

Temporal and Frequency-Based Variations in Seafloor Bathymetry and Acoustic Properties

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LONG-TERM GOALS

1) Multibeam studies – Bathymetry – Frequency and Temporal Variations

In previous years, we focused on acquiring (ONR surveys 2007-2009) and processing (HIPS and SIS from CARIS software) multibeam data from several shallow water sites in the Gulf of Mexico with multiple multibeam, side scan, and sub-bottom profiler systems, all acquired from the same vessel, at the same time, using the same motion reference unit and GPS. The preliminary results indicate a relatively large (>100m) amount of lateral seafloor movement in the West Delta area offshore Louisiana, proposed by the PIs to be related to mud flows triggered by hurricane events (Garcia-Garcia and Orange, 2010). The bathymetric data reveal several distinctively shaped (and thus traceable) blocks at the seafloor have been displaced downslope up to 140m over a 1.5 year period (Figures 1a and 1b). Our goal is to expand these preliminary observations and to quantify, on a per block basis, the vector motion (distance and direction) of each, where possible, and to understand the implications for the area and structures in it. Seafloor data acquired in the Panama City, Florida, area show seasonal, but less pronounced, differences in the seafloor between the surveys.

Data acquired at the same time using two different frequency multibeam systems, a low frequency of 95 kHz and a high frequency of 300 kHz, demonstrated differences between the systems. In all our surveys, the lower frequency (95 kHz) yields a deeper seafloor depth than the higher frequency system; our preliminary interpretation is that the lower frequency system ‘penetrates’ the uppermost (least consolidated) sediment in muddy areas an average of 0.4-0.8m in comparison to the high resolution (300 KHz) system (Figures 1c and 1d; other survey sub-areas document a difference of up to 2-3m at wreck sites). Our goal is to further investigate these differences. Recently, Scheider et al., 2010 have confirmed a difference in 8-10 m water bottom depth between a 12 kHz and 95 kHz system in 100m water depth, where the low frequency ‘penetrates’ the seafloor in muddy areas. Schneider et al. were able to demonstrate that the 12 kHz system ‘penetrated’ the seafloor and recent sediments to image the surface of glacial till, by comparing the lower frequency data to the sub-bottom profile data. They also point out that the 95 kHz system ‘penetrated’ the seafloor in a few instances, but only in the nadir and near-nadir beams (pers. comm.). Schneider et al.’s results are very relevant to our Gulf of Mexico multi-frequency data sets, and are something we propose to investigate further.

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To achieve our goals we are using multiple software systems to evaluate the data. Specifically, in addition to the initial CARIS processed data, we intend to process the original field data with Triton Imaging Inc.'s BathyPro/Bathy1 software to compare the results. We may reprocess some of the data with the most recent version of CARIS software and/or apply the latest version of Fledermaus Professional software (both incorporate the GeoCoder backscatter processing routines to minimize the angular dependence of multibeam backscatter).

