Numerical modelling of beach morphological change: A case study of Ka'anapali Beach, Maui, Hawaii

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This case study reports results from field observations and numerical simulations of waves and morphological changes along a portion of Ka'anapali Beach on West Maui, Hawai'i, which is protected by a hard coral reef and experiences shoreline changes from season to season. The SWAN spectral wave model shows reasonable agreement with ADCP observations of wave heights for the winter months. Simulated beach profile change over one-month time frame was able to reasonably capture the trend of beach face migration (accretion or erosion); the modeled shoreline also shows satisfactory agreement with beach survey data. This case study suggests that Delft-3D is able to capture key features of sediment transport along a narrow beach protected by a fringing reef .

provide in simulating shoreline and beach profile changes.

Keywords: Sediment transport; beach survey; SWAN Model; beach profile; Delf3D

1. Introduction

In the face of global warming-induced sea level rise, the Hawaiian Islands are experiencing overall beach erosion and loss (Romine and Fletcher, 2013; Romine *et al.*,

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2013). The trend of coastal engineering in Hawaii is moving towards a better understanding of sediment transport and morphological changes due to rising water levels and changing wave climates. Beach nourishment projects have become a popular engineering solution to beach loss in the state of Hawai'i and other places. Much of our knowledge of beach migration patterns come from long-term monitoring of shoreline movement and historical beach change annually and seasonally.

Numerical modeling has been a very useful tool used by coastal engineers to describe nearshore hydrodynamic processes including waves and currents (Noye, 1999). However, process-based morphological models for sediment transport and morphological changes are still in a state of development as part the coastal engineering discipline (Blanco *et al.*, 2019), and sediment transport phenomena in the nearshore region is still not commonly investigated using numerical models in engineering practice due mainly to the lack of field data for calibration of existing models and the high demand for computing resources. It is important to tune existing models that have been developed for one project site for the unique beach characteristics and hydrodynamics found in another project site. With more field data available for model verification and calibration, existing models for simulating coastal morphological changes can be improved, making them more applicable to engineering applications.

This paper reports a case study of beach morphological change at Ka'anapali Beach, which is situated on the west coast of the island of Maui, Hawaii. This case study was conducted to support a beach nourishment project at Ka'anapali Beach. Referring to Fig. 1, Ka'anapali Beach extends 2.3 km from Puu Kekaa (Black Rock) in the north to Hanakaoo Beach Park to the south. Ka'anapali Beach is exposed to north Pacific swells during the winter months and south Pacific swells during the summer months. The surrounding Hawaiian Islands of Moloka'i, Lana'i, and Kaho'olawe act as wave shadows and reduce much of the wave energy through refraction and diffraction before reaching Ka'anapali Beach shoreline.

Ka'anapali beach is characterized by two littoral cells: the Ka'anapali Littoral Cell (KLC) which extends 1.2 km from Puu Kekaa to Hanakaoo Point, and the Hanakaoo Littoral Cell (HLC) which extends 1.1 km from Hanakaoo Point to Hanakaoo Beach Park (see Fig. 2). The KLC backshore, foreshore, and nearshore areas typically consist of sand while the HLC backshore/foreshore consists of sand with a nearshore fringing reef. The shoreline position at the site is very dynamic from season to season. During the winter months, prevailing north swells drive beach sand to the south along the KLC, whereas in the summer, prevailing south swells drive the sand to the north. This causes the KLC shoreline position to change seasonally due to the longshore sediment transport mechanism occurring in this region. The Hanakaoo portion of the beach is narrower compared to the Ka'anapali portion. Close to Hanakaoo Beach Park, the HLC shoreline position is relatively stable season to season, but close to Hanakaoo Point, seasonal changes still exist. The HLC shoreline position might be more susceptible to erosive events caused by high water

