DISTRIBUTION STATEMENT A: Approved for public release; distribution is unlimited.

Wave-Mud Interactions Across the Louisiana Inner Shelf to the Shoreline

Tim T. Janssen
Department of Geosciences, San Francisco State University
San Francisco, California 94132
t: (415) 338 1209; f: (415) 338 7705; e: tjanssen@sfsu.edu

Award Number: N000141010217

LONG-TERM GOALS

The wave-driven dynamics of the coastal ocean, which is important for transport processes, mixing and circulation, is strongly affected by mud deposits on the continental shelf and in the nearshore. However, the mechanics of wave-mud interaction is not well understood. The overall objective of this work is to contribute to the understanding of the damping effects of mud on waves and to improve modeling and prediction of wave evolution along muddy coastlines.

OBJECTIVES

The specific objectives of the proposed effort are to: 1) establish a comprehensive dataset from two newly acquired sets of field observations (ONR-funded wave-mud MURI) of waves propagating across more than 25 km over a muddy seafloor, from 13 to 2m depth, 2) determine the characteristics of mud-induced dissipation of wave energy from intermediate- to shallow-water depths, and 3) identify the effects of nonlinear interactions on the evolution of the dissipating wave field.

APPROACH

To improve our understanding of mud-induced damping rates on surface waves, its variation across the shelf, and the role of nonlinear interactions, we integrate observations made during the 2008 MURI field experiment (MUDEX08) by the NPS/SIO and WHOI teams, to establish a comprehensive data set of wave evolution. The high spatial coverage will enable -- for the first time -- a detailed analysis of mud-induced wave damping across the shelf to the shoreline, including the transition to shallow water where quadratic (triad) interactions are important. The proposed work includes: 1) a detailed analysis of the combined data set to determine damping characteristics across the shelf, 2) implementation of a conventional third-generation wind-wave model to assess the effects of mud on wave propagation and wind-wave generation, and 3) establishment of the role played by nonlinear interactions in the damping of short waves.

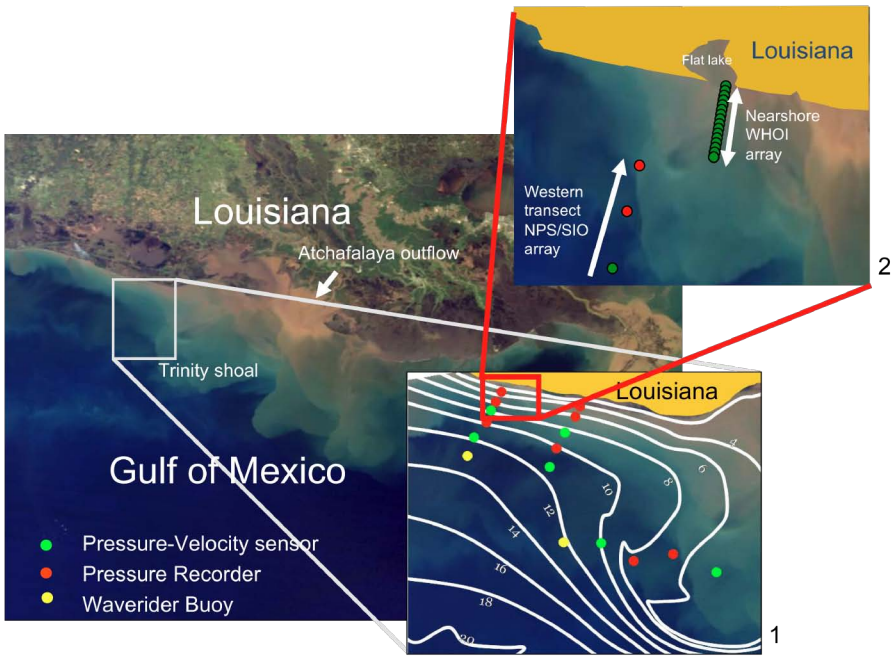

Figure 1 Field site and sensor arrays of the Louisiana waves-over-mud field experiment February-March 2008 (MUDEX08). Inset 1 shows the inner-shelf array (NPS/SIO team) consisting of three transects (16 instrumented sites), deployed between 13 and 4 m depth. White curves are depth contours (depth indicated in meters). Inset 2 shows the high-resolution nearshore array (WHOI team) consisting of 16 colocated pressure gauge and Doppler velocimeters deployed between 5 and 2 m depth. Mud deposits from the Atchafalaya River are evident in the satellite image.

