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

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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 and the impacts on coastal wave dynamics is not well understood. The overall objective of this work is to contribute to the understanding of the macro-scale 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 new datasets acquired in 2008 (ONR-funded wave-mud MURI) of waves propagating across more than 25 km over a muddy seafloor, 2) determine the characteristics of mud-induced dissipation of wave energy from intermediate- to shallow-water depths, and 3) investigate the effects of nonlinear interactions on the wave dynamics.

APPROACH

To improve our understanding of mud-induced damping rates on surface waves, and its variation across the shelf, 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 allows a detailed analysis of mud-induced wave damping across the shelf to the shoreline, including the transition to shallow water. 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) investigate the role played by nonlinear interactions in the damping of short waves.

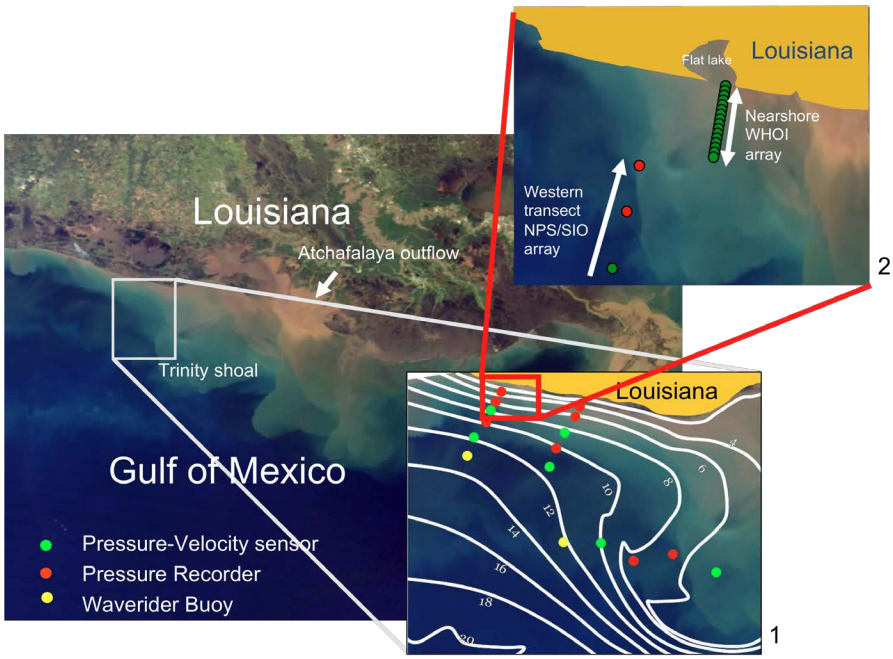


Figure 1 Field site and sensor arrays of the Louisiana waves-over-mud field experiment February-March 2008 (MUDEX08). Inset 1 shows the inner-shelf array (NPS/SIO team) consisting of three transects (16 instrumented sites), deployed between 13 and 4 m depth. White curves are depth contours (depth indicated 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

The datasets collected by the NPS/SIO and WHOI teams during the 2008 MURI field experiment on the Louisiana shelf (see also Trainor, 2009; Trainor et al. 2008; Garcia-Garcia et al, 2011), were combined 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 will provide a 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.