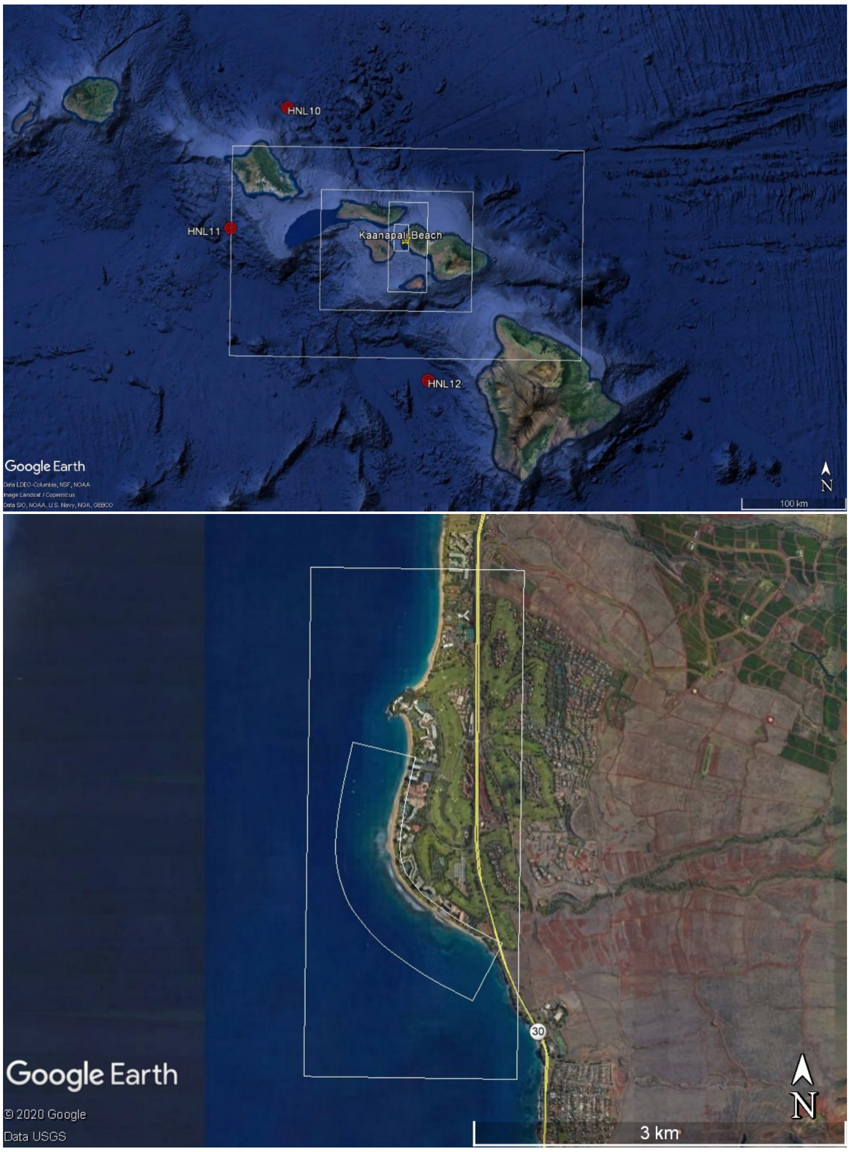

Fig. 1. The case study site Ka'anapali Beach (20.9178° N, 156.6966° W) and SWAN nesting scheme with nearshore flow grid with locations of virtual buoys.

levels coupled with south swells or Kona storm waves. Historically the HLC has experienced beach narrowing and erosion which in some cases has led to undermining of backshore pathways.

Ka'anapali Beach is a unique place as the KLC portion of the beach experiences significant beach change from the winter to summer seasons while much of the HLC shoreline does not have a clear seasonal trend. This has been shown through beach monitoring, which tracks the beach volume change over time. Fig. 3 shows how the

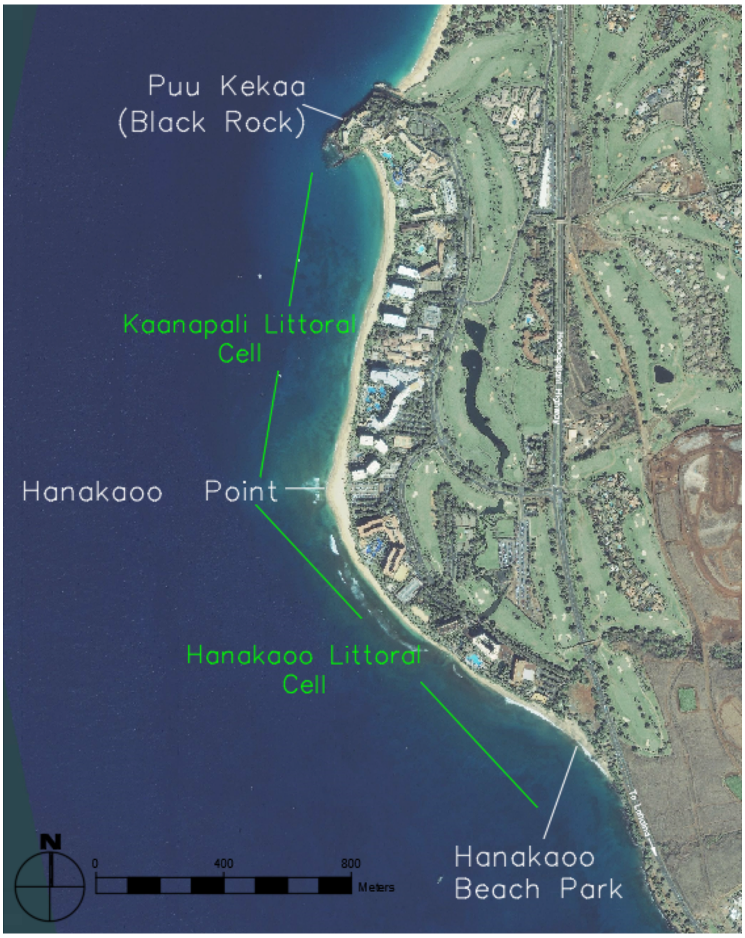

Fig. 2. Overview of project site showing the KLC and the HLC. The location of Ka'anapali Beach, Maui, is indicated in Fig. 1.

