ALONGSHORE VARIABILITY OF COASTAL MORHODYNAMICS IN EASTERN LAKE ERIE DUE TO LOW FREQUENCY OSCILLATIONS OF LAKE LEVEL

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Lake Erie has the fourth largest surface area, shallowest water depth and smallest volume among the five Great Lakes in North America (NOAA). The dominant wind direction over Lake Erie's is southwest-northeast, along the lake's longitudinal axis. The atmospheric and water level data of the lake demonstrate that high wind and moving pressure systems can result in high storm surge of up to 3 m on the eastern end of the lake and significant drop in the water level at the western end of the lake Due to its shallow depth, such a water level gradient can trigger unique post-storm free water-level fluctuations or seiches in Lake Erie (Farhadzadeh, 2017). The morphodynamic implications of such low frequency oscillations are yet to be studied for the lake's shorelines. Most of studies on the contributions of long waves to beach morphology changes focused on low frequency harmonics induced by short waves, e.g. infragravity waves, edge waves, etc., oscillations with periods of up to a few minutes. Wright and Short (1984) discussed the differences in hydrodynamic processes and relative contributions of various mechanisms to morphological changes of beaches of different states, i.e., reflective, dissipative or intermediate. They concluded that for reflective beaches, incident waves and subharmonic edge waves are dominant while for dissipative beaches currents associated with infragravity standing waves are dominant in nearshore areas. Russell (1993) stated that as low frequency wave energy increases toward a shoreline, the offshore-directed transport at low frequency can become more pronounced.

In this study, the effects of seiches on beach morphology in eastern Lake Erie were evaluated by simulating beach evolutions for actual recorded water level time series and for the water level time series filtered for frequency band corresponding to seiches.

METHODOLOGY

The morphological changes in the beaches near Buffalo are investigated using two morhpodynamic models, CSHORE and XBeach. CSHORE (Kobayashi and Farhadzadeh, 2008) is a 1D cross-shore time-averaged model which predicts cross-shore variations of the mean and standard deviation of the free surface elevation, the depth-averaged cross-shore current, the cross-shore velocity standard deviation, the cross-shore bed-load transport rate, and the cross-shore suspended sediment transport rate (Harter and Figlus, 2017). XBeach is a 2D numerical model developed for short-term nearshore morphological changes due to storms (Roelvink et al., 2010). XBeach model solves depth averaged two-dimensional flow equations coupled with wave transformation and morphodynamics. The wave and surge data used as input for the morphodynamic models are extracted from the coupled ADCIRC and SWAN model results for a number of historical storms described in details in Farhadzadeh and Gangai (2017). In order to evaluate the short-term (storm-specific) contribution of seiche to the beach evolution, a band-pass filter will be utilized to remove the oscillations with the frequencies of the main seiching modes (Fig. 1) from the water level time series. The resulting "seiche-free" water level time series along with the wave data will be used as input to the morphodynamic models (CSHORE and XBeach) to predict the bottom evolution. The resulting beach profile will be compared with those that will be simulated using the original water level time series.

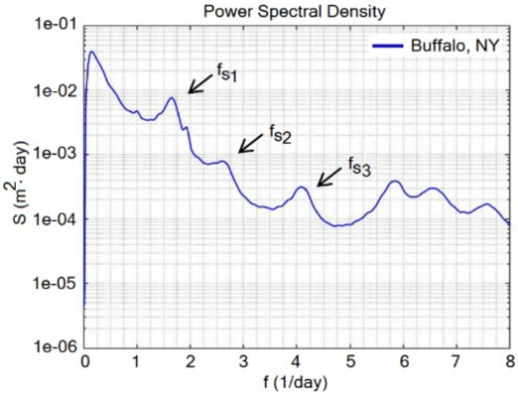

Figure 1. Power Spectral Density of Hourly Water Level at Buffalo (f_{s1} = 14.2h, f_{s2} = 9.2h, f_{s3} = 6.0h)

In order to obtain water level and wave conditions at the offshore boundaries of morphodynamic models, coupled ADCIRC+SWAN simulations covering whole lake area (Fig. 2) are carried out.

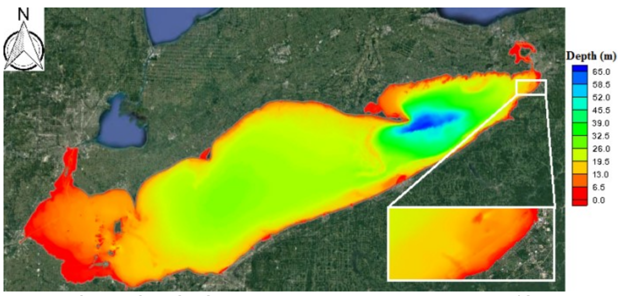

Figure 2. ADCIRC+SWAN coupled model domain (Small rectangle shows the region of interest in morphodynamic models)

The results of ADCIRC+SWAN simulations are compared with the water level station and wave buoy data distributed along the lake. After validation of this coupled model, water level and wave data obtained from coupled model simulations are enforced to XBeach and the two model results are compared at boundary and control point locations (Fig. 3) to validate XBeach hydrodynamics (Fig. 4).