WORK COMPLETED

Integration of the 2008 MURI data sets

We have successfully integrated the NPS/SIO and WHOI observations, made during the 2008 MURI field experiment on the Louisiana shelf, into a comprehensive dataset. The combined data set includes a three-transect array on the inner shelf (Figure 1, inset 1) and a high-resolution nearshore array that smoothly connects to the shallow-end of the western transect of the shelf array (Figure 1, inset 2). The new data set includes observations with a high spatial resolution (see figure 2) across many wavelengths (approximately 25 km) and provides a unique and much needed database for the study of the evolution of waves over mud. The dataset consists of observations of a wide range of wave and wind conditions (figure 3), including fetch-limited wave growth (wind from northerly directions), swell propagation (southerly waves, weak winds), and mixed sea-swell events.

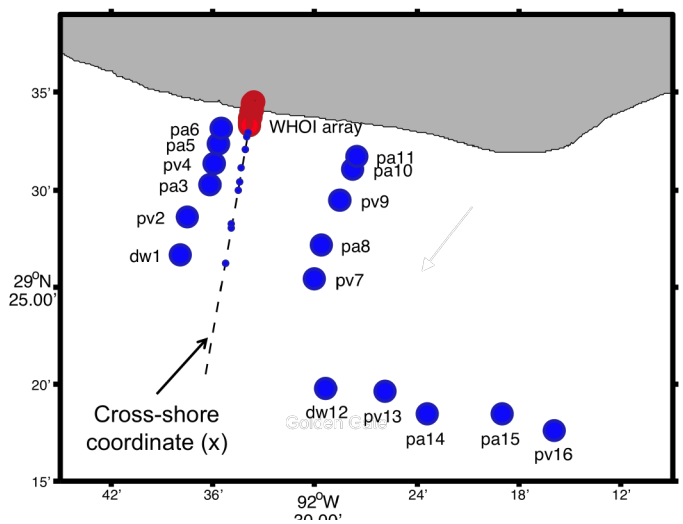

Figure 2 Overview map, indicating definition of the 'cross-shore' coordinate orientation (rotated 10° clockwise from North); blue markers are NPS/SIO sensor locations; red markers represent WHOI nearshore array.