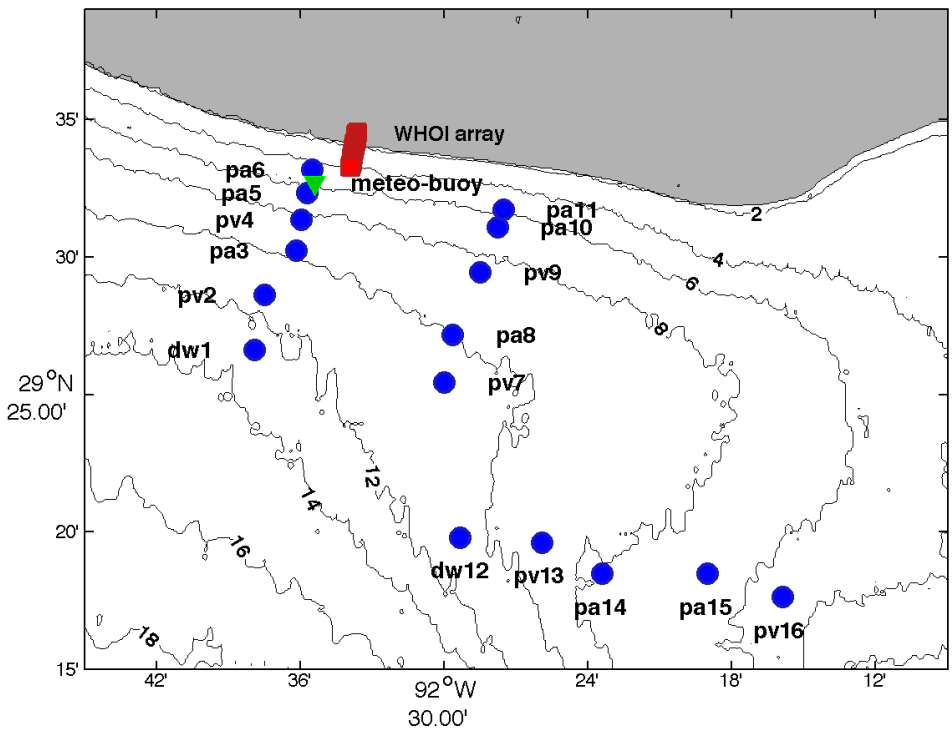


Figure 2 Overview of sensor locations in the study area. Blue dots indicate the inner shelf stations (NPS/SIO) where dw-stations indicate Datawell Waverider buoys, the pv are Nortek Vector pressure-velocity sensors, and pa are pressure recorders. Red dots show the WHOI nearshore array; the nearshore sensors are referenced in the text as n1, n2, …., n16, in order of increasing depth. The green dot shows the approximate location of the meteorological buoy.

Implementation third-generation wave model

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.
To account for the down-wind variability of the atmospheric boundary layer due to the decrease in roughness length over water, wind speeds during offshore wind events (defined as wind events with mean wind directions < $\pm\frac{\pi}{2}$ from exactly offshore) are modified by a spatially varying scaling factor (Taylor & Lee, 1984). The model was run in third-generation mode (GEN 3) with saturation-based whitecapping (Van der Westhuysen et al., 2007) combined with the Yan wind input term (Yan, 1987). All available source terms are included in the computations except the triad interactions.

The present model implementation was used as a reference for an equivalent sandy shelf to identify the principal effects of the mud on the observed wave dynamics. Thereto we ran the model with a standard

bottom friction term (Hasselmann et al., 1973) with the (fixed) friction coefficient set to 0.038 m^2s^{-3} (Van Vledder et al. 2011).

Analysis of cross-shelf wave dissipation

To analyze the effects of mud on the wave energy balance, 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). Through comparison of the observed and modeled cross-shore energy flux gradient (1), and normalized growth rate

$$\alpha = \frac{1}{\mathcal{F}}\frac{d\mathcal{F}}{dx}, \tag{2}$$

we assessed the macro-scale effects of wave-mud interaction on evolution of waves across a muddy continental shelf.

RESULTS

The model-data comparison shows that wave heights are generally predicted well with the standard Jonswap bottom friction term, apart from episodic events when dissipation levels in the observations appear to be enhanced (see figure 3). This suggests that a simple (fixed) friction coefficient is inadequate to capture the more dynamic (and time varying) rheology of the muddy seafloor, which is consistent with previous findings by other researchers (e.g. Sheremet et al., 2005). Further, during swell-type events (longer-period waves) the muddy seafloor appears to affect wave-bottom interaction, and results in time-varying enhancement of losses of wave energy. During times that the wind is blowing in offshore direction (fetch-limited and slanted fetch wave growth) the effect of mud appears to be a suppression of wave growth, either through the damping of short waves or through decreasing the effectiveness of the momentum transfer from the wind to the water.