KLC erodes to the south and accretes to the north during the summer months; this trend will reverse direction during the winter months.

A beach nourishment project at Ka'anapali Beach has been designed to address the issues being faced there (Sea Engineering, 2017, 2020). The proposed plan involves beach face nourishment of the HLC portion of Ka'anapali Beach with sand collected offshore from the project site and enhancement of the existing beach berm within the KLC. There is a need to have a numerical tool that can help the designers and decision makers to assess various nourishment scenarios at Ka'anapali Beach.

Using the open source numerical package Delft3D (Deltares, 2016), which was developed to simulate near-shore hydrodynamics, sediment transport, and morphological changes, Vitousek (2007) performed a case study of Ka'anapali Beach; his study focused on the longshore sediment transport and hydrodynamics which take place within the KLC portion of the beach, and not the sediment transport characteristics which take place at the HLC. Outcomes from that study show that Delft3D simulates wave heights and currents around West Maui quantitatively, while the morphological changes were more represented qualitatively. The scope of the present study will focus on numerical modeling of hydrodynamics and morphological changes in the HLC portion of the beach.

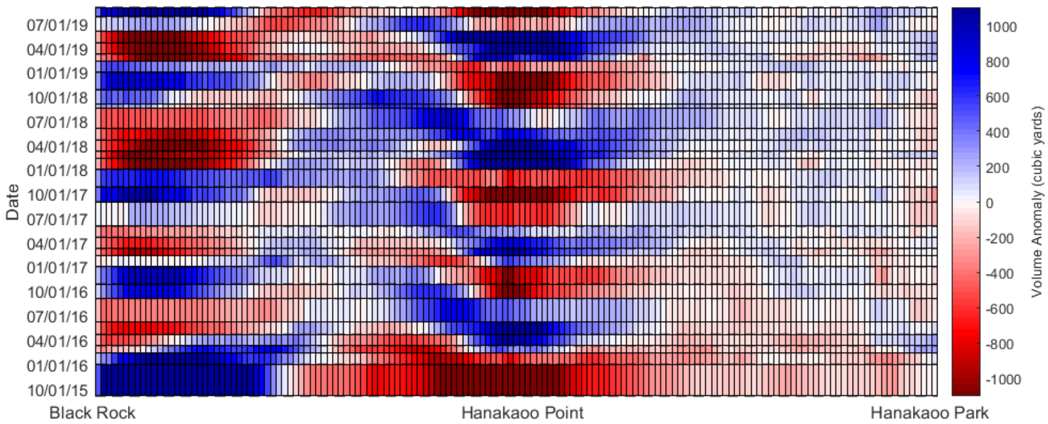

Fig. 3. Beach volume change along Ka'anapali Beach (Ailana Surveying and Geomatics and Sea Engineering (2017) and Sea Engineering (2020).)

2. Methods

This section provides information of the field data and numerical models used in this case study. As in Vitousek (2007), Delft3D (Deltares, 2016) is adopted to perform numerical simulations of morphological changes in the HLC portion of Ka'anapali Beach.

2.1. *Field data*

Numerical modeling requires a variety of data to generate the numerical grids and boundary conditions and to validate and verify the model using field observations. This section covers all the datasets used for this case study, including the field data collected for the beach nourishment project at Ka'anapali Beach (Sea Engineering, 2017, 2020), online resources including wave and topographic/bathymetric data and the data in Vitousek (2007).

2.1.1. *Offshore wave data*

The offshore wave climate is derived from virtual buoy data provided by the wave hindcast numerical model WAVEWATCH III [1](WW3). For this study, hindcast data was obtained from three virtual buoy locations HNL10, HNL11, and HNL12; the locations of these virtual buoys in relation to the Hawaiian Islands and Ka'anapali Beach are shown in Fig. 1. Spectral wave data were compiled for the time frame between October 30, 2015 to February 9, 2016. This time frame was chosen to coincide with the time frame for the ADCP data (Sea Engineering, 2020). It should be noted that spectral wave data is output every three hours.

2.1.2. *Nearshore wave data*

Nearshore wave data has been generously provided by Sea Engineering, Inc. for this study. Two Acoustic Doppler Current Profilers (ADCPs) were deployed offshore from Ka'anapali Beach for a 3-month period between October 30, 2015 to February 9, 2016. The locations of the ADCPs are shown in Fig. 4. ADCP-1 to the north and ADCP-2 to the south were deployed at water depths of 39 and 31 feet, respectively, and setup in an 'upward-looking' configuration. Each ADCP recorded the water surface elevation over the deployment period. The raw ADCP data was processed by the analysis program WavesMon which provides hourly significant wave height, peak period, and direction calculated from the hourly recorded spectrum. This dataset will be critical in the assessment of the hydrodynamic model performance during typical winter conditions.

