for short waves. The indirect mechanism, which is an extension of the direct mechanism by accounting for resonant and near-resonant wave interactions, does not provide significant additional dissipation for short waves. Resonant interactions between surface waves and interfacial waves (on mud surface) however furnish a strong mechanism for the transfer of surface wave energy into interfacial waves which are then dissipated by the mud. The effectiveness of this mechanism depends on the depths and densities of water and mud layers that are strongly affected by the complex process of resuspension in realistic environments.

Wave-Induced Cohesive Sediment Transport in the South Bay Salt Pond Restoration Project

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The State of California and the Federal government are embarked on the restoration of 15,100 acres of Cargill's former salt ponds in South San Francisco Bay. This project, the San Francisco South Bay Salt Pond Restoration Project (SBSPRP), is the largest tidal wetland restoration project to date on the west coast of the United States. With large-scale tidal restoration, alterations in the sediment dynamics within the estuary are expected that will affect this mix of habitats and the ecologic functions dependent on them. Restoring these ponds to vegetation colonization elevations requires taking advantage of the natural deposition of estuarine sediments brought into the restored site on flood tides. This new sediment

demand or "sink" will affect Bay bathymetry and the extent of offshore mudflats and marshes over the long-term in the South Bay.

Predictive numerical modeling has been conducted to assist in designing an effective restoration strategy and evaluating design alternatives. A key component of this effort and many wetland restoration efforts is the quantitative description of physical sediment transport processes (including wave induced erosion and transport of cohesive sediment). An accurate quantitative description of the interaction of these processes yields a model that can predict the sediment transport in an estuarine system. Consequently, for the SBSPRP an adaptive, multi-class, mixed (cohesive and cohesionless) sediment transport model was developed and applied to the system. Different formulations for calculating bottom shear stress from combined wave-current interaction were incorporated into the model and their impacts on bottom boundary layer sediment flux and suspended sediment concentration compared.

Depositional Processes and Sediment Properties of Fluid Muds on the Inner Shelf: Western Mississippi Delta, Louisiana, USA

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On the muddy inner shelf of the western Mississippi River Delta, Gulf of Mexico, regional sediment flux and coastal currents combine with local morphology and hydrodynamics to induce deposition of fluid muds along the open coastline. This generally progradational coast, known as the Louisiana Chenier Plain, has been the subject of geological and hydrodynamic studies from the 1950's to the present, because of scientific interest in similar environments associated with many large river systems worldwide, and in the ancient rock record.

Over the last seven years, depositional and stratigraphic patterns of this dynamic seabed have been studied with sidescan and CHIRP subbottom sonar, sediment coring, radioisotope geochronology, X-radiographic imaging, and sedimentological analyses, in conjunction with more recent hydrodynamic observations. Results indicate that the formation of seasonal fluid-mud deposits requires a combination of high and temporally concentrated sediment supply from the Atchafalaya River, in conjunction with currents and waves generated by frequent cold front passages. Wave energy is attenuated inshore, facilitating sediment deposition primarily in water <10m depth. Resultant strata are composed of stacked upward-fining beds that possess laminated and/or rippled silty basal units overlain by clay drapes (to 25 cm thick with porosities >85%). Bioturbation is generally minimal, and porosity may remain above 80% a meter into the seabed.

During storm or cold front passages when alongshore sediment flux from the river is minimal, seabed erosion can occur, reshaping and redistributing deposits formed during periods of higher sediment flux. As a result, short –term deposition rates commonly exceed long-term sediment-accumulation rates, due to the dynamic response of the seabed to temporally and spatially varying sediment supply, wave energy, and wave attenuation.

Be-7 Inventories as Tracer for Sediment Movements on the Inner Shelf: Western Atchafalaya River Delta, Louisiana, USA

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We have undertaken seabed studies on muddy inner shelf west of the Atchafalaya River Delta to elucidate controls of cold front passages and seasonal supply of river sediment on formation, deposition, and physical properties of fluid muds. Sediment boxcores were collected during cruises in February, March and April 2007 and 2008, coordinated with time-series hydrodynamic observations, to coincide with peak river discharge and the occurrence of ~weekly cold fronts that occur in winter and spring. Cores were taken along repeat transects perpendicular to the shoreline and subsampled for X-radiography, and measurements of grain size, water content, and Be-7 (half life 53.3d), a cosmogenic particle reactive radioisotope that can be used as a tracer of fluvially derived sediments in coastal marine settings.

Measurable Be-7 activities were generally confined to physically stratified surficial sediments (the upper ~2-6 cm of the seabed) with high water content (porosity >80%), indicating that these sediments were recently deposited and/or remobilized by currents. Changes in spatial distributions of Be-7 inventories between cruises demonstrate that this high-porosity sediment layer (representing 7-20 kg of dry sediment per square meter of seabed) is highly mobile over monthly timescales, in response to wind-wave resuspension and transport associated with cold fronts. Patterns of Be-7 inventories suggest that sediment is first delivered from fluvial sources to the east following peak river flow in early spring, and then deposited across a wide region extending 10-15 km from the shore. Subsequent sediment resupension and shoreward transport in the bottom boundary layer (associated with cold front passage) results in occurrence of high Be-7 inventories within 5-10 km of shore, landward of the 10 m isobath.

Laboratory Measurements of Wave Damping over Mud

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The decay of water waves propagating over mud is examined in two experimental facilities: a 18 m long wave tank and a shaker table apparatus that creates standing waves. Experiments using kaolinite clay show that the history of wave motion is very important in determining the wave damping in that the damping changes with time, corresponding to changes in the mud rheology.

An extension of the theory of Sheremet and Stone for damping of deep water waves over mud is presented. These authors have pointed out that second order difference waves in the spectrum create long waves that affect the bottom. The higher frequency sum waves can also reach the bottom when the wave angles of incidence are large.

Wave Dissipation by Muddy SeafloorsWave Dissipation by Muddy Seafloors

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Muddy seafloors cause tremendous dissipation of ocean waves. Here, observations and numerical simulations of waves propagating between 5- and 2-m water depths across the muddy Louisiana continental shelf are used to estimate a frequency- and depth-dependent dissipation rate function. Short-period sea (4 s) and swell (7 s) waves are shown to transfer energy to long-period (14 s) infragravity waves, where, in contrast with theories for fluid mud, the observed dissipation rates are highest. The nonlinear energy transfers are most rapid in shallow water, consistent with the unexpected strong increase of the dissipation rate with decreasing depth. These new results may explain why the southwest coast of India offers protection for fishing (and for the 15th century Portuguese fleet) only after large waves and strong currents at the start of the monsoon move nearshore mud banks from about 5- to 2-m water depth. When used with a numerical nonlinear wave model, the new dissipation rate function accurately simulates the large reduction in wave energy observed in the Gulf of Mexico. Funded by the US Office of Naval Research.