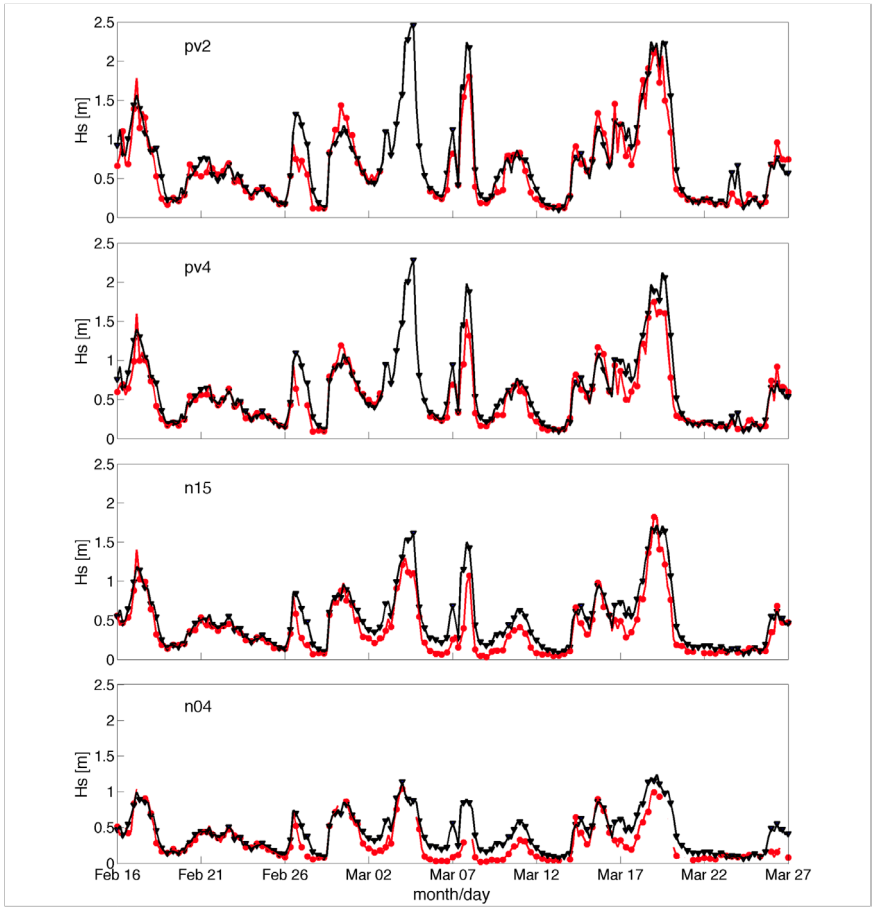


Figure 3. Comparison of observed (red line with dots) and modeled (black line with triangles) significant wave heights for sensors pv2, pv4, n15, and n04 (top to bottom). Observations are missing for the inner shelf stations (pv2 and pv4) from March 2 to March 5 due to instrument turn-around.

The observed and modeled growth rates (figure 4) are of comparable magnitude for the inner shelf stations (figure 4, left panels). However, in particular for the higher frequencies, there are differences (including opposite sign), generally indicative of the fact that while the model predicts wave growth (due to wind) the observations are dominated by dissipation.

In the nearshore (figure 4, right panels), dissipation is stronger on account of the shallower depth. Although observed and modeled dissipation rates are overall of similar magnitude, there is considerable variability in the estimates, both in the lower (0.04-0.20 Hz) and higher (0.20-0.25 Hz) frequencies.