2.1.3. *Offshore bathymetry data*

Fig. 5 shows the offshore bathymetry, which was compiled from the 50 m resolution data from the Hawai'i Mapping Research Group through SOEST, University of Hawaii at Manoa. This dataset was used for the offshore grid generation for the numerical model discussed in the following sections.

2.1.4. *Nearshore bathymetry data*

Detailed nearshore bathymetry was compiled from the LiDAR data obtained through the online Data Access Viewer tool administered by the NOAA Office for Coastal Management[2]. The LiDAR data shown in Fig. 6 was compiled from the Scanning Hydrographic Operational Airborne Lidar Survey (SHOALS) dataset [3]. The data at this location was sampled between the months of October 2013 to November 2013 and hence corresponds to the post 2013 summer beach state at

[1] WAVEWATCH III Model Data Access: `https://polar.ncep.noaa.gov/waves/ensemble/download.shtml`
[2] The website for downloading the Data Access Viewer: `https://coast.noaa.gov/dataviewer/#/`
[3] The website for SHOALS: `https://shoals.sam.usace.army.mil/`

Fig. 4. Locations of ADCPs deployed (Sea Engineering, 2017, 2020)

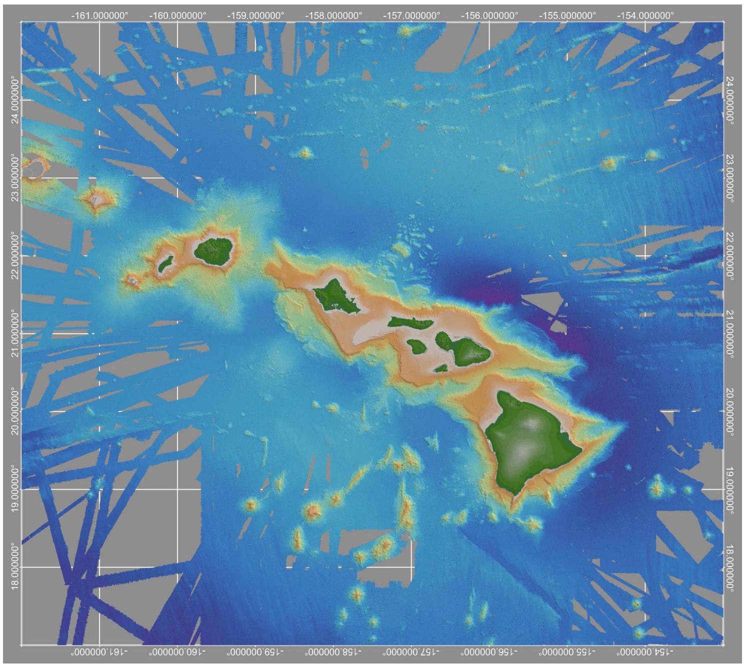

Fig. 5. Offshore 50m bathymetry data for the Hawai'ian Islands

Ka'anapali. Modification to the LiDAR dataset was carried out to construct a representative shoreline and beach face at the time of the start of the simulation. Beach survey data, discussed in the next section, was also used for this case study.

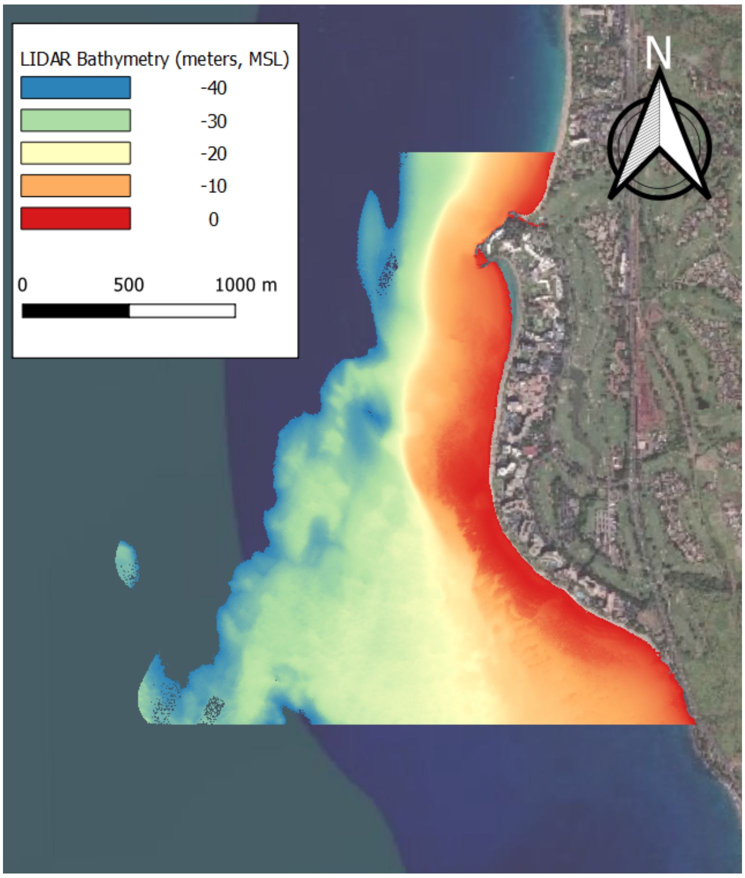

Fig. 6. LiDAR data used for nearshore model setup

2.1.5. *Beach survey data*

Beach survey data has been collected for this study (Sea Engineering, 2020), and was used to compare with the simulated morphological changes. Fig. 7 shows the beach survey points from January 3, 2016 along the HLC. This data set was also used to reconstruct the beach state for the simulation time frame.