Sediments and Water Fluxes in a Muddy Coastline: Interplay between Waves and Tidal Channels

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Tidal channels are ubiquitous in muddy coastlines and play a critical role in the redistribution of sediments, thus dictating the general evolution of tidal flats and marshes. In muddy coastlines the morphology of the tidal channels and adjacent chenier plains strongly depends on the supply of fine sediments from the shelf and on the resuspension of sediments by wind waves. To investigate the processes that regulate sediment fluxes in muddy coastlines, we measured velocity and sediment concentration in Little Constance Bayou, a tidal channel in the Rockefeller State Wildlife Refuge, Louisiana. The tidal measurements were integrated with measurements of wave activity in the bay just in front of the channel, thus allowing the quantification of the feedbacks between waves and sediment fluxes in the channel. Preliminary results indicate that the sediment concentration in the channel is directly related to the wave height in the adjacent bay during flood and high slack water, whereas the concentration during ebb depends on local channel velocity. Moreover, the sediment discharge during ebb is proportional to the flood discharge during the previous tidal cycle, showing that only a small part of the sediments are stored in the chenier plain during a tidal cycle. Finally, storm surges remobilize large volumes of sediments that are transported through the channels in the internal chenier plain.

Modeling Wave-Induced Entrainment of Mud in Lake Apopka, Florida

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Lake Apopka is a 31,000-acre, shallow eutrophic lake in central Florida that is loaded with fine-grained, organic-rich fluid mud at the bottom. It has mean and maximum depths of 1.7 m and 2.7 m, respectively, and its stage is regulated by a lock and dam structure located on the Apopka-Beauclair Canal, the lake's only outlet. Lake Apopka's eutrophic state is a result of excessive phosphorus loading over more than 40 years from a 20,000 acre farming area, formerly located on the shores of the lake. There is a need to investigate the potential impacts of changing Lake Apopka's water elevation regime on water quality; specifically how changes in depth would affect wind-generated fluid mud entrainment within the lake. Increased sediment resuspension would likely increase internal nutrient recycling in the lake due to desorption of phosphorus from the anoxic bottom sediment when it is resuspended and mixed in the overlying oxic lake waters. A modeling study of Lake Apopka, that consisted of the development and application of a public-domain 3D hydrodynamic and fine-grained sediment transport model (EFDC) that can simulate the entrainment and vertical mixing of the organic-rich fluid mud for varying wind velocities and lake levels will be described.

The Lake Apopka modeling study consisted of the following. 1) Incorporate the ability to simulate wave-induced entrainment of fluid mud into the EFDC modeling system. 2) Use a wave generation and transformation model (SWAN) to simulate the wave field for given wind speeds and lake levels. The spatially varying wave conditions were used in EFDC to calculate the combined bottom shear stress due to currents and short period waves using the methodology by Soulsby. 3) Calibrate and validate the hydrodynamic and sediment transport models in the modified version of EFDC and SWAN using wind, current, wave and SSC data measured at an instrument tower located in the central region of Lake Apopka. 4) Lastly, the SWAN and EFDC models were used to simulate the wave field, circulation and resulting sediment transport for selected water levels and wind velocities to determine the affect of the varying water levels and wave conditions on the entrainment of the organic-rich fluid mud in Lake Apopka. Results from these simulations will be presented.

Dynamic Mud Behavior in Response to Wave Loading: Observations, Predictions and Interpretations of Seawave-Seabed Interaction

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Wave interaction with soft marine mud has been a topic of research for many decades with various proposed theories and a moderate number of observations. Models of this interaction have simulated responses assuming viscous, viscoelastic, poroelastic, and plastic beds; however, our ability to monitor the actual rheologic properties of natural mud bottoms under oscillatory strain is extremely limited, especially in terms of field observations under storm wave conditions. Therefore, we see a strong disconnect between the assumptions of available models and the reality of the boundary conditions and relevant sediment parameters used to drive them. One important example is with respect to the common assumption of static rheological conditions. Observations made in southern Brazil and in the Atchafalaya Basin during 2005 - 2008 suggest that marine muds respond dynamically to environmental forcing such that the bottom can assume an almost continuous stratification in terms of density, fluidization thickness, viscosity and consolidation. At times, for specific depths, the fluid mud layer is ~1-2 mm thick during the onset of wave-energy buildup and becomes thicker (over 30 cm) as the magnitude and duration of wave activity increases. Also, the identification of the top of the consolidated layer is not always precise and this stratum may well exhibit elastic as well as rigid behaviors. Lastly, the rate of mud fluidization can be quite rapid, as eruptive events have been recently observed, while the rate at which fluid mud is consolidated appears to be more gradual. Because these dynamic properties and behaviors are difficult to measure and model, we explore the relative importance of fluid and consolidated mud properties that can be observed in the field using theoretical predictions of seawave-seabed interaction (Foda et al., 1993). Our simulations of bed fluidization under measured conditions reveal many of the possible complications of working with natural sediments in a field setting. Our interpretation of these findings, when combined with our experiences in data collection, helps identify the more successful monitoring approaches and provides suggestions for topics in need of further research.

The Settling Process of Cohesive Sediment

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This research deals with the settling process of cohesive sediments. An array of Optical Backscatter Sensors (OBS) and Acoustic Doppler Velocimeters (ADV) are mounted in an experimental water tank and observe the sediment concentration and turbulence of fresh water and salt water. The results reveal that the interaction between diffusive dispersion and gravitational settling will cause different settling behavior before hindered settling occurred. As salinity increases, buoyancy and flocculation will also have influences on the settling process. Two distinct settling mechanisms including (1) diffusive dispersion which dominates the process in low sediment concentration cases and (2) gravitational settling which dominates the process in high sediment concentration cases are found in this experiment. Shock waves in the sediment concentration profile are also observed during the gravitational settling process.