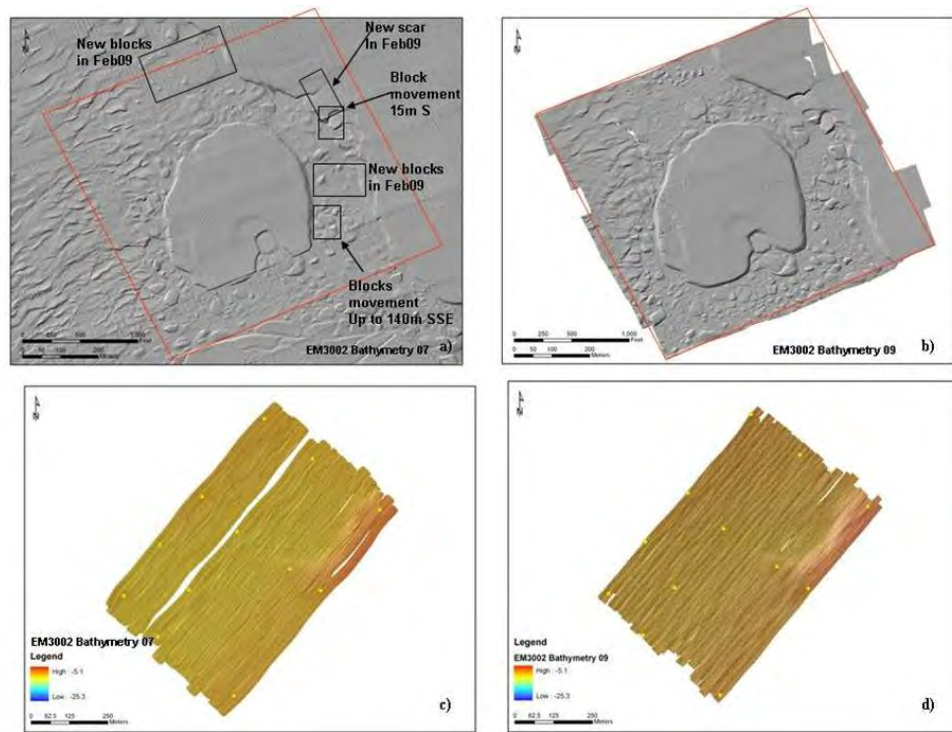


Figure 1. Multibeam bathymetry map of the West Delta seafloor in June 2007 (a) and February 2009 (b). Note some of the blocks in 07 image have moved in the 09 image; imageries of area A in Panama City, Florida in June 2007 (c) and February 2009 (d). All imagery is 50 cm resolution.

2) Multibeam studies – Backscatter– Frequency and Temporal Variations

Recent developments in multibeam echosounder backscatter processing, specifically an integrated suite of processing algorithms called Geocoder (developed by Luciano Fonseca and Brian Calder of the University of New Hampshire, see Fonseca and Calder, 2005), are now included in some commercially available processing software packages. These tools provide properly corrected backscatter mosaics and add more robust qualitative and quantitative discrimination of seabed materials to their seafloor characterizations (Hewitt et al., 2010).

Geocoder uses the original acquisition data, considers any modifications made to it, and then applies various radiometric and geometric corrections. Each raw backscatter sample is corrected for the time-varied gains, transmit power and receiver gains that are applied during acquisition. The processing then considers the transmit/receive beam pattern and compensates for spherical spreading, attenuation

in the water column, seafloor slope and the actual area of insonification on the seafloor (Fonseca and Calder, 2005; Hewitt et al., 2010). In Geocoder-processed backscatter data, the angle-dependent across-track variations in backscatter are effectively eliminated, including the near-nadir stripe artifact, resulting in fewer obvious data seams between adjacent survey lines, a narrower nadir no-data zone, and reduced speckle noise. Thus, the imagery has an overall more uniform tone against which seafloor features can be better defined, and subtle features revealed that may be absent or difficult to image in side scan imagery (Fonseca and Calder, 2005).

We will use GeoCoder to process the ONR multibeam data acquired from 2007-2009 in order to obtain a backscatter product which can be compared and integrated with the rest of the data. Ana Garcia-Garcia will work with the latest versions of CARIS' HIPS and SIPS software that includes Geocoder, which can work with GeoBaRs and process the backscatter data.

We also intend to compare backscatter results obtained with Geocoder (within CARIS' HIPS software) with the BathyPro/Bathy1 software of Triton Imaging Inc., which also processes backscatter (www.tritonimaginginc.com). We will compare these results and confirm which software is faster/more reliable/more robust, etc.

3) Subbottom/chirp Data studies – Interpretation and Ground-Truthing

We will continue our research in the Gulf of Mexico survey sites by examining the sub-bottom profiler (SBP) collected in previous years with the SBI-Perspective package (Triton Imaging Inc.). After meeting Dr. Sergio Fagherazzi from University of Boston, it was clear that Dr. Fagherazzi's work in the Fluid Mud-MURI project with current channels (Fagherazzi et al., 2008) was closely related to our work offshore the same area in Louisiana. Currently we are collaborating with Fagherazzi and colleagues' integrating their modeling of buried channels with observations / interpretations we are making from the chirp sub-bottom profiler data collected by ONR in 2007 and 2009 (see Figure 2). Ana Garcia-Garcia attended a Triton Imaging training session of the software 9-10 February 2011.

Scheider et al., 2010 have worked in muddy environments with low frequency multibeam systems and subbottom profilers to distinguish gassy and non-gassy sediments. We will apply this approach to our data sets of the Gulf of Mexico.