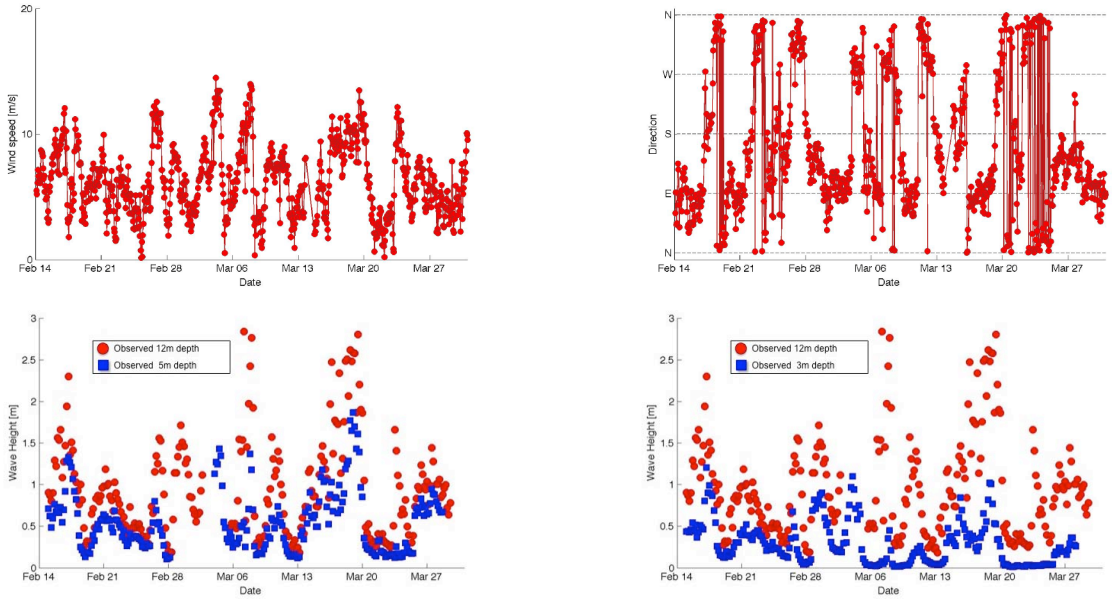

Figure 3 Top panels: wind speed (left) and wind direction (right); date courtesy Drs Trowbridge and Fredericks (WHOI). Bottom panels: on left, wave height time series comparison offshore sensor in12m depth (pv2) in red and nearshore sensor in 5m depth (pa6) in blue; on right, wave height time series comparison offshore sensor in 12m depth (pv2) in red and nearshore sensor in 3.2m depth (nearshore WHOI array) in blue.

Analysis of cross-shelf wave dissipation

To analyze cross-shore changes in wave energy, we have performed an energy flux analysis along instrument transects. Thereto we defined a cross-shore direction at about 10° clockwise from North (see figure 2), and assumed straight and parallel depth contours in the alongshore direction so that, for a stationary wave field, the wave energy balance reduces to

$$\frac{d}{dx}\mathcal{F}(\omega,\theta) = \mathcal{S}_{\mathrm{gen}}(\omega,\theta) + \mathcal{S}_{\mathrm{dis}}(\omega,\theta) + \mathcal{S}_{\mathrm{nl}}(\omega,\theta) \tag{1}$$

where $\mathcal{F}(\omega,\theta)$ is the cross-shore wave energy flux and the forcing terms on the right account for (from left to right): wind generation (input), dissipation (whitecapping, wave-bottom interaction etc.), and nonlinear interactions (redistribution).