Problems in modeling mud rheology in a dynamic settling

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Loss of incoming wave energy at muddy coasts has significant implications for shoreline stability. Prediction of the rate of energy loss of a given wave train depends on the rheological properties of bottom mud. Common rheological models implicit in mechanisms describing the rate of energy loss include those representing viscoelastic and poroelastic behaviors of mud. Review of literature suggests that in most cases selection of the dissipation mechanism and the associated rheological model have been based on inadequate knowledge concerning the properties of mud in a dynamic setting. Accordingly, some problems that can arise from the use of these models for prediction of the wave attenuation coefficient are addressed.

For wave attenuation due to viscoelastic mud, results based on a semi-analytical model are reviewed. This and an existing model for poroelastic beds have been tested against selected laboratory data. Using results from these tests it is emphasized that fluid-like mud should be modeled as a viscoelastic *fluid* medium, and that only non-fluid beds can be modeled as poroelastic media.

Mechanisms for wave energy dissipation depend the solids volume fraction, porosity or density, and on a characteristic Péclet number defined by particle size, permeability and wave frequency. Due to the critical role of the latter parameter, the chosen rheological model for a bed of given compactness must be applicable over the expected range of wave frequency. This stipulation is a step towards quantification of the procedure to

select the optimal model for wave attenuation.

is larger in water with significant fluctuations.

Direct Simulation of Mud Flow in Bottom Boundary Layer

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We perform direct simulation of mud flows in the bottom boundary layer in order to investigate the dynamics of wave-mud interaction at small scales and to establish a physical basis for the development of improved dissipation models for wave simulation at large scales. In our computation, the continuity equation and momentum equations in the primitive form are simulated with a hybrid pseudo-spectral and finite-difference scheme. A clustered grid is used in the vertical direction to fully resolve the boundary layer. A Bingham plastic model with viscosity regularization is employed. From simulations, we obtain a detailed description of the unsteady, three dimensional mud motion. Comparison between the mud flow and water flow simulation results shows that there exists substantial difference in the velocity, vorticity, kinetic energy, and dissipation statistics between the two fluids. In particular, the presence of mud makes the fine vortical structures near the bottom merge to form coherent structures. In the vicinity of the bottom, dissipation rate in mud is higher with smoother distribution comparing to that in water. Away from the bottom, dissipation

Waves, Mud and Buoyancy – Positive Feedbacks on a Muddy Coast

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Research since the 1970s suggests the repeated passage of cold-fronts on the Louisiana Chenier Plain during the winter and spring months plays an important role in the accretion of this coastline, despite widespread retreat in adjacent areas. More recently, hydrodynamic observations have

documented the wave, water column, and sea bed interactions responsible for the seemingly contradictory situation of energetic or stormy conditions leading to accretion not erosion of the coastline. The combination of wave dissipation over a muddy seabed and fluid muds, event-driven mean currents, particle characteristics and water column stratification all contribute to net onshore transport and accretion. Typically sediment from the Atchafalaya River is delivered to the shelf in late winter. During the passage of cold-fronts waves initially suspend sediment but strong dissipation during post-front conditions protects the coast from erosion. Rapid settling of flocculated fine sediments after the front passes leads to formation of high-concentration bottom layers, or fluid muds. Rapid settling is also enhanced during post-front periods with stratified conditions resulting from the offshore advection of fresher surface waters and onshore advection of higher-salinity sediment-laden bottom waters. The added near-bed stratification due to the fluid mud layer damps turbulence, further promoting flocculation and rapid settling. While the orientation of the coastline and weather patterns are specific to this system, the processes are not. The combination of and positive feedbacks between processes are typical of many fluid mud environments, giving rise to the statement ‘mud breeds mud.’

Modeling of Fluid-Mud Induced Wave Damping Within SWAN

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Soft, liquefied mud can damp surface waves efficiently, as observed at the coasts of Louisiana, Guyana, India, Thailand, and in the laboratory. A number of two-layer fluid mud schematizations have been presented in literature to model this damping, using various rheological models. It can be argued though that a simple Newtonian model with augmented viscosity accounts for the majority of observed damping rates.

We have developed a new dispersion relation for a two-layer schematization with a non-hydrostatic upper layer and a viscous hydrostatic lower layer, and derived the dissipation rate from this new dispersion equation. As the soft mud also affects the wave length, we elaborate on the group velocity and turning rates as well. The dispersion equation has at least four roots, of which only two have physical meaning in the current context. As the various roots may be very close, a robust solver had to be developed to find the proper ones. The new dispersion equation, solver and energy dissipation rate were implemented in SWAN, which required a considerable restructuring of the code as well. As in the existing SWAN-approach, We assume linear superposition with respect to wave frequency and direction to account for real-world wave fields in two-dimensional horizontal space.

We have compared the new model in multi-dimensional parameter space with those presented in the literature, specifying their domain of applicability, and the rate of dissipation as a function of water depth, wave frequency, and mud layer thickness, viscosity, and density. We show that pronounced peaks in dissipation rate can occur at shorter or longer wave periods, or that the damping rate is more or less constant for various wave frequencies, depending on parameter settings. Finally we have defined a number of idealized cases with real-world characteristics, for which exact analytical solutions exist, or for which the mud-wave response can be assessed qualitatively. We found that the new SWAN model predicts wave damping, shoaling and refraction over soft, liquefied mud layers on a horizontal or sloping bed properly.

Short and Long Waves over a Muddy Seabed

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Available experiments have shown that, in time-periodic motion the rheology of fluid - mud displays complex viscoelastic behavior. Based on empirical data, we study the interaction of water waves and fluid-mud by a two-layered model where water above is assumed to be inviscid and mud below is viscoelastic. As the fluid-mud layer is usually very much thinner than the water layer above, an analytical theory is derived by a multi-scale perturbation analysis for the interaction between fluid-mud and small-amplitude waves with a narrow frequency band. It is shown that at the leading order and within a short distance of a few wavelengths, wave pressure from above force mud motion below. Over a much longer distance, waves are modified by the accumulative dissipation in mud. At the next order infragravity waves due to radiation stresses are affected indirectly by mud motion through the slow modulation of the short waves. Explicit results are obtained for a wave train entering a semi-infinite region of muddy bed. Mean set down and bound long waves are found to attenuate with the short waves, and free long waves can be radiated from the junction.