Recently, we had the opportunity to apply learnings from our Gulf of Mexico sub-bottom profiler work to chirp sub-bottom profiler data to be acquired in 2011 in the Elkhorn Slough, California, where numerous Institutions and Governmental Organizations collaborate to do research in a delicate estuarine environment. EPA funded coring in 2010 and a chirp sub-bottom profiler survey in 2003. Using the same methodology we used in the identification of the paleochannels off the Gulf of Mexico (Garcia-Garcia et al., submitted), we have joined a collaboration effort to acquire more chirp lines at the core locations in order to ground-truth the sub-bottom profiler data. In addition to ourselves, the organizations involved in this effort are:

- EPA (funding field acquisition), <http://www.epa.gov/>
- Elkhorn Slough National Estuarine Research Reserve (collaboration, vessel).
<http://www.elkhornslough.org/esnerr/index.htm>
- Seafloor Mapping Lab, California State University, Monterey Bay (collaboration, side scan sonar and sub-bottom profiler acquisition), <http://seafloor.csumb.edu/index.html>

- Triton Imaging Inc. (collaboration, software acquisition/processing/interpretation),
<http://www.tritonimaginginc.com/site/>

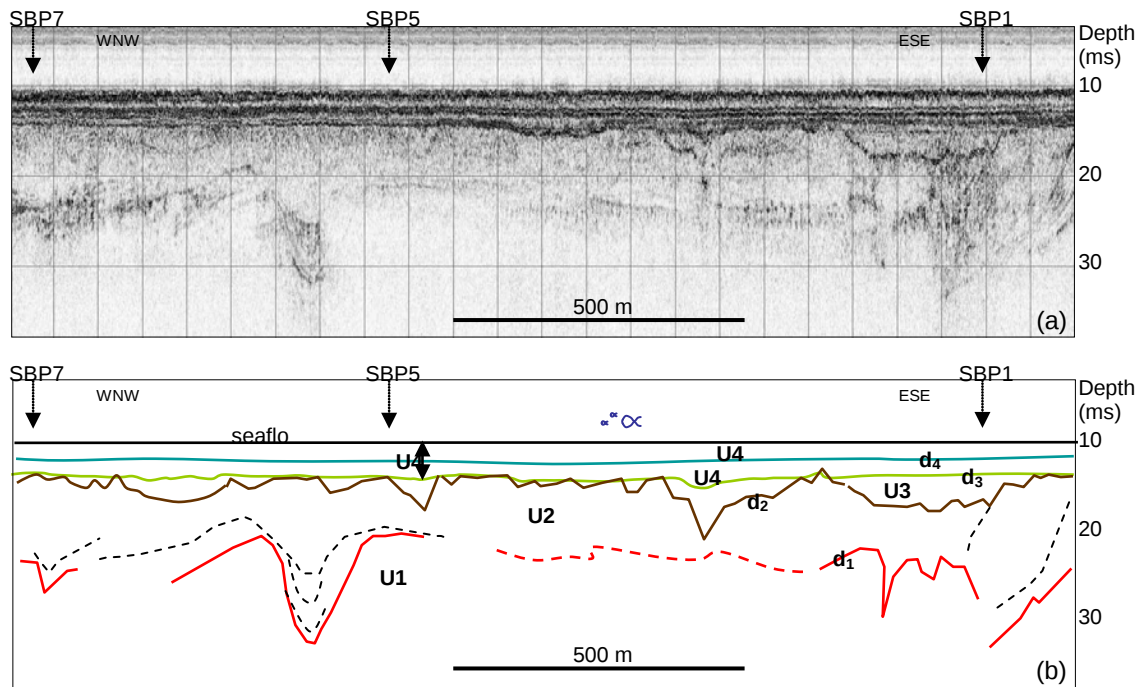


Figure 2. Fluid Mud MURI Gulf of Mexico chirp profile SBP x01 (WNW-ESE); (a) uninterpreted profile; (b) interpreted profile with seismic units U1-U4. Location of crossings with other survey lines indicated with black dashed arrows. Note buried paleochannel on the left side of the profile.