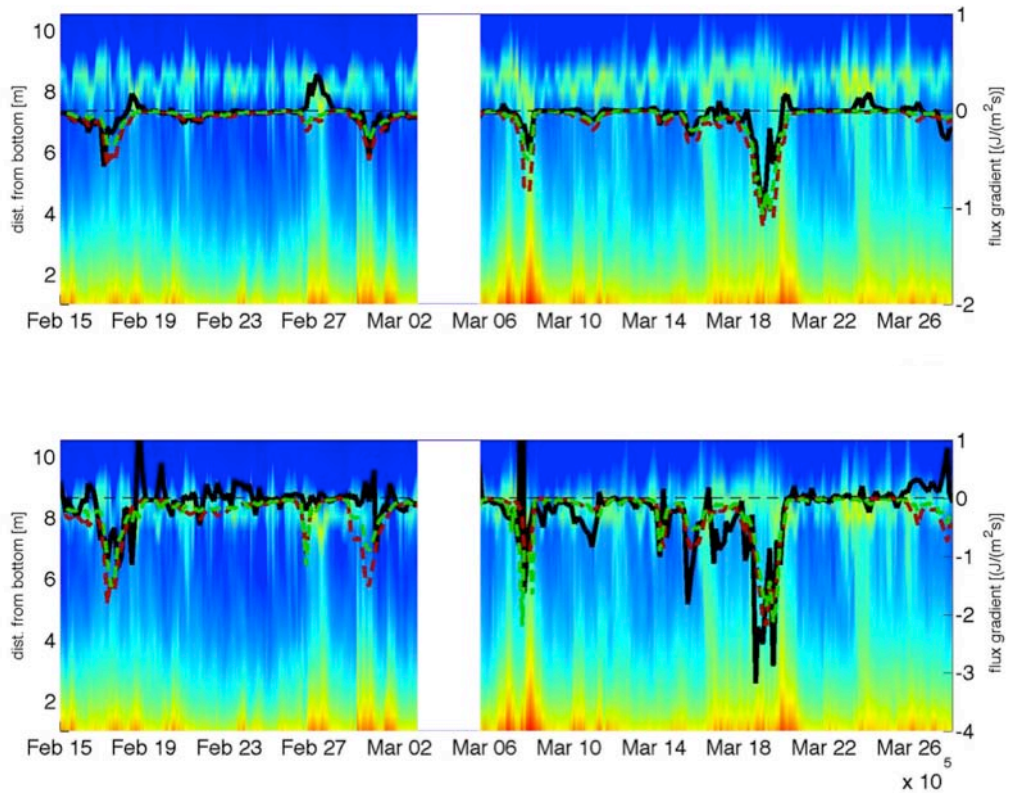

Figure 4 Comparison between observed (black solid line) and modeled cross-shore flux gradient. Models shown are Jonswap bottom friction (green dashed line), and boundary layer two-layer model (red dashed line) [Ng, 2000]. Top panel: flux gradients between 12m and 9.5m water depth (pv2 and pv4) on the western transect (see figure 2). Bottom panel: flux gradient between 5m and 3.5m water depth (WHOI array). Background colors show backscatter intensity (proxy for sediment concentration) through the fluid column as measured by acoustic Doppler instrument (aquadopp) in 8.5m depth (pv9).

Energy flux gradients were estimated directly from observations between sensors through finite differencing (see figure 4) and compared to a standard Jonswap dissipation model for bottom friction

[Hasselmann et al. 1973] and a boundary-layer approximation of a two-layer model [Ng, 2000]. In this comparison, the friction coefficient in the Jonswap term was set to 0.067 m^2/s^3 (standard value for wind sea, see Bouws & Komen, 1983); the settings for the two-layer model were (values loosely similar to those by Rogers & Holland, 2009) $\rho_1 = 1028\,\mathrm{kg/m^3}$, $\rho_2 = 1400\,\mathrm{kg/m^3}$, $\nu_1 = 2.6 \cdot 10^{-6}\,\mathrm{m^2/s}$, and $\nu_2 = 2.0 \cdot 10^{-3}\,\mathrm{m^2/s}$, and the mud layer thickness was set at 0.05m (based on visual observations from grab samples, see e.g. Trainor et al. 2008; Trainor, 2009; Garcia-Garcia et al. 2010).

The results of this analysis suggest that, with reasonable choices for the model parameters, both models predict bulk dissipation rates that are in good agreement with the observations. Moreover, the distribution of dissipation across frequencies predicted by the bottom friction model and boundary-layer mud model is in good qualitative agreement with what is observed (figure 5).

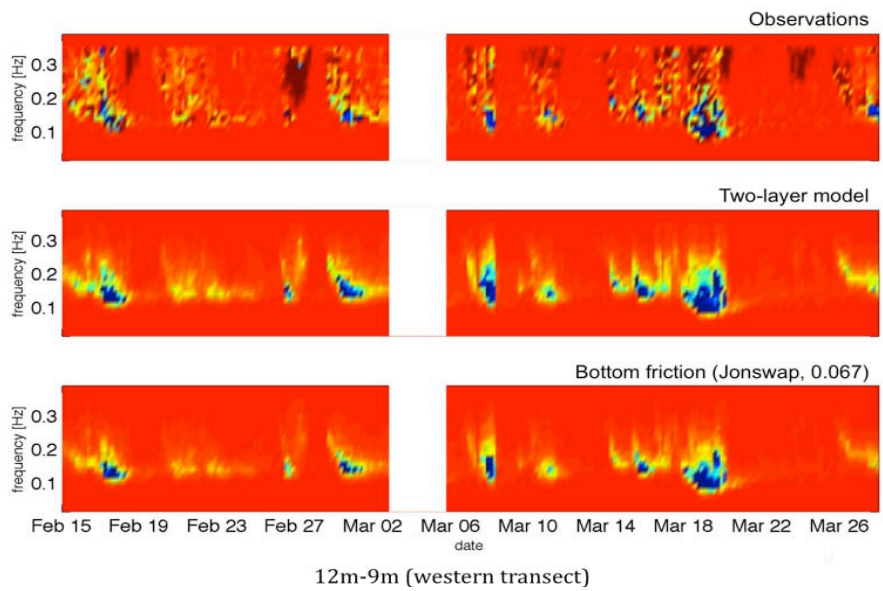

Figure 5 Comparison between observed flux gradient (top panel) as a function of frequency and time against two-layer model (middle panel) and JONSWAP bottom friction (bottom panel) between 12m and 9m depth (western transect).