Modeling of surf-zone response to synoptic meteorological variations

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Accurate prediction of surf-zone response to wave forcing and wind forcing in general and atmospheric fronts in particular is important in quantifying sediment mobility and change in beach morphodynamics. Nearshore wave climate and associated alongshore sediment transport in the Southeast US is dominated by local wind-generated waves, while offshore swell contribution is of limited importance. Observed energetic wave conditions are related to three atmospheric front systems: 1) Cold fronts, 2) Warm fronts, and 3) Tropical Storms. Low pressure systems associated with cold fronts moving from west to east-northeast, change the wind direction from northeast to southwest (oceanographic convention). Conversely, warm fronts are accompanied by an opposite change in wind direction. Tropical storms moving offshore the coast rotate the wind direction slowly from southwest to southeast. Analysis of long term (2004-2007) nearshore wind, wave and current information from a station located at mean water depth of 5 meters on the coast of SC (Springmaid Pier), is utilized to examine the relationship between meteorological forcing and nearshore hydrodynamic conditions. During this time period, 24 cold fronts, 18 warm fronts and 14 tropical storms were detected on average for each year.

In this contribution, a 2-D wave propagation model, Simulating WAves Nearshore (SWAN), coupled with the coastal-circulation model Regional Ocean Modeling System (ROMS v 3.0) is being used to predict longshore current and sediment transport in surf zone in response to the different types of fronts. The performance of the coupled models is evaluated with in-situ measurements along the coast of South Carolina and the results and model performance is discussed. The impact of atmospheric fronts and tropical storms over a year in terms of net alongshelf sediment transport in the surf zone will be presented using the model results.

A Stochastic Interpretation of Cohesive Bed-Suspension Particle Exchange Paradigm

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Bed exchange for cohesive sediment has been treated by some as an exclusive erosion or deposition process and by others as a simultaneous process. Test cases have been developed that support each approach. Cohesive sediment bed exchange has historically been treated as a bulk process, where erosion is a function of the excess shear stress above an erosive threshold shear strength of the sediment bed and deposition is typically a function of a probability of deposition based on a depositional threshold critical shear stress. These bulk thresholds lead to the exclusive paradigm. The development of detailed cohesive particle flocculation models that explicitly address the effects of turbulence on floc size and settling rates forces one to consider the range of effects of the shear stresses on the spectrum of floc sizes. This consideration leads to the simultaneous bed exchange paradigm. The incorporation of a stochastic representation of shear stress, settling velocity and floc strength into a vertical sediment transport model with a flocculation model helps to resolve apparent contradictions and supports simultaneous erosion and deposition processes.

Using Acoustic Waves for Identifying the Change from Fluid Mud to Solid Bed.

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To understand the material properties of mud is a critical issue for correctly simulating wave-mud interactions. Past experience on using viscous fluid, viscoelastic, porouselasticl, etc. were all partially successful for simulating the significant wave attenuation, but these simulations could not help to identify what exactly the material properties should be. Direct experiments to find the correct material properties for mud, to find parameters for classification or/and to describe the change from one type of material to others are scarce. In general, it is believed that bulk density is an important parameter, but consolidation duration also plays an important role.

Acoustic waves have been used extensively at labs and fields for many applications, and it is also possible for identifying the status of mud, e.g., using the difference in pressure wave attenuations to identify the change of bulk density. It is also possible to use the different echo strength to determine the bulk density, and to identify where is the bed. The feature of shear wave transmission, however, has not been used yet probably because of the difficulty to generate shear waves and the coupling problem.

In laboratory experiments, acoustic chirp pressure waves were used to measure the bulk density profiles for various consolidation stages. Tone bursts on 250 khz shear waves and 500 khz pressure waves were used together to mark the variation of bulk density and the development of solid structure. Kaolinite was used for these experiments.

Comparison and application of different rheological model to fluid-mud interaction

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Mud in general can range from being a highly rigid and weakly viscous material to one that can be approximated as a purely viscous fluid, depending on the properties of the constituent sediment, the ambient fluid and the wave characteristics. A proper rheological model of mud should be adopted in order to investigate wave-mud interaction. Due to the complexity of mud behavior, different constitutive equations have been assumed for the response of muddy beds during past decades. The large list of the rheological models includes: viscous, visco-elastic, visco-plastic, poroelastic, visco-elastic-plastic, etc. Moreover, some researches have employed empirical formulas which they primarily developed for their interested sites.

The paper overviews some of the current rheological models and examine their performances on laboratory and also real field conditions. The effect of rheological models on the two main phenomena of wave-mud interaction, i.e. wave attenuation and mud mass transport, are particularly studied. Although the more sophisticated rheological models look better to represent the mud behavior, they have the demerits of evaluating the required parameters both in laboratory and field.

Video Observations of a Mud Deposition Event at the Surf Zone of Cassino Beach, Southern Brazil

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Most beaches around the world are composed of sand, gravel, or mud. In some instances a heterogeneous environment is created by the combination of sand and an episodic mud deposition, as is the case of Cassino Beach, southern Brazil, located south of the Patos Lagoon Inlet. Mud deposition events fill the entire surf zone, and at times, the entire backshore. Although the periodicity patterns of such events are still unknown, the duration of the deposition lasts between days and months depending on the amount of incoming sediment and the prevailing wave energy. Recently, in February 2008, a large deposition event occurred at Cassino Beach in response to a storm and was remotely detected using a video imaging system with deposition effects lasting approximately 15 days. The images show the wave attenuation in the inner surf as a reduction in image intensity contrast, supporting the idea of the inner surf zone being filled with fluid mud. Differences in the light reflection pattern by the water surface and by the fluid mud surface were also evident, providing a contrast between the inner and middle surf zone. In addition to this clear boundary, it was also possible to observe the boundary fluctuating in the cross-shore position with time. Such fluctuations are a response of the wave groups that were not totally attenuated by the mud and entered the fluid-mud region. A spectral analysis was performed on a cross-shore pixel intensity time stack and a change in the dominant peak frequency was found during the second day of the event as the waves propagated from the outer surf zone to the shoreline without dissipating their energy by breaking. The fluid mud signal observed at the water surface lasted for 20 hours after the mud was initially observed in the images. Based on the present findings, it is clear that the wave-mud interactions in the surf zone can be remotely detected during the early stages of mud deposition events.