In addition, average beach profile is obtained by taking a number of cross-sections along the beach. Using the Dean's equilibrium beach profile approach, the median grain size (d_{50}) is calculated as 0.11mm (Fig. 5) which is consistent with the findings of Thomas et al. (1976) and Dusini (2005).

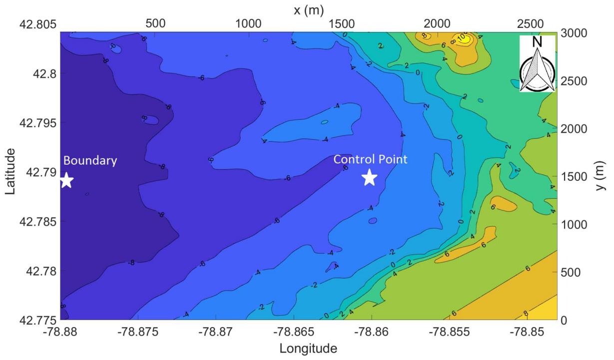

Figure 3. Bathymetry used in morphodynamic model

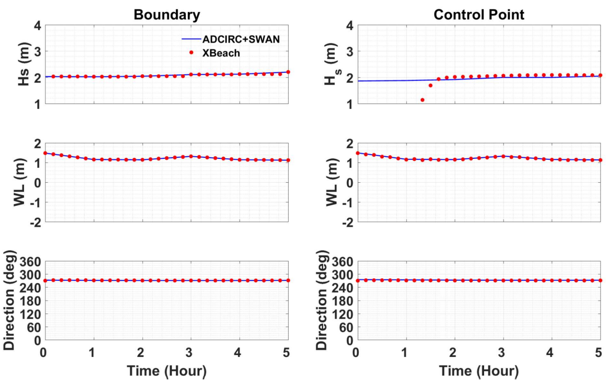

Figure 4. Comparison of ADCIRC+SWAN coupled model water level and wave results with XBeach.

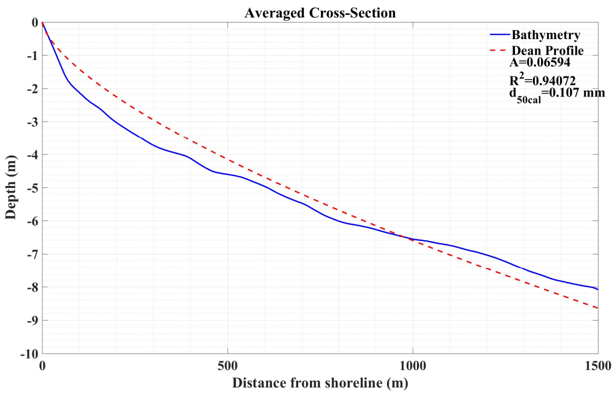

Figure 5. Equilibrium beach profile calculated for Eastern Lake Erie

DISCUSSIONS

Farhadzadeh et al. (2018) showed for a specific beach location south of Buffalo more erosion is expected that under actual lake levels that include seiche than seiche-free condition. To quantify alongshore variabilities of seiche-induced morphological evolution, comparisons of the bottom profiles and sediment transport regimes are made along a shoreline in eastern Lake Erie. Since the magnitude of low frequency oscillations varies along the Lake Erie shoreline (Farhadzadeh, 2017), their contributions to the nearshore morphodynamics may vary spatially, as well. The outcome could have some implications on predictions of long-term beach responses under a changing climate.

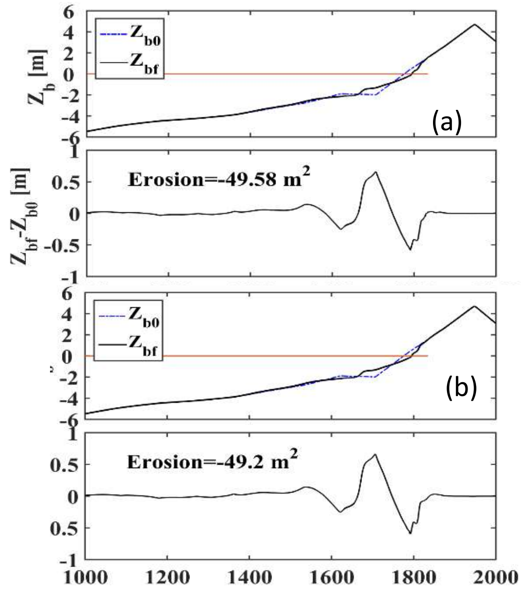

Figure 6. Beach profile evolution and eroded areas for (a) actual, and (b) seiche-free lake levels (Farhadzadeh et al., 2018)

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