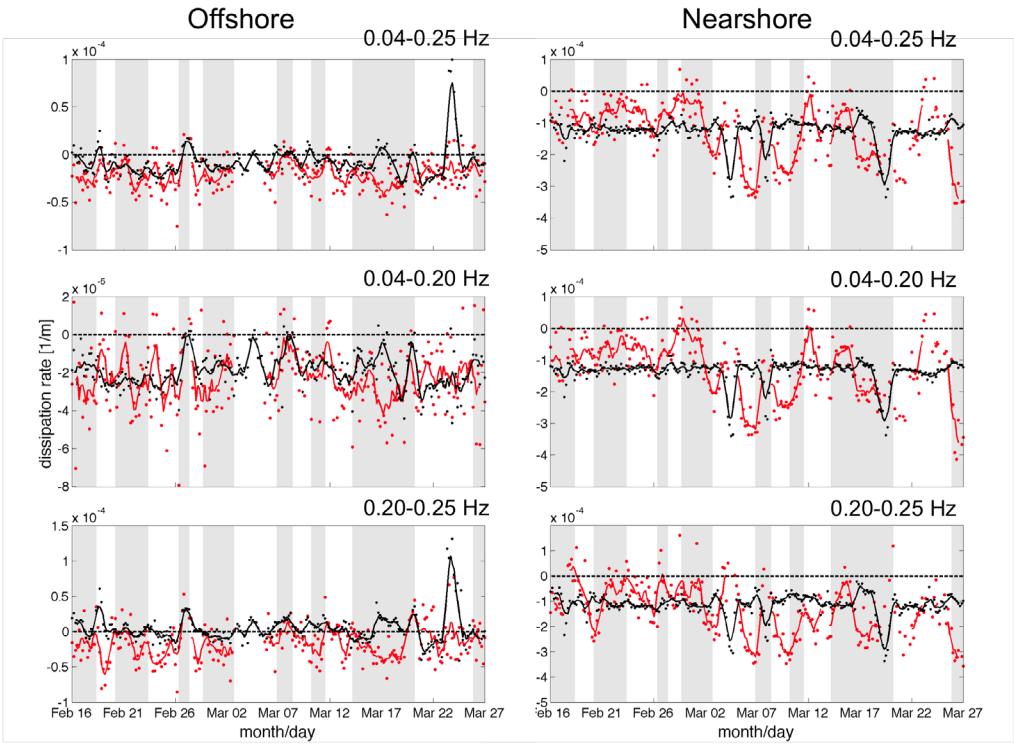


Figure 4. Shown are integrated dissipation rates for observations (red dots) and model (black dots) for the inner shelf (pv2 to pv4, left column) and nearshore (n15 to n04, right column). A running mean (window width of 20 hrs) for observations (red line) and model (black line) is shown. Integration limits are 0.04-0.25 Hz (upper panels), 0.04-0.20 Hz (middle panels) and 0.20-0.25 Hz (lower panels). Positive/negative values indicate growth/dissipation. Grey-colored areas indicate times when wave heights at station pv2 exceed 0.4 m. Notice the difference in scales across panels.

Both on the inner shelf and in the nearshore, large negative flux gradients (dissipation) occur during high-energy, long-period wave events. Overall, modeled dissipation rates are in good agreement with the observations, although the model tends to generally underestimate the magnitude of dissipation somewhat (see figure 5). In the nearshore region (right panels figure 5), where the (non-normalized) dissipation rates are overall larger, the agreement is generally better. On the inner shelf the model predicts several growth events at higher frequencies (0.20 – 0.25 Hz), where wind input thus dominates over dissipation, while the observations show either no growth (e.g. March 24) or even dissipation (around March 17), which suggests that some differences in the energy balance on the inner shelf remain.

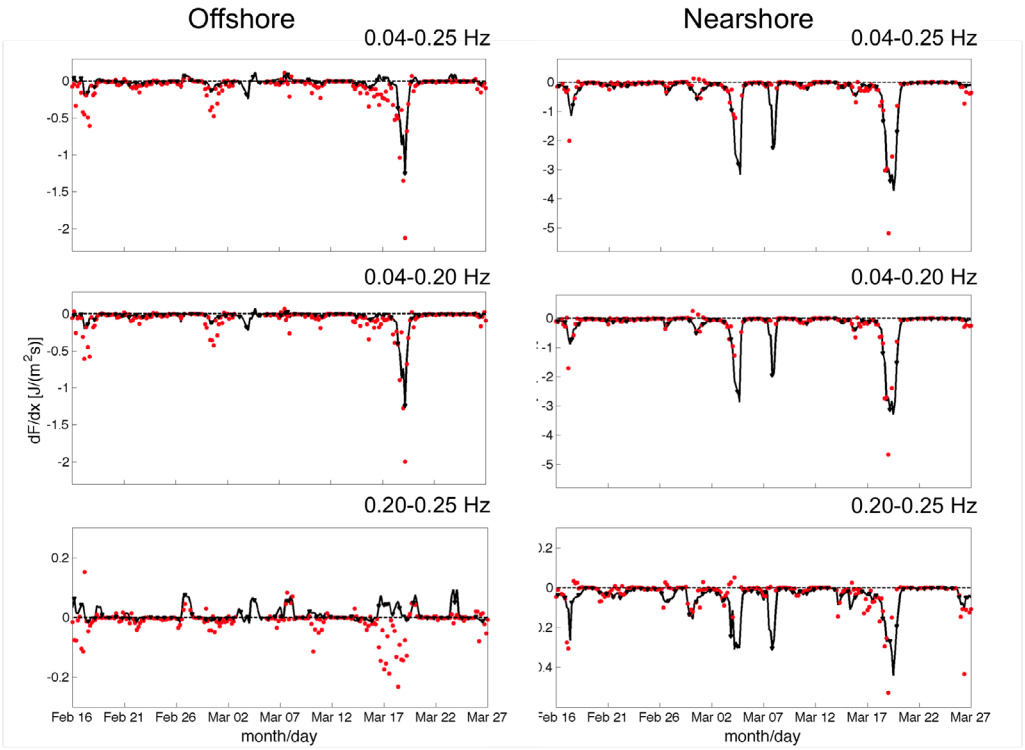
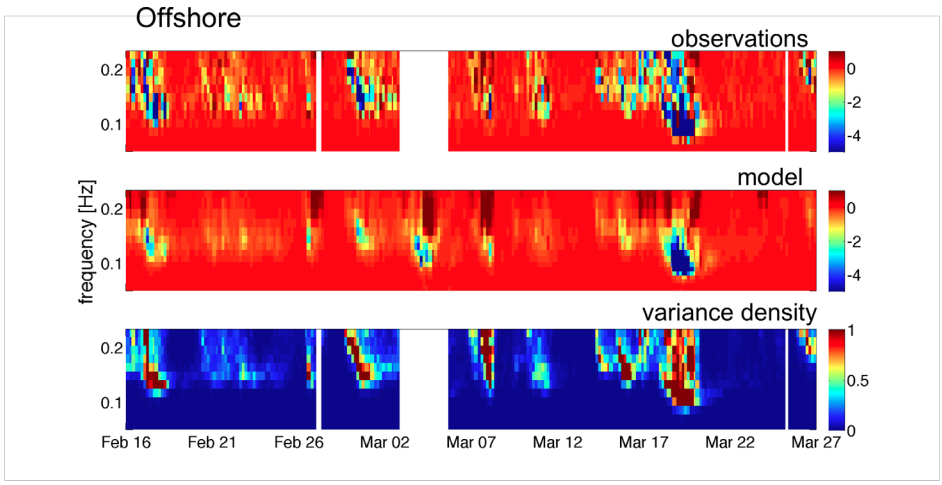