Short-Wave Effects on Mud Deposition at a Flat-Marsh Interface

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Although the Bahía Blanca Estuary (Argentina) is, in general, in an erosional stage, there are certain sectors in which depositional processes are occurring due to local hydrodynamic conditions. For instance, a number of *Spartina* marshes have developed since the major dredging of the 60 km navigational channel made in 1989-1990. The Villa del Mar tidal flat-marsh complex is regularly affected by short, locally generated waves due to the strong winds that commonly affect the estuary. Measurements of wave and tidal currents were made at the interface between the marsh and tidal flat with two ADV, each located every environment, for a

neap-spring tidal cycle. The ADV systems also allowed the determination of the distance of the sensors to the sediment surface. Events of mud deposition and posterior erosion were detected after intensive wave activity, however, these depositions were concentrated only on the tidal flat and there were only minor changes on the marsh. In fact, it is clear from the analysis of the marsh, inclusive from data of SET, that sedimentation in this complex only occur at the tidal flat, whereas few sectors of the marsh are actually having some sedimentation in mud pockets depositional processes are occurring due to local hydrodynamic conditions. For instance, a number of Spartina marshes have developed since the major dredging of the 60 km navigational channel made in 1989-1990. The Villa del Mar tidal flat-marsh complex is regularly affected by short, locally generated waves due to the strong winds that commonly affect the estuary. Measurements of wave and tidal currents were made at the interface between the marsh and tidal flat with two ADV, each located every environment, for a neap-spring tidal cycle. The ADV systems also allowed the determination of the distance of the sensors to the sediment surface. Events of mud deposition and posterior erosion were detected after intensive wave activity, however, these depositions were concentrated only on the tidal flat and there were only minor changes on the marsh. In fact, it is clear from the analysis of the marsh, inclusive from data of SET, that sedimentation in this complex only occur at the tidal flat, whereas few sectors of the marsh are actually having some sedimentation in mud pockets

Comparative Analysis of Two Methods Used To Analyze the Rheological Properties of High Density (Fluid Mud) Suspension (HDS).

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Results of rheological analyses of HDS (fluid muds) were compared in order to assess the quality of rheological data provided to wave-energy dissipation models (e.g., SWAN). This includes yield stresses (static and dynamic), 'apparent viscosities', and flow behavior (shear thinning/thickening). This data was assessed for three different environments: 1) coastal area (<10 m) off Cassino Beach, southern Brazil, 2) nearshore (< 10 m) in the Atchafalaya mud stream, southwestern Louisiana, and 3) estuarine (including the turbidity maximum) of the Neuse River, North Carolina. Analyses were performed with an 8-speed Brookfield RVT rotational viscometer equipped with a couette coaxial cylinder apparatus with a narrow gap (1.24 mm). The data were analyzed as a Newtonian fluid using standard Brookfield Engineering Company analysis and as a non-Newtonian fluid using a modification (Rosen, 1976) of the method proposed by Krieger and Maron (1954). Comparisons between the data were made at each of the eight spindle rotation rates (0.5, 1, 2.5, 5, 10, 20, 50 and 100 rpm). Flow behavior curves and rheograms were constructed for both the Newtonian (fixed shear rates) and non-Newtonian behavior (variable shear rates) to compare results. Differences in shear rates were observed, with Coefficients of Variation (CoV's) ranging from 6-10% in the lowest two rpm, with maximum CoV's between 20 – 30% in the next four rpm, and minimum CoV's (4.03% and 4.61%) at the two highest rpm. However, flow diagrams and rheograms resulting from both techniques, when superimposed, show little deviation from each other. While individual shear rates at each rpm may differ, the overall viscous relationships used in wave models (i.e., yield stress, 'apparent' viscosities, and flow behavior) are nearly identical. Numerous models to predict rheological behavior of specific types on non-Newtonian suspensions, e.g., Casson, Herschel-Bulkley, Worrall-Tuliani, Robertson-Stiff, etc., and have been used with varying success. However, due to the parametric variability of HDS and that the Krieger and Maron (1954) computational analysis assumes a non-specific, non-Newtonian behavior, rather than an ideal behavior (e.g., Bingham or power-law fluid), we suggest that, in cases when the HDS behaves in a non-Newtonian fashion, the rheological and flow behavior analysis be determined with the Krieger and Maron (1954) procedure.

Stress-Strain Behavior of Cohesive Seabeds

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Many occasions have been chronicled of severe sea conditions being significantly calmed after propagation over a predominantly clay fractioned, cohesive (mud) seabed. Knowledge of the mud seabed structural properties and mineral composition is important in order to understand the influence the seabed will have on the dissipation rate of water wave energy-flux. The objective of this study is to gain a better understanding of the structural mechanics of a mud seabed and how its dynamics influence dissipation of water wave energy-flux.

In the process of attenuating wave energy, adaptation of the mud seabed to the external energy forcing of the wave field includes changes in its viscous properties. This bed adaptation can cause the dynamic viscosity of the seabed to vary by orders of magnitude with depth in the bed. The resulting shear-stress depth profile along with knowledge of the yield stress depth profile in the bed enables estimation of how much energy is lost by the wave field to the seabed.

Stress-strain behavior of natural mud from the Atchafalaya River, LA delta system was measured under laboratory conditions. The results from this analysis were used in a model to predict the depth of bed liquefaction and the dissipation rate of wave energy-flux over a constant depth bed.

The same natural mud was placed in a wave flume and the dissipation rate of wave energy-flux was measured across the bed for various monochromatic wave forms. Model results were compared with wave energy-flux dissipation rate data collected from the wave flume study.

Results demonstrate that the mud displays a self-similar structure up to the 'space-filling' density of the mud. This density is specific for the mineral composition of the mud and is defined as the density at which the volume of free pore water is zero. Below and above this density, the yield stress of the bed is related to the specific bed concentration by different power law relationships. A method is presented that determines both the space-filling density and the power law relationship between bed concentration and yield stress. Knowledge of these relationships is critical to accurately determine the energy dissipation ability of the mud seabed.

Observations of Waves and Turbulence on a Muddy Shelf

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Two synchronized Sontek Hydra ADVs (Acoustic Doppler Velocimeter) were deployed for 2 weeks in early spring 2008 on the Atchafalaya Shelf, Louisiana, USA to observe near-bottom wave, turbulence and sediment transport processes over cohesive sediment sea beds. To separate the effects of waves and turbulence, the ADVs sampled at 10 Hz and were mounted in a vertical array. Near bottom velocity profile and suspended sediment concentration were also monitored using high resolution optical backscatter sensors and acoustic Doppler current profilers. Estimated Reynolds stresses are strongly correlated to observed near-bottom suspended sediment concentration. A uni-dimensional boundary layer model for fine sediment transport is used to reconstruct the near bed suspended sediment concentration and simulate its effects on the velocity field.