Modeling wind-wave evolution across the shelf

To study the effects of mud on the seafloor on the nearshore wave energy balance in more detail, we have implemented a conventional third-generation wind-wave model (SWAN). Wave boundary conditions are taken from the most offshore buoy (DW12), wind forcing is obtained from meteorological observations made available by the WHOI team (Drs Trowbridge and Fredericks), and bathymetry information was taken from the NOS coastal relief model augmented with nearshore observations by the WHOI team (Elgar 2009, personal communication) during the experiment. Further improvements to the model implementation are ongoing to incorporate the inhomogeneity of the wind stress in offshore wind conditions [e.g. Taylor & Lee, 1984] and to incorporate more accurate lateral boundary conditions.

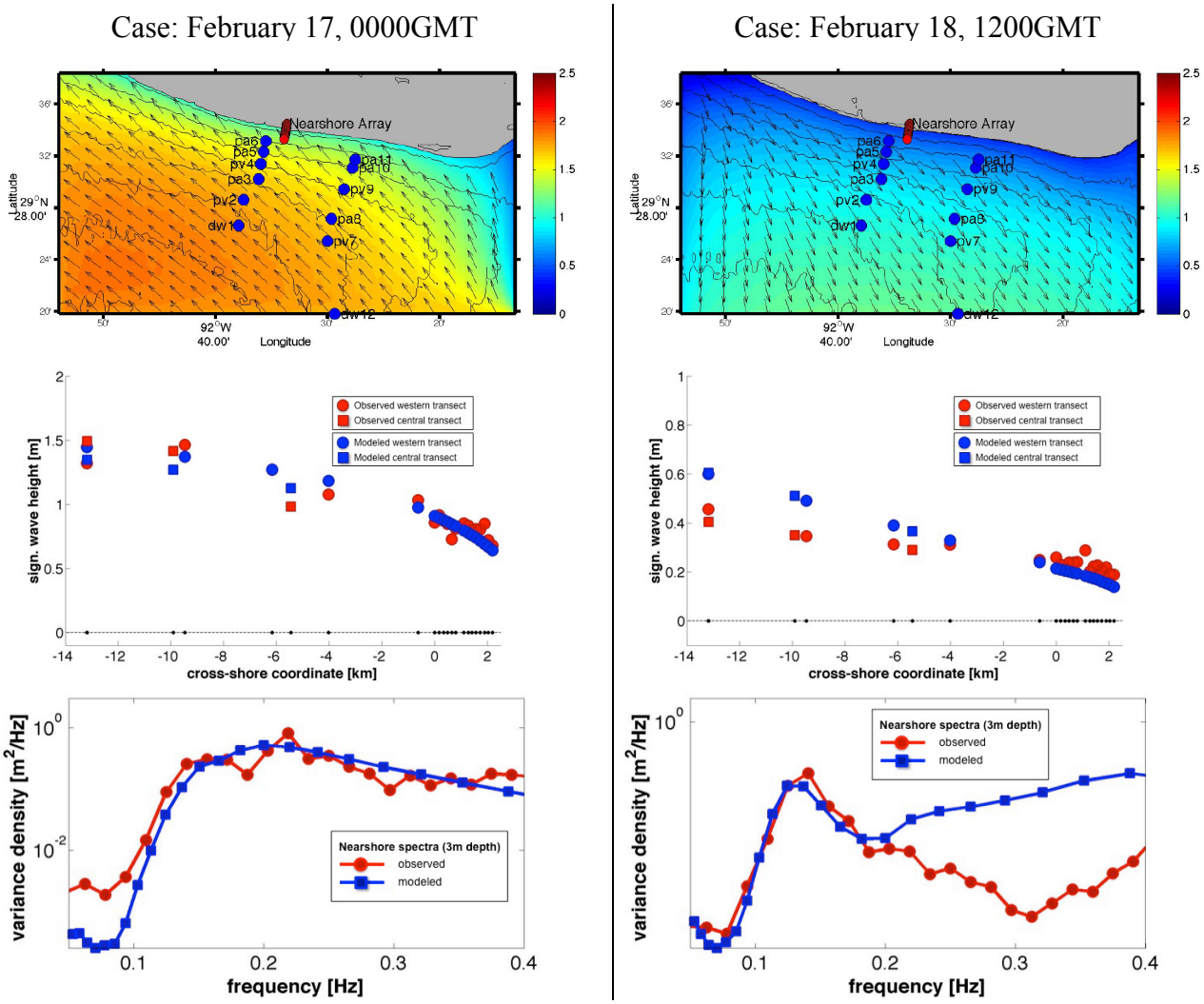

Figure 6 Comparison of SWAN model predictions of wave height and spectra to observations for two cases. Left panels: model-data comparison for 0000Z, 17 February 2008. Right panels: model-data comparison 1200Z, 18 February 2008. Top panels: model-predicted wave height (color scale in m), model-predicted direction (vectors), depth contours, and instrument locations. Middle panels: modeled and observed wave heights along the 'cross-shore' coordinate (see figure 2). Bottom panels: nearshore spectra (3m water depth).

The hindcast study for the experimental period allows the identification of the effects of the presence of mud on the wave energy balance across the shelf. The wave model was run with mostly default settings (WAM cycle 4), and uses a Jonswap bottom friction term for wave-bottom dissipation. Using the model results, we have made comprehensive model-data comparisons, including case-studies (see figure 6), time series of bulk statistics (see figure 7), and detailed analysis of spectral distribution of source terms (figure 8).

From the case studies it shows that in cases were wind forcing is relatively weak and non-locally generated waves (swell) propagate across the shelf to the shore, the bottom friction term seems to capture the principal damping characteristics reasonably well, including the details of the spectral evolution (left panels figure 6). However, in cases with offshore wind, where waves are generated in fetch-limited conditions, the spectral evolution is represented considerably less satisfactory by the model (right panels figure 6). For such cases however, we expect that the inhomogeneity of the wind field is of particular importance and work is ongoing to account for those effects.

The time series comparison shows that flux gradients are in good agreement everywhere (figure 7), although dissipation is consistently underestimated in the model. The spectral structure of the source terms (figure 8) is in good agreement with the observations, in particular the dissipation in the energetic range of the spectrum.