4) Evaluation of Mid-Life Sonar Upgrade Systems on Pathfinder-class Vessels (collaboration with NAVO)

As part of one of our's (Orange) work outside of ONR we have been pushing the limits of hull-mounted multibeam systems in order to identify small (sub-footprint) natural hydrocarbon seeps on the seafloor. In April, 2009, we began a discussion with NAVO personnel (Mel Broadus and Becky Martinolich, NAVO Stennis) regarding the different approaches to system calibration and survey execution. NAVO extended an invitation to join their personnel on the sea trials of the upgraded Pathfinder, July 2009, and this resulted in several operationally significant findings regarding achievable resolution and survey strategy. Given the success of the 2009 collaboration, NAVO extended an invitation to join in the sea trials of the Heezen in April, 2010, again with operationally significant findings on beam configuration ($1^{\circ} \times 1^{\circ}$ vs. $1^{\circ} \times 2^{\circ}$) and achievable swath, achievable resolution 10 knots vs. 12 knots vs. 14 knots, and vessel-dependent acquisition differences controlled by vessel noise profiles.

Our collaboration with NAVO on these two sea trials, supported by Orange's industry employer, has yielded insights into acquisition that are relevant for all frequency acquisition systems. Due to berth limitations and gender, Orange was unable to join NAVO for the Henson sea trails in 2011. NAVO has

tentatively scheduled the sea trials for the next Pathfinder-class vessel in the Mid-Life Sonar Upgrade program for April, 2012 (Mary Sears). NAVO has extended a tentative invitation to us to continue to collaborate with them on their evaluation of the vessels (Mel Broadus, pers. comm., March. 2011, pending gender breakdown of cruise participants and berth availability). We propose to continue this collaboration, and to make the findings available to ONR.

OBJECTIVES

We have two distinct research efforts, one involving the processing and software comparison of our previously acquired datasets, and a second effort collaborating with NAVO to evaluate the ongoing upgrades to the Pathfinder-class survey vessels.

The majority of our effort will be applied to the processing and evaluation of high resolution multibeam and backscatter data, as well as sub-bottom profiler data. In the current phase of research we are also applying our learnings to sub-bottom profiler data acquired in the estuarine Elkhorn Slough, California. In addition, we are continuing our collaboration with NAVO evaluating the capabilities of the multibeam survey systems being incorporated into the Pathfinder-class vessels as part of NAVO's Mid-Life Sonar Upgrade project.

APPROACH

Reprocess all acoustic/geophysical data sets acquired in 2007-2009 using as many of the latest-generation software packages as possible to evaluate the differences in bathymetry and acoustic properties between same time / different frequency systems, and different time / same frequency systems. Integrate seafloor data with sub-bottom profiler data. Coring data will be used to complete and ground truth the indirect geophysical results.

RESULTS

- Multibeam Bathymetry and Backscatter

We are currently working on re-processing the ONR Gulf of Mexico data (starting with the Panama City data) with Triton Imaging's package to compare with results from CARIS processing in 2007 (Figure 3) and 2009. We are also working on integrating the core data into the new SB-I package where the acoustic data can be displayed as well.

- Sub-bottom profiler

2011 processing, analysis and interpretation has included the previously acquired ONR data sets in the Gulf of Mexico (see papers Garcia-Garcia et al. submitted) and the newly acquired data set in the Elkhorn Slough (collaborating with Triton Imaging Inc., EPA, MLML, Seaspatial Consulting).

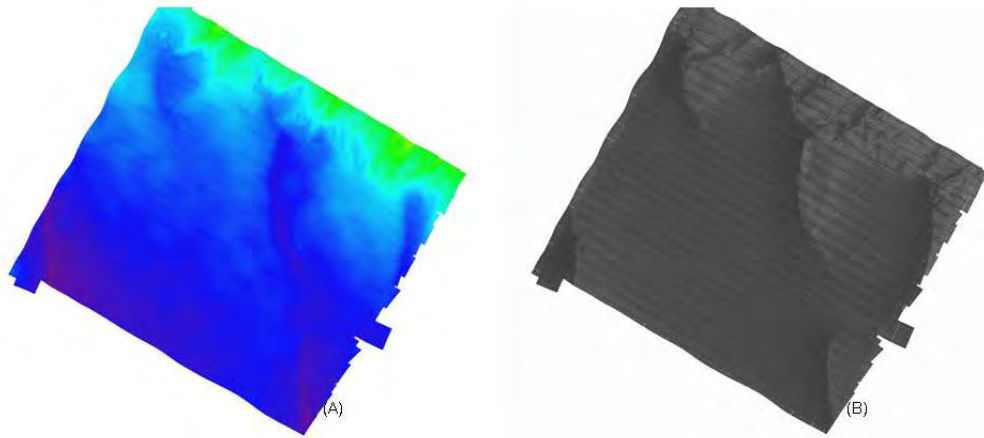


Figure 3. Example of seafloor maps from the 2007 Panama City survey, 300 kHz EM3002 system; (A) multibeam EM3002 bathymetry, (B) EM3002 backscatter amplitude (CARIS).