Interactions Between Bedload and Mud Transport in Sand-Mud Mixtures Subjected to Wave Forcing

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Bed armoring and consolidation can significantly limit the erodibility of bottom sediments. These effects are most complex and least understood for sand-mud sediment mixtures. Qualitative and quantitative changes occur in the remobilization, transport, and deposition of mixed sediment beds at about 5-10% clay by weight. Bedload transport of the sand fraction (via bedform migration) appears to decrease and eventually cease as the mud fraction increases. Erosion and deposition of the mud fraction appears to be controlled throughout the transition region by bed mixing due to bedload transport, based on qualitative observations in flume studies. This paper will present an exploratory modeling study of these interactions, focusing on the wave forcing case. Starting with the bed model of Sanford (2008), we model bedload transport as a large, dynamically varying sediment diffusivity, building on an idea of Armanini (1995). The non-equilibrium wave-formed ripple model of Traykovski (2007) is used to predict time-varying ripple morphologies, which are related to the bedload mixing rate. Pure sand ripple scales are modified for different mud content based on the observations of Banasiak and Verhoeven (2008). Several example calculations are presented. In addition, we outline an approach for modeling enhanced deposition of fines into a stationary rippled sediment bed (Pilditch and Miller, 2006; Precht and Huettel, 2004). This approach treats wave-forced pore water advection is as a pumping velocity that introduces fines into the bed. Feedbacks occurring because of mud

accumulation are represented as an effective permeability change based on a power law relating porosity and permeability. This approach has been evaluated for the case of the accumulation of clay-sized particles in sand beds under steady flow, and it appears to apply reasonably well (Chen et al., 2008a; Chen et al., 2008b). Overall, the model indicates that bedload transport and pore water flows associated with bedforms can significantly increase the flux of mud from or to a mixed sediment bed, but that bedforms and their effects are significantly reduced in scale by increasing mud percentages.

Establishing Limits on the Applicability of Acoustic Backscatter Techniques for the Measurement of High Concentrations of Suspended Sediment

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Optical backscatter and laser diffraction techniques for the measurement of suspended sediment concentration are of limited use in high concentration environments because of saturation or obscuring of the optical path. Acoustic signals are generally better able to penetrate highly turbid suspensions, which has led to the use of various acoustic instruments in field studies of turbidity currents and fluid mud interactions. Now that multi-frequency acoustic backscatter instrumentation is commercially available for the profiling of mean suspended sediment particle size and load, an inevitable question from potential users is 'Will it work in the suspended sediment regime that we are studying?'

We examine the frequency-dependent relationships between backscatter amplitude and signal attenuation as a function of particle size and concentration. We describe the practical limitations of high frequency acoustic signal measurement in this context. Finally, we describe the development of a predictive tool for the establishment of practical operating range limits for the AQUAscat 1000 multi-frequency acoustic suspended sediment profiler.

Mud Rheology and Wave Dissipation on Shallow Muddy Shelf

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Wave dissipation characteristics are studied based on field measurements collected on Atcahfalaya Shelf, Louisiana, USA, in Spring 2008. During energetic storms, large swells liquefy the bed, resuspend the mobilized sediment, and produce wave-supported fluid-mud layers which last for the duration of the storm. As the bed sediment is reworked, wave dissipation rate increases rapidly, reducing swell energy by an average of 30-40% over about 4 km. Surprisingly, the largest net dissipation rates (up to 60% energy decrease over 4 km) are observed in the wake of the storm, when the water column is nearly clear of sediment and no fluid-mud layers are detected. The analysis of the vertical structure of wave phase suggests an increased role of bottom sediment rheology; direct observations (bed sampling) indicate that at this stage the bed is typically in an under-consolidated state, better described by non-Newtonian (e.g., visco-elastic) approximations. We employ numerical inversion techniques based on nonlinear three-wave interaction models to study the rheological properties of the bed sediment, and understand the importance of non-Newtonial rheology for wave dissipation processes.

Predictability and Invertibility of Wave-Mud Interaction

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There has been interest recently in the problem of deducing relevant mud (or mud proxy) characteristics from measurements of the wavefield. A successful implementation of such an inverse scheme would allow for remote deduction of mud characteristics using data from various remote sensing platforms (e.g. video). However, due to the range of potential behaviors of bottom mud when subject to wave disturbance, it is not clear that direct inversion for the mud properties will offer a unique or even a sensible solution, even if all other parameters (water depth, etc) are known. Furthermore, Kaihatu et al. (2007) showed that, for two dimensional wave propagation over finite mud patches, the damping and diffraction patterns which result can interact, making unique estimations of the bottom mud extent difficult.

In this presentation we outline an investigation into the invertibility of relevant mud proxy parameters using standard inversion tools (nonlinear least squares, primarily) and discuss the pitfalls and benefits of each. Narayanan et al. (2004), in an attempt to invert free surface elevation for depth parameters, noted the limits of predictability and invertibility in this problem, and the conditions under which unique solutions are unattainable. We show a similar analysis herein, with an emphasis on what sort of physical meaning can be lent to conditions of non-uniqueness.

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On the Morphodynamic Evolution of Salt Marshes: Sediment and Vegetation Interactions

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Stability of salt marshes is a very delicate issue depending on the subtle interplay among hydrodynamics, geomorphology and ecology. Here, we extend the simple one dimensional model for the morphodynamic evolution of a tidal channelformulated by Lanzoni and Seminara (2002) to study the development of a saltmarsh located at the landward end of a tidal channel, under different scenariosof sea level rise. Growth of vegetation in the salt marsh is allowed using thedepth dependent biomass productivity measured for Spartina by Morris et al.(2002). As a first step, we focus on the case of a tide dominated salt marshneglecting the possible effects of sediment resuspension induced by wind waves in the shoals. Results show that the production of biomass plays a crucial role on salt marsh stability and, provided productivity is high enough, it may turn out to be sufficient to counteract the effects of sea level rise even in the absence of significant supply of mineral sediments. The additional effect of wind resuspension is then introduced. Note that the wind effect is twofold: on one hand, it generates wind waves the amplitude of which is strongly dependent on the shoal depth and on the wind fetch; on the other hand it generates currents driven by the surface setup induced by the shear stress acting on the free surface. Here, each contribution is analysed separately. Results show that the values of the bottom shear stress induced by wind setup are small compared with those associated with the wind waves. However, the flow field induced by wind setup turns out to be as significant as tidal currents in determining the direction and the intensity of the advected sediment flux.