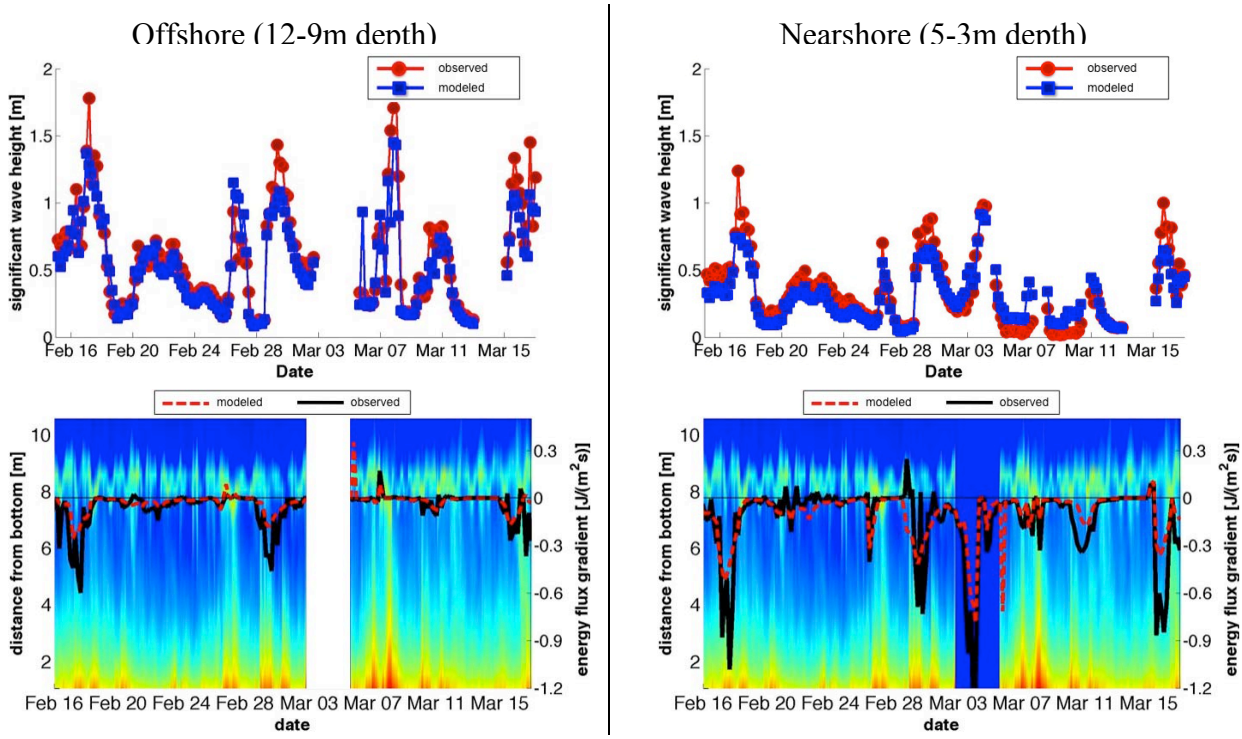

Figure 7 Top panels: model-data comparison of wave height time series at 12m depth (left panel) and 5m depth (right panel). Bottom panels: model-data comparison flux gradient estimated between 12m-9m depth (left panel) and 5m-3m depth (right panel).