Beach survey data from February 14, 2016 was also used in this study to compare the modeled beach profile shape. It should be noted that both beach survey transects do no extend very far seaward of the water line to meet the reef substrate, leaving some uncertainty in the beach toe shape for each of the survey dates. The gap between the surveyed beach and the reef is about 10 m.

2.1.6. *Sediment characteristics*

The sediment at Ka'anapali Beach is composed primarily of carbonate sand which is most common of the beaches found in Hawai'i. The sediment characteristic data

Fig. 7. Beach survey points from January 3, 2016 marked in red

for this study is based on field investigation and sampling done at Ka'anapali Beach. In total, 6 sediment samples were taken along the HLC and were each analyzed for grain size distribution to determine the representative D_{50} value for each sample, and the average D_{50} value of all the samples is 0.31 mm. Other sediment characteristics required for the sediment transport model include the specific density and the dry bed density. Specific density of carbonate sand was determined based on existing literature on carbonate sand found in Hawai'i. Smith and Cheung (2002) analyzed sand samples from 11 beaches around the island of Oahu to determine various grain size parameters, and found the densities ranging between 2.22 to 2.97 g/cm^3 with an average of 2.55 g/cm^3. Another study by Dai (1997) reports on specific densities in the range of 2.22 to 2.56 g/cm^3 and 2.35 to 2.50 g/cm^3 for calcareous sand from both the islands of Oahu and Kaua'i. The average of the results from these two studies suggests a specific density of 2.4 g/cm^3 for calcareous sands (Smith and Cheung, 2002). The final input sediment parameter required for the model is the dry bed density which represents the bulk density of the sediment bed layer in a dry state. Laboratory testing of carbonate sand samples from both Kailua and Waimanalo on the island of Oahu found dry bulk densities between 1200 to 1230 kg/m^3 (Stark *et al.*, 2012). A dry density value of 1200 kg/m^3 was used in this study based on the recommendation of Stark *et al.* (2012).

2.2. *Numerical models*

Delft3D is an open source 3D modeling suite which can simulate hydrodynamics, sediment transport, and morphological changes for coastal regions [4]. The primary modules within the modeling suite include the FLOW module which includes a module for morphological change, and WAVE modules; these modules can be coupled together to simulate wave induced flows, sediment transport and morphological changes (Deltares, 2016).

2.2.1. *Wave module*

The Delft3D-WAVE module uses the third-generation spectral wave model SWAN (Simulating WAves Nearshore) developed at the Delft University of Technology, The Netherlands. The SWAN model provides a phase-averaged solution of the generation and propagation of ocean waves to the nearshore region. The model is based on the wave action balance equation which contains parameters for physical processes such as wind energy input, nonlinear energy transfer between frequency components, and energy dissipation due to wave breaking and bottom friction (see for example, Filipot and Cheung, 2012). The models used to describe wave breaking and bottom friction in SWAN are from Battjes and Janssen (1978) and the empirical JONSWAP model of Hasselmann *et al.* (1973), respectively.

2.2.2. *Flow module*

The Delft3D-FLOW module is a multi-dimensional model for hydrodynamics and sediment transport, which solves the non-steady shallow-water equations with the hydrostatic and Boussinesq assumptions (Deltares, 2016; Vitousek, 2007). Delft3D solves these equations in either the Cartesian coordinate system or an orthogonal curvilinear coordinate system, and in the vertical direction, muti-layers can be defined using a so-called Z-grid (Davidsen, 1993; Deltares, 2016). For this study the model is run with one depth layer which is equivalent to a depth-averaged simulation.

2.3. *Model setup*

2.3.1. *Bathymetry and grid generation*

Grid generation was carried out using the RGFGRID software developed by Deltares. The QUIKIN software, also developed by Deltares, was used to assign bathymetric data to the model grid cells. The Universal Transverse Mercator (UTM) coordinate system (Zone 4 for West Maui) was used as the horizontal datum and the mean sea level (MSL) was used as the vertical datum for all grid generation and model runs.