Coupled Wave, Current, and Morphology Approach for Accurate Coastal Flow Simulation

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Accurate simulation of coastal ocean flows is now urgently needed, but this is challenging because, in general, the flows are multi-physics and multi-scale in nature. In this study we adopt a multi-physics approach by coupling models individually designed for different phenomena. Particularly, wave, current, and seafloor morphology models are coupled in a simultaneous manner. The system of governing equations consists of the wave action equation, the shallow-water equations, and the Exner equation, which reproduce the framework of existing models (e.g., SWAN and SHORECIRC). A flux-limited version of the Roe scheme is derived to discretize the system for high-resolution solutions. Numerical experiments will be presented for validations of the scheme, and example simulations such as evolution of a wind driven sand dune will be demonstrated for the performance of the coupling system.

An investigation into the thixotropic wave dissipation potential of fluid mud

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Thus far, theoretical studies in the movement of fluid mud under wave action have been studied by various simplified rheological models, going from pure viscous to visco-elastic and visco-plastic. None of them accounts for the actual microscale physics of the aggregate network structure. In reality, the mud layer behaves as a poro-visco-elastic medium as long as the pore water pressures remain below the submerged weight. As soon as this pressure exceeds the effective stress, the network is broken and the mud fluidizes. Liquefaction under wave induced shear stresses will occur at the same time.

As a real fluid mud, its rheological behavior should now be described by a thixotropic rheological model, which can account for the breakage and restructuring of the aggregate structure under the varying stresses.

The present study presents results of the wave energy dissipation potential by thixotropic behavior using a numerical model. The rheology is described by a modified version of Toorman's (1997) thixotropy model. This model is implemented into the author's virtual laboratory FENST-2D, a finite element code for the study of processes in a vertical plane.

An Integrated Numerical Model for the Study of Wave-Mud Interactions

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Prior field and laboratory observations on wave-mud interaction have revealed many important processes related to wave-induced mud transport and wave energy dissipation. However, these studies have also pointed out the difficulties in modeling the dynamics of wave-mud interaction. The complexity relies on the nonlinear coupling between the free-surface wave propagation and the underlying fluid-mud transport. This nonlinear coupling is difficult to incorporate in multi-layer models where the fluid-mud layer thickness and properties are often given as an input parameter instead of being part of the solution of the model. The present work aims to overcome some of the limitations in the conventional modeling of this problem in order to gain insight on the physics of wave-mud interaction. By extending the fluid-mud modeling framework introduced by Hsu et al. (2007, /J. Geophys. Res./, 112), a well-validated depth/phase-resolving wave propagation model (COBRAS, Lin and Liu 1998, /J. Fluid Mech./, 359) based on Reynolds-Averaged Navier-Stokes equations has been modified to model wave-mud interactions. The numerical model consists of a simplified two-phase formulation based on the Fast Eulerian Approximation (Ferry and Balachandar 2001, /Int. J. Multiphase Flow/, 27), which retains several mechanisms originated from the complete two-phase formulation. The governing equations reduce to the RANS equations when the sediment concentration approaches zero. Hence, the numerical model is able to simulate continuously and consistently the nonlinear water wave propagation, the wave-boundary layer processes, turbulence modulation owing to the presence of the fluid-mud, and the rheological effects on attenuating the waves with a single set of balance equations and closures. Preliminary results demonstrate the model capability for simulating the above mentioned processes as well as the role of the nonlinear wave energy transfer on attenuating the higher and lower frequencies of the incident wave spectrum. Ongoing research comprehends testing the model using different wave group conditions and fluid-mud rheological closures.

Observations of mechanisms of wave dissipation on the Louisiana shelf: The role of short wavelength lutocline internal mode waves

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Field observations were performed on the Louisiana shelf, west of Marsh Island, in the spring of 2007 and 2008 to elucidate the mechanisms of wave energy dissipation over a muddy seafloor. During the 2008 observations the Atchafalaya River discharge was approximately double the 1930-2007 average, which produced large quantities of new mud on the inner shelf. Acoustic backscatter profiler (ABS) measurements showed deposition of 20 cm in 5 to 7 m water depths after each of three wave events with wave heights of near 2 m on the 9 m isobath. While total wave energy dissipation was greatest during the high energy periods, the normalized dissipation (Dissipation/Energy Flux, with dimensions of an inverse length scale) was largest after the wave events, as the recently deposited mud layer consolidated from 20 cm to 10 cm thickness. The ABS data also showed waves on the lutocline with heights ranging from 10 cm during periods of high total wave energy dissipation to 2 cm during periods of maximum normalized dissipation. The amplitude of these waves is much larger than predicted by models for the surface mode (with the wavenumber of the interface mode matching the surface wavenumber) of a two layer, water over viscous higher density mud system. Analysis based on the continuity equation and measurements of orbital velocity decay away from the interface show that these waves have short wavelength (1.5 to 3 m) relative to the surface waves (~ 60 m), but oscillate at the same frequency. These observed waves are consistent with the internal mode solutions to the two layer dispersion equation. The dispersion equation also shows that in the high viscosity, or thin normalized mud layer (mud layer thickness/viscous boundary thickness) regime the dissipation due to the internal waves with the observed amplitudes can be significantly larger than the dissipation due to the surface mode.

Dynamics of Interfacial Waves in Muds on the Louisiana Shelf*

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Peter Traykovski reported profile measurements of acoustic echo intensity that reveal interfacial waves on the lutocline that separates thin layers of dense mud from the overlying column of relatively clear water in new deposits of riverine sediments on the inner shelf off Louisiana. The interfacial waves are forced by wind-generated surface waves and are likely part of the mechanism by which surface waves damp rapidly over muddy seafloors. The characteristics of the observed interfacial waves negate two prevalent theories of wave-mud interaction: the interfacial wavelength is much smaller than the surface wavelength, which is inconsistent with the bound-wave model proposed by Dalrymple & Liu (1978), and the period of the interfacial waves is nearly equal to that of the surface waves, which is inconsistent with the subharmonic resonant triad instability proposed by Foda & Hill (1996). A linear analysis, which captures both Kelvin-Helmholtz instability and the viscous Yih (1965) instability of free-surface flow to in-plane oscillation of the lower boundary, indicates a parametric mechanism that produces interfacial waves with periods equal to those of the forcing surface waves and wavelengths much smaller than the surface wavelength. A weakly nonlinear analysis indicates possible controls on the amplitudes of the interfacial waves.