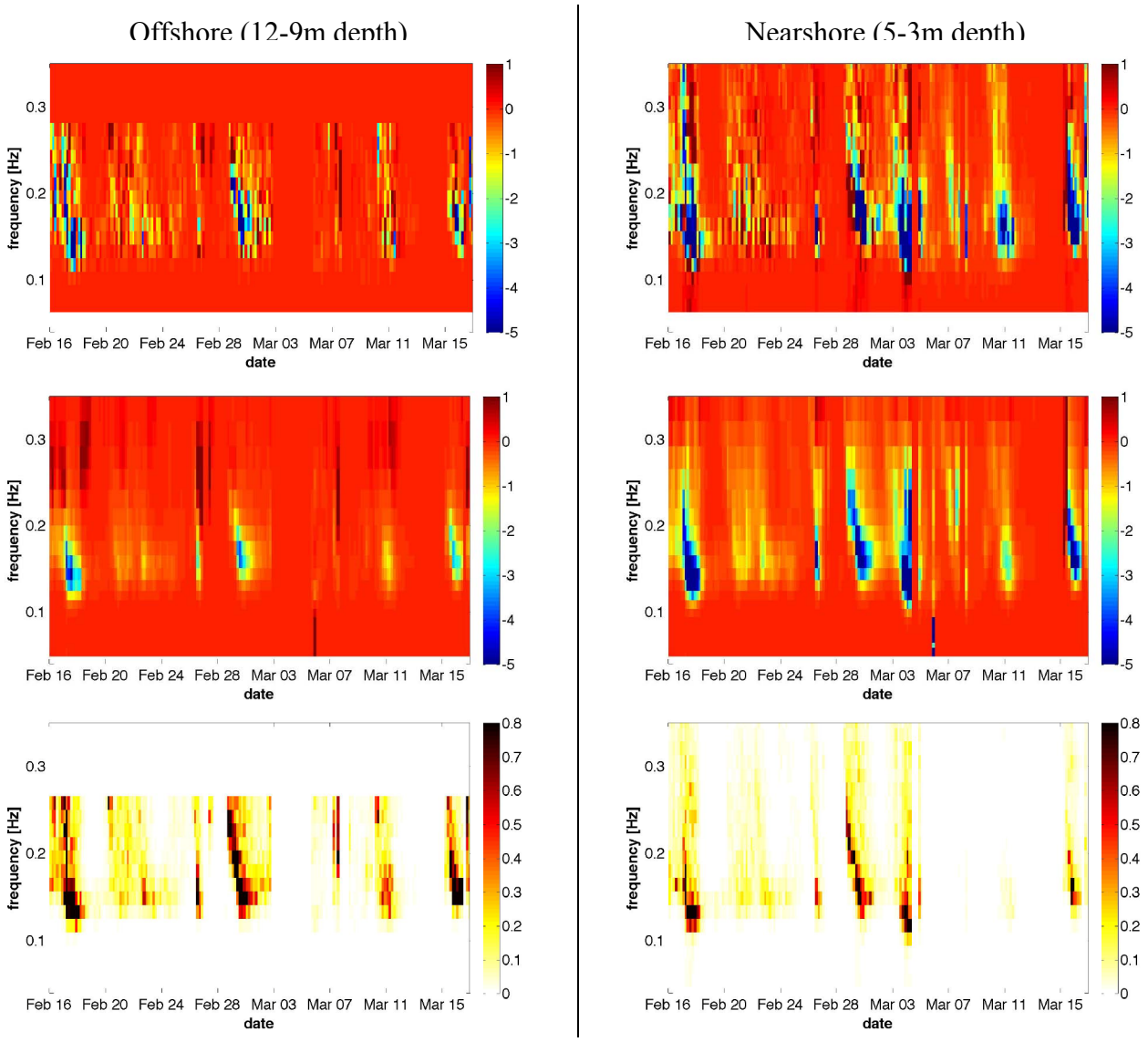

Figure 8 Comparison between observed flux gradient (top panels) as a function of frequency and time against SWAN model-predicted flux-gradient (middle panels). Left panels: deeper water (12-9m depth); right panels: shallow water (5-3m depth). Bottom panels show variance density spectra at 12m (left) and 5m (right).

RESULTS

A principal result of this study so far is the integration of the observations made during the 2008 MURI field experiment of wave propagation across the Louisiana shelf. This new comprehensive dataset provides high spatial resolution and includes a wide range of wave and weather conditions.

A one-dimensional flux analysis of the observations shows that observed dissipation is in good agreement with estimates from a standard bottom friction term or a boundary-layer approximation of a discrete two-layer wave-mud model, when using reasonable choices for model parameters.

Comparison of the observations to SWAN model predictions (using a standard bottom friction term), shows good agreement for time series of flux gradients and other bulk statistics. However, for individual cases, in particular for fetch-limited conditions, the agreement can be less satisfactory. In part this discrepancy is ascribed to an unrealistic representation of the wind field in the transitional zone from land to ocean and efforts are ongoing to improve this.

IMPACT/APPLICATIONS

The availability of a comprehensive community dataset of wave propagation across a muddy shelf will be an important contribution to the study of wave-mud interactions and the validation and calibration of new theories and modeling approaches.