Currently we are collaborating with Dr. Sergio Fagherazzi from University of Boston to integrate his modeling techniques to the buried channels we interpret from the chirp ONR data collected in 2007 and 2009. The preliminary results will be presented at this years' AGU Fall Meeting.

On Sept 1st 2011 a 1-day survey was run in the Elkhorn Slough using an EdgeTech SB-424 Full-Spectrum sub-bottom chirp profiler. The SB-424 has a frequency range of 4-24 KHz, with ± 4 cm vertical resolution and a typical penetration ranging from 3 m in calcareous sand, to 40 m in clay. The data is currently being processed and interpreted (SB-I software). See setting and chirp examples in Figures 4 and 5.



Figure 4. Elkhorn Slough National Estuarine Research Reserve's research boat with Edgetech SB24 sonar. 1 September 2011.

This muddy environment of Elkhorn Slough shows hints of acoustic blanking on the sediments, mainly in the upper portion of the Slough. This is something we are working on as well. A comparison between the 2003 data and 2011 will be made, as well as tying the core data to the chirp data. The preliminary results will be presented at this years' AGU Fall Meeting.

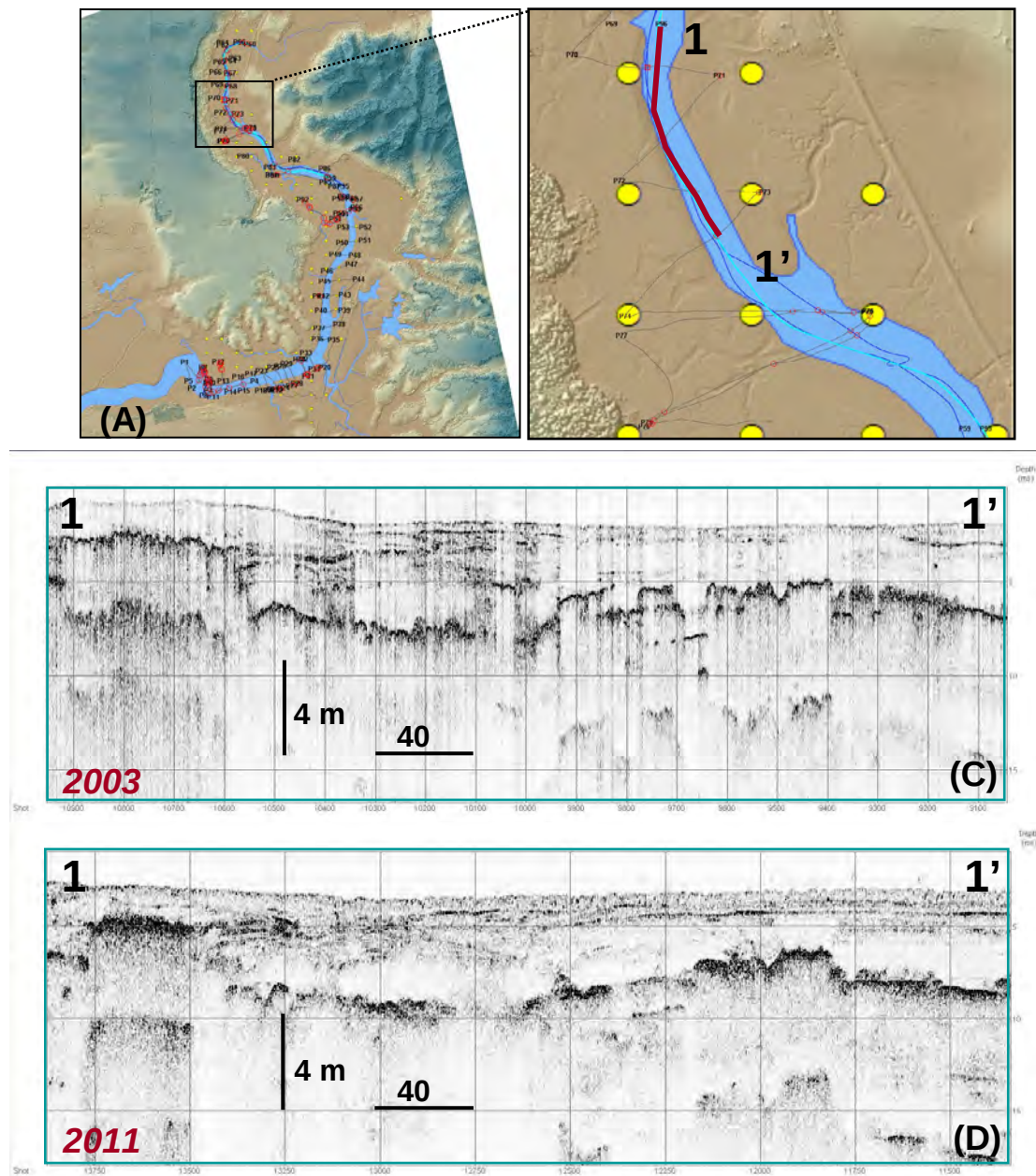


Figure 5. (A) Map view of the survey area with chirp lines (black) and core locations (yellow dots) at the Elkhorn Slough (left) with an example of a line (line 1-1' shown in detail, right) run in 2003 (B) and again in 2011(C).

IMPACT/IMPLICATIONS

At the Fluid-Mud MURI field site, the geophysical/acoustic dataset and groundtruthing provide a comprehensive baseline and a geophysical context for studies for all MURI scientists. All of the seafloor data are georeferenced, combined with all provided MURI instrumentation locations, and provided to all MURI scientists as a GIS. As an example of this collaborative effort, multibeam datasets have been shared with WHOI (Dr. Peter Traykovski and colleagues), and the sediment analysis data with NSP/SIO (Dr. Tomas Herbers and colleagues) and Johns Hopkins University (Dr. Robert Dalrymple). We hope our future comparison of software helps as well in providing a better understanding on the data.

In our work on the recent infill of the inner shelf off the Chenier Plain coast, just west of the recent deltaic deposits of the Mississippi River, using shallow seismic analysis and the identification of paleochannels, we are starting to understand their relationship with current rivers off the present coastline.