Figure 5. Shown are integrated energy flux gradients for observations (red dots) and model (black line) at inner shelf stations (pv2 to pv4, left column) and nearshore stations (n15 to n04, right column). Integration limits are 0.04-0.25 Hz (upper panels), 0.04-0.20 Hz (middle panels) and 0.20-0.25 Hz (lower panels). Positive/negative values indicate growth/dissipation. Notice the difference in scales across panels.

The frequency distribution of the dissipation (see figure 6) between observations and model shows good agreement, although the model underestimates dissipation toward higher frequencies (> 0.2 Hz) at the inner shelf stations. It can be seen (figure 6) that dissipation takes place in the energetic ranges of the spectrum. The distribution of dissipation is mostly consistent with a direct interaction mechanism where damping is induced through interaction of wave-induced fluid motions with the seafloor, such as is the case for bottom friction (Hasselmann et al, 1973), or a direct-interaction two-layer model (e.g.Dalrymple & Liu, 1978; Ng, 2000).

a.)



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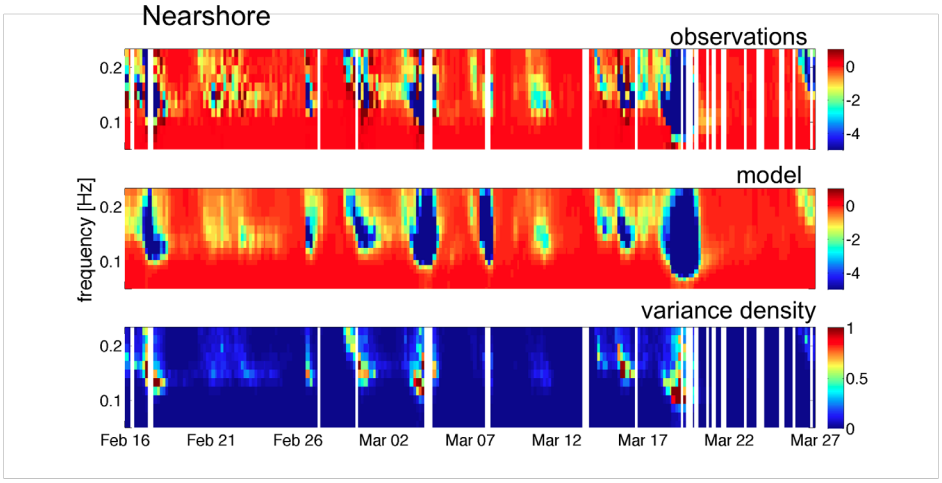

Figure 6. a) Shows time series of observed energy flux gradient between pv2 and pv4 (upper panel) and model energy flux gradient (SWAN) at same location (middle panel), and observed energy density (lower panel). b) same information as a) but between the nearshore stations n15 and n04. For the flux gradients, negative/positive values represent dissipation/generation.

IMPACT/APPLICATIONS

The availability and analysis 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 fact that the time-varying properties of mud are important even for the macro-scale effects of wave propagation in coastal areas, and cannot be adequately represented by a fixed rheology, is important for operational wave prediction in coastal areas.

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