The comparison between observations and model simulations will improve understanding of the effects of mud on wave propagation across the shelf and in the nearshore, and advance modeling capability in muddy coastal areas.

REFERENCES

Bouws, E., & Komen, G.J. (1983). On the balance between growth and dissipation in an extreme, depth limited wind-sea in the southern North Sea, *J. Phys. Ocean.* **13***,* 1653-1658.

Garcia-Garcia, A., T. T. Janssen, T. H. C. Herbers, D. Alden, A. Orange, D. Orange, P. Jessen, S. Kawamoto, and P. Harvey (2010) A geophysical baseline for the Fluid-Mud MURI site, west of Atchafalaya Bay, submitted to *Geo-Mar. Lett*.

Hasselmann, K., et al. (1973). Measurements of wind-wave growth and swell decay during the Joint North Sea Wave Project (JONSWAP). *Dtsch. Hydrogr. Z. Sup.* **A8**(12)*,* 95.

Ng, C. (2000) Water waves over a muddy bed: a two-layer Stokes' boundary layer model, *Coast. Engn* **40**, 221-242.

Rogers, W. E. and T. Holland (2009) A study of dissipation of wind-waves by mud at Cassino Beach, Brazil: prediction and inversion. *Cont. Shelf Res.*, **29**, 676-690.

Taylor, P.A. and R. J. Lee, (1984) Simple guidelines for wind speed variations due to small-scale topographic features *Clim. Bull.* 1**8**, 3-32

Trainor, L.T., (2009) Field observations and SWAN model predictions of wave evolution in a muddy coastal environment, *MSc dissertation*, Naval Postgraduate School, Monterey 73p.

Trainor, L.T., T.H.C. Herbers, T.T. Janssen, A. Garcia-Garcia, and P.F. Jessen (2008) Observations of ocean surface wave damping on a muddy continental shelf -Louisiana MUDEX 2008, poster presented at AGU meeting, San Francisco