Wave Mud Interaction, Some Lessons From Cassino Project

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A mud deposit is observed offshore Cassino Beach, Southern Brazil, mainly originated from the fine sediments flushed by meteorological tides from the adjacent Patos Lagoon (Vinzon et al, in press). The mud, located between the 6 m and 15 m isobaths, migrates episodically from offshore to the beach, with storm waves. In these situations, the typical sandy beach is covered with a substantial amount of mud, a unique process along the Brazilian coastline (Calliari et al., 2000) meaning a risk for tourism and fauna.

The action of water waves over a soft marine mud bottom can elevate the mud-water interface to a level 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. On the other hand, this lutocline plays an important role in the wave damping (Gade, 1958), in a feed back way. Aiming to investigate the dynamic behavior of this mud deposits under the wave action, a field experiment started in 2004 at Cassino. The first measuring plan considered (1) an ‘initial’ characterization, using geo-acoustic methods and sampling for laboratory determinations, in order to identify the extension, thickness and relevant characteristics of the mud deposit, and (2) the deployment of wave measurement devices in a transect along the main direction of the incident waves, in order to register the attenuation induced by the mud deposit, considering also a measurement station in a close sandy bottom for comparison.

Rogers and Holland (in press) showed, by modeling the wave attenuation observed through the mud deposit, that the thickness of the mud deposit, its density and viscosity, are key parameters in modeling the wave damping, so a better description would be necessary. A new measuring strategy was then adopted, and the properties of the mud deposit were then obtained simultaneously with the wave measurements. Short records of waves offshore and along the mud deposit were collected, recording at the same time the density and viscosity profiles using an in situ densimeter. Core samples were also obtained for calibration.

It will be shown the observed variations of the lutocline height, which are due to the variations in the wave field or the concentration in the fluid mud layer. The interplay of this factors is not clear yet, but is consistent with the lutocline prediction proposed by Vinzon & Mehta, 1998.

For these measurements, during fairly good weather conditions, the wave spectrum recorded along the transect, when compared with the corresponding spectrum at the foremost station, showed little wave damping, except at the
shallower stations where the lutocline height increased significantly, causing expressive

wave damping in quite short distances. This result indicates the importance of including the mechanisms for lutocline formation in the wave damping modeling approaches. From the new observations, it's evident that the first approach of the project, with the mud characterization uncoupled with the wave measurements, was inadequate to properly assess the wave attenuation.

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Lateral Circulation and Sediment Transport in a Curved Estuary

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Flow and sediment concentration experimental data are presented from a partially mixed estuary (Winyah Bay, SC). The data are analyzed to examine the interaction of lateral flow, sediment transport and trapping along a curved section of the estuarine channel. Across-channel momentum balance analysis is used to elucidate the interaction between centrifugal, Coriolis, and lateral baroclinic pressure gradient forces on lateral flows. During ebb when the water column is highly stratified, the interaction between centrifugal acceleration and opposite-directed lateral baroclinic forcing results in weak lateral flows. During flood lateral flows are dominated by centrifugal acceleration, which is directed toward the outside of the curvature at the mid-depth due to the non-logarithmic current profile, and reinforced by lateral baroclinic forcing. This results in a strong two-layer clockwise circulation during flood.

The eastward-directed bottom currents during ebb deliver only a small amount of suspended sediment from the relatively narrow western shoal to the channel bed. During flood, the west-directed near-bed currents deliver a significant amount of sediments from the gentle, broad eastern shoal, which in conjunction with the locally resuspended sediment load promotes the development of the estuarine turbidity maximum. Increased lateral advection of sediments during flood reinforces a tidal asymmetry in the development of turbidity maximum. Decomposition analysis of lateral sediment fluxes averaged over a tidal cycle, suggests convergence of sediment toward the center of the channel is driven mainly by the oscillatory tidal component. The implication of lateral sediment flux on the development of turbidity maximum and on the long-term morphodynamics of the curved estuary are discussed.

Mud-Induced Wave Damping in the Dutch Wadden Sea

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This paper describes a feasibility study to assess whether soft mud deposits along the Dutch Wadden Sea coast can liquefy under wave-induced cyclical loading, and, if so, whether the resulting fluid mud layers would damp the incoming wave energy. Liquefaction would occur through failure of internal bonds within the mud skeleton, inducing a sharp increase in pore water pressure. Waves would subsequently be damped through viscous dissipation within the fluid mud. This work is of interest to determine the hydraulic boundary conditions for the design heights of the dikes along the Wadden Sea coast, focusing on the "Zwarte Haan" area at the head of the Tidal Inlet of Ameland (Borndiep – Amelander Zeegat).

The study consisted of three phases: 1) Field inspection to map soft mud deposits, their extension and depth, to measure a few mud properties in-situ, and to take samples for laboratory analyses, 2) Triaxial tests to assess the conditions at which these samples may liquefy, and 3) Simulations with SWAN to compute possible wave damping rates.

Also the principal stresses in the soil induced by surface waves have been established, defining the stress conditions for the triaxial tests. The SWAN simulations have been carried out with both the so-called Gade and DELFT-setting, and we show important differences in wave damping between these approaches.

None of the mud samples liquefied during the triaxial tests, though some 10% damping of the total stored energy was measured. The SWAN simulations predict a 10% dissipation of wave energy when the mud properties measured in the laboratory are prescribed. However, if the mud deposits would liquefy, and the mud would attain values for density and viscosity typical for such liquefied mud layers, about 90% damping of wave energy is predicted over a stretch of about 600 to 1000 m, i.e. within 10 – 15 wave lengths.

Visual observations of significant wave damping along the Wadden coast during storm conditions, and assessment during the field inspection, suggesting mud deposits at the Liquid Limit, are not consistent with the results of the triaxial tests. The first two observations would suggest liquefaction of the mud deposits during storm conditions, whereas the latter revealed no liquefaction at all (i.e. no significant increase in pore water pressure). Possible causes for these contradictions are 1) The samples were taken at the end of summer, were deposited at their location at least a half year before, and therefore well consolidated, and 2) The samples have densified considerably, gaining strength during sampling and the subsequent transport to and storage in the laboratory. In a next phase of the study we will develop a procedure to measure the liquefiability of the mud at in-situ conditions and at the right time of the year.