[4]The code and documentation can be obtained from this website: `https://oss.deltares.nl/web/delft3d`

A critical and challenging part of this case study was to construct a curvilinear nearshore flow grid for modeling the wave-induced flows, sediment transport and morphological change in the nearshore region. The model bathymetry was generated from the combination of the LiDAR data with beach survey data, which provides historical information on the beach profile at specific times (Sea Engineering, 2017, 2020). To generate a representative beach state and corresponding bathymetry, the LiDAR data was cropped and merged with the beach survey data corresponding to the time/state of interest and used as input into the nearshore grid bathymetry. LiDAR data within the footprint of the survey boundary was removed prior to merging the two datasets. Areas known to be reef substrate were included in the LiDAR data. In some areas there were some gaps between the beach survey data and LiDAR [5] which were linearly interpolated to obtain an approximate elevation. Both datasets were adjusted to the same coordinate system and datum prior to being merged. Interpolation of point elevation data was carried out using a grid cell averaging technique for areas with dense point coverage (LiDAR data) and triangular interpolation for areas with minimal point coverage (beach survey data). Fig. 8 shows the comparison of survey data to the generated bathymetry along six evenly spaced transects along the HLC; the locations of these six transects are shown in Fig. 9.

Three overall grid characteristic criteria were followed to create and check the flow grid used for this case study. These criteria include grid orthogonality, smoothness, and aspect ratio: grid orthogonality values are less than 0.04, grid smoothness is less than 1.1 in the area of interest and less than 1.4 further away, and the grid aspect ratio is in the range of 0.5-2.0.

2.3.2. *SWAN wave model*

A 5-grid nesting scheme was used to propagate and transform the offshore wave conditions to Ka'anapali Beach. The resolutions of the nested grids are 1 km, 500 m, 200 m, 100 m, 50 m, and 10 m. Offshore bathymetry data was used for the 1 km, 500 m, 200 m, 100 m, and 50 m grids while the nearshore bathymetry data was used for the nearshore 10 m grid. Boundary conditions for the overall 1 km grid were taken from WW3 output at virtual buoys locations HNL10, HNL11, and HNL12 for the same time frame as the ADCP data collected for this study. The North and East boundaries are forced using HNL10 while the West and South boundaries are forced using HNL11 and HNL12, respectively. The overall SWAN nesting scheme used and virtual buoy locations for this study are shown in Fig. 1. Observation points were integrated into the nearshore model domain at the the locations of the deployed ADCPs to compare the modelled waves with the observations from the

[5] These gaps are located between the surveyed beach and the hard coral area. The size of the gaps is about 10 m. The fact that hard coral reef areas do not change over time makes it possible to merge the LIDAR data obtained in 2013 with the surveyed data in 2016.

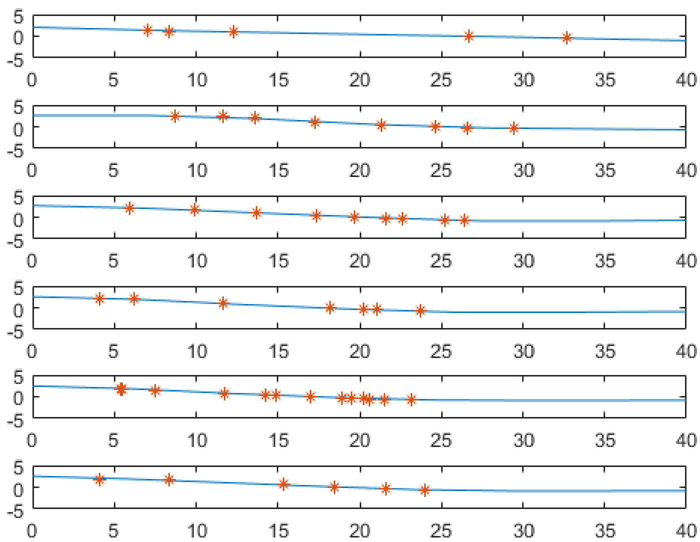

Fig. 8. Comparison of the survey data (orange marks) to the generated bathymetry (blue line) along 6 evenly spaced transects along the HLC. Transect #1 is the top panel and transect #6 is the bottom panel. Horizontal axis is the distance from the MSL shoreline. Elevations are in meters relative to MSL and distances are in meters

ADCP data.

For this case study, the parameters calibrated by Filipot and Cheung (2012) were used as input to the SWAN model; this is because the default parameters used in the SWAN model to characterize the wave breaking mechanism and bottom frictional dissipation have been found to not adequately represent some fringing reef environments found in Hawai'i. The SWAN model uses the following formula by Battjes and Janssen (1978) to quantify dissipation due to wave breaking:

$$D_{tot} = \frac{1}{4} B Q_B \bar{f} H_m^2 \tag{1}$$

where B is a constant which controls the level of energy dissipation, Q_B is the probability of wave breaking in a random sea state, and $\bar{f}$ and H_m are the mean frequency and breaking wave height, respectively, with the limiting wave height determined by a given value of γ=H/d. The default values used in the SWAN model for B and γ are 1.0 and 0.73, respectively, which have been previously determined from calibration at locations on the mainland with gently sloping sandy beaches. Filipot and Cheung (2012) found that B=1.09 and γ=0.94 best described the wave breaking and corresponding wave setup over a reef flat based on comparison with wave flume tests. The optimum roughness scales were chosen to be 0.5 m over the reef flat and 0.16 m over the reef slope (Filipot and Cheung, 2012).