In the last 3000 yrs, sediments from the Mississippi Delta have been transported to the western part of the Louisiana shelf, triggering beach progradation through a series of shell and sandy ridges (cheniers) separated by muddy hollows. Distinct events of chenier plain development have been explained as being the result of delta lobe switching in the Mississippi delta combined to local processes responsible for formation of beach ridges, recurved spits, eolian deposits, storm berms, and natural levees.

We identified four seismic units (U1 to U4; Figure 2) and their associated surfaces and discontinuities in the sub-bottom profiler data. A tentative reconstruction for the last 20 ky sedimentary infill has been developed correlating observed horizons with available dates for the area. The identification and tracking of several buried channels across the shelf in units U1 and U3 allow us to track the position of the Mermentau-Calcasieu hydrological system during previous lowstands. Based upon our combined observations, we and our colleagues interpret the Mermentau river as flowing more easterly during the Wisconsinan lowstand, occupying the location of our study area, and later diverting to the west as a result of coastal processes and the development of the Chenier plains. Also, the Mermentau hydrological system was re-occupying almost the same location at different lowstands, and only when the Chenier formed (due to reactivation of the west Mississippi lobe), was the Mermentau deviated westward due to sediment accumulation at the shoreline.

Analyzing the repeat survey data highlights the activity of the mudflows which we infer to be related to hurricane forcing. Also, by revisiting the SS Virginia wreck we determined its present location relative to the previously surveyed locations and compared and studied its movement. Because the location as well as the outline of the wreck has been imaged multiple times we can use the wreck as a strain indicator of the mud flow's movement. This can give us an idea of the rate at which these features move at various locations so that we can better understand the impact of these flows on existing or future seafloor installations.

The Panama City data sets show subtle differences between frequencies. This is a promising start and we are presently working on getting quantitative results of the acoustic/geophysical data. We expect to integrate all datasets (acoustic/geophysical surveys and coring data) in the upcoming year and have an updated GIS available to share with colleagues at Panama City, included Ray Lim and Kerry Commander, as well as work on peer-review publications.