2.3.3. *FLOW model*

The FLOW model was constructed multiple times in order to meet the grid requirements discussed previously. After many iterations, a curvilinear flow grid was developed with a resolution of approximately 5-7 m in the nearshore region. The north and south lateral boundary conditions for the FLOW module are defined based on the Neumann boundary conditions, which are implemented by imposing an alongshore water level gradient instead of a fixed water level. The open seaward boundary is defined as a water level boundary, which is required for Neumann boundaries to be implemented (Roelvink and Walstra, 2005; Roelvink and Reniers, 2012). ADCP-2 was also incorporated into the flow model to compare the modeled wave heights with the observations throughout the morphological simulations.

The seaward water level boundary is defined as a water level boundary to match the tide level observed at the Kahului tide station obtained from the NOAA's website for Tides & Currents [6]. The water levels observed at Kahului were used as input for the seaward water level boundary condition over the simulation time frame.

The sediment transport and morphology module is currently integrated into the FLOW module and accounts for both bed load transport and suspended load transport of non-cohesive sediments. Several sediment transport formulas can be implemented (Li and Huang, 2013). The sediment transport formula of van Rijn (1993) was chosen for this case study as it has been widely used in past studies and common input parameters are well documented through the existing literature. The following values suggested by Trouw *et al.* (2012) were adopted for the following model parameters: (1) the wave-related bed load (BEDW) and suspended load (SUSW) factors, which are in the range of 0 to 0.1 for coastal applications; (2) viscosity and diffusivity, which are 0.1 and 1.0 m^2/s, respectively; (3) the wave-related bed load and suspended load factors, which are primary tuning parameters chosen for this case study. The values for these tuning parameters were varied between 0 to 0.1 to match the observed beach profile and shoreline change over the time frame of interest.

The six transects shown in Fig. 9 were implemented into the flow model to show the beach profile evolution over the time frame of interest. These transect locations were chosen in line with provided survey data to compare the model output to actual observations.

3. Results

This section compares the modeled waves, morphological and shoreline changes with field observations at Ka'anapali Beach. A full morphological simulation over the time frame between January 3, 2016 to February 14, 2016 was carried out using spectral wave boundary conditions to the SWAN model from the WW3 output. It was

[6]The web address for the National Oceanic and Atmospheric Administration (NOAA) Tides & Currents is `https://tidesandcurrents.noaa.gov/`

Fig. 9. Transect locations along the HLC to compare model output with observed beach profile change

hypothesised that the wave-related bed load and suspended load transport factors are the tuning parameters for this problem. A comparison between the simulation results and the observation shows that a value of 0.1 for these parameters can give results in good agreement with the observations.

3.1. *Modelled waves*

A standalone SWAN model was performed to simulate the propagation of offshore waves to Ka'anapali Beach. The simulation was carried out for the time frame between November 1, 2015 to February 1, 2016 to coincide with the ADCP deployment. It should be noted that these simulations do not account for tidal driven and/or wave driven currents which would only slightly affect the wave propagation. Simulations were carried out using both parametric boundary conditions and spectral boundary conditions from WW3 model and the one that provides results matching the observations better is adopted.

The simulation results show that parametric boundary conditions underestimate wave heights between early to mid-November and between mid to late-December for both ADCP locations (Hardy, 2017). The SWAN results obtained using spectral wave boundary conditions are shown in Figs. 10 and 11, together with observations at ADCP-1 and ADCP-2 for comparison. Good agreements with ADCP observations at both locations can be observed. Significant wave heights at ADCP-1 show a slight underestimation when compared to observations but overall closely match the trend. Modeled wave heights at ADCP-2 show very good agreement with observations overall except for the weak storm event in early January, which is underestimated by using spectral wave boundary conditions but captured reasonably well using hourly parametric boundary conditions (Hardy, 2017).

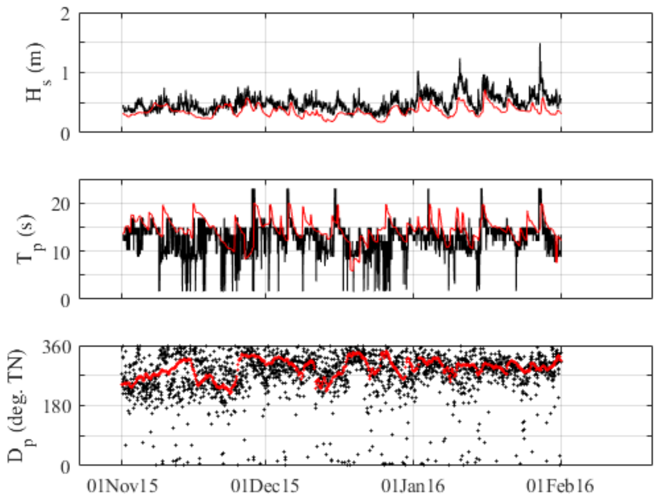

Fig. 10. Modeled (red) compared to observed (black) wave parameters (significant wave height Hs, peak period Tp, and direction Dp) at ADCP-1 using spectral boundary conditions.

It is concluded that SWAN model appears to give results in good agreement with observations at Ka'anapali Beach during typical winter months. In particular, spectral wave boundary conditions seem to produce better agreement overall with ADCP data. However, modeled wave heights still seem to be underestimated, especially for the weaker storm event which can be seen within the month of January. This could be associated with the inability of the SWAN model to resolve diffraction around the shadowing islands (Li *et al.*, 2016). Results obtained using hourly parametric wave boundary inputs, even though do not have better agreement overall, seems to better resolve these larger wave events as seen at ADCP-1.

3.2. *Modeled Shoreline*

The modeled shoreline movement obtained using a wave-related transport factor of 0.1 is compared to the observed shoreline from the beach survey data in Fig. 12 for the HLC. Even though there is very little migration of shoreline over the month and half period in the middle portion of the HLC, the modeled shoreline to the north of the HLC shows reasonable agreement with the surveyed shoreline; even to the south the small amount of movement is reasonably captured by the model.

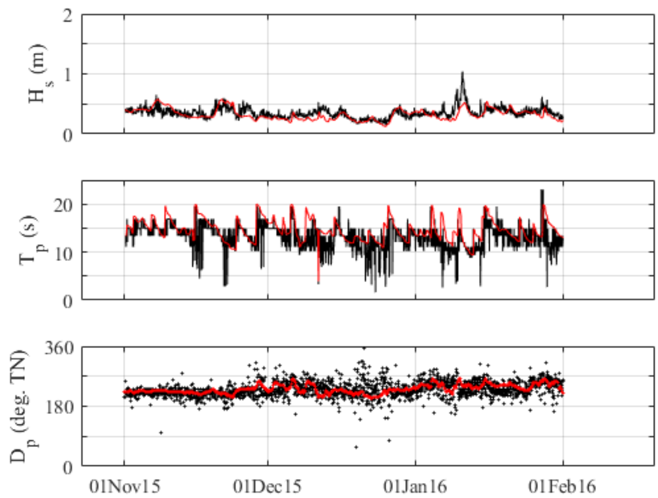

Fig. 11. Modeled (red) compared to observed (black) wave parameters (significant wave height Hs, peak period Tp, and direction Dp) at ADCP-2 using spectral boundary conditions.

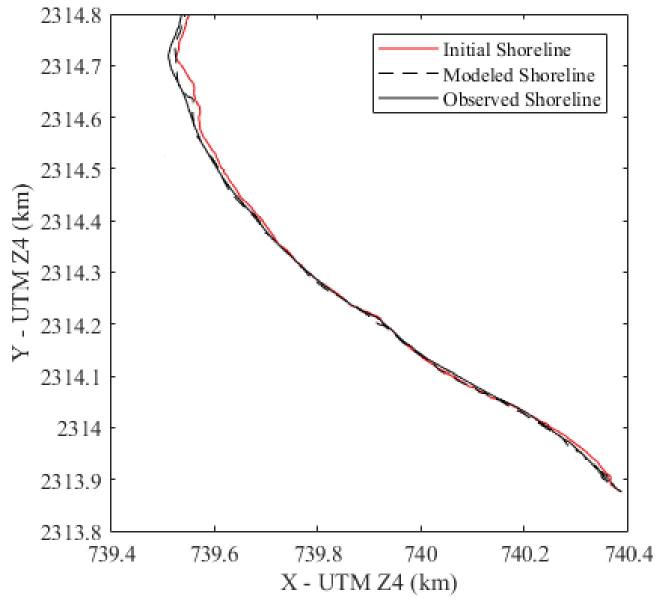

Fig. 12. Comparison of the modeled and observed shoreline movement at Ka'anapali Beach between November 1, 2015 to February 1, 2016.

3.3. *Morphological changes*

Fig. 13 shows the simulated accretion and erosion regions in HLC with the wave-related bed load and suspended load transport factor being set to 0.1. Cross-shore sediment transport occurred mainly outside the fringing reef and the general trend of sediment transport is onshore.

Fig. 13. Modeled sediment accretion and erosion in HLC at Ka'anapali Beach between November 1, 2015 to February 1, 2016.

It is remarked that if the wave-related bed load and suspended load transport factor was set to 0.05, the onshore sediment transport trend would still be seen over the model domain but reduced in magnitude (Hardy, 2017). However, if the wave-related bed load and suspended load transport factor was set to 0 as in Vitousek (2007), the modeled results would show a general trend of offshore sand transport from the beach face (Hardy, 2017).

Fig. 14 shows the modeled beach profiles at