Elkhorn Slough:

To delineate historical estuarine habitats and estuarine morphology for the purpose of conservation planning within the Elkhorn Slough National Estuarine Research Reserve (ESNERR) near Moss Landing, California, sediment cores and subbottom profiles were obtained in 2010 and 2011.

Dated stratigraphic profiles and seismic interpretation are being analyzed using geospatial analysis within Geographic Information Systems (GIS) to produce maps illustrating geological changes to the upper Slough area over the previous 3000 years. Modern anthropomorphic changes to the geometry of the oceanic inlet has resulted in tidal scour, loss of sinuosity in estuarine channels, and increased submergence that negatively impacts wetland habitats. The wetland persistence at Elkhorn Slough has been variable throughout recent times. Data gathered by this study are being used to help set logical targets for marsh acreage in the estuary and to provide insight into the current episode of wetland submergence.

RELATED PROJECTS

Sergio Fagherazzi (Boston University)

Tidal channel dynamics and muddy substrates: a comparison between a wave dominated and a tidal dominated system ONR N00014-10-1-0269

Peter Traykovski (WHOI)

Analysis of Field Measurements of Viscous Damping of Ocean Surface Waves by Fluid Mud. NSF 10-59914; Mechanisms of Fluid-Mud Interactions Under Waves ONR N00014-06-1-0718

Tim Janssen (San Francisco State University)

Wave-Mud interactions across the Louisiana Inner Shelf to the Shoreline ONR N00014-10-10217

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Hewitt, A., Salisbury, R., Wilson, J. (2010) Using Multibeam Echosounder Backscatter To Characterize Seafloor Features Geocoder Processing Gives Multibeam Echosounder Backscatter an Advantage Over Side Scan Sonar in Producing Reliable Seafloor Maps, *Sea Technology*:10-13, September issue.

Schneider, J., Deimling, V., Burk, D., Fossing, H., Toth, Zs., Endler, R., Spiess, V., Rehder, G. (2010) Subbottom mapping of shallow gas using low-frequency multibeam systems, AGU Fall Meeting 2010, poster B41D-0328.

PUBLICATIONS

Publications – In Press (Proofs)

García-García, A., Schoolmeester, T., Orange, D., Calafat, T., Fabres, J., Grossman, E., Field, M., Lorenson, T., Levey, M. and Sansoucy, M. (2012) Recent Sedimentary Processes in the Cap de Creus canyon head and adjacent continental shelf, NE Spain: evidence from multibeam bathymetry, sub-bottom profiles and coring. *International Association of Sedimentologists*, 44, pp. 71-98.

Hoffmann, G., Silver, E., Day, S., Driscoll, N. and Orange, D. (in press) Deformation versus Deposition of Sediment Waves in the Bismarck Sea, Papua New Guinea. *in* Shipp, R.C., Weimer, P., Posamentier, H.W., eds., *Mass Transport Deposits in Deepwater Settings*, SEPM (Society for Sedimentary Geology), Tulsa, Special Publications 95.

Publications - Peer Reviewed, in Preparation or Submitted

García-García, A., Fagherazzi, S., Janssen, T., Herbers, T., Alden, D., Orange, A., Orange, D., Jessen, P., Kawamoto, S., Harvey, P., Lorenson, T. (submitted) Sediment Characteristics and paleochannels of the Chenier Plain Inner Shelf, Louisiana. *Geo-Marine Letters*.

Conferences (accepted)

García-García, A., Fagherazzi, S., Orange, O. (2011) Paleochannels and Sediment Characteristics of the Chenier Plain Inner Shelf, Louisiana. Submitted to AGU Fall Meeting, San Francisco, December 2011.

Levey, M., García-García, A., Watson, E. B. (2011) Mapping Modern and Historical Geological Changes to the Upper Elkhorn Slough Estuary, Moss Landing, California. Submitted to AGU Fall Meeting, San Francisco, December 2011.

Invited Speaker

García-García, A. (2011) 'High resolution seafloor mapping surveys and characterization of mudflows off the Louisiana coast; the wreck of the S.S. Virginia', Invited Speaker Seymour Marine Discovery Center, Santa Cruz, CA, February 9th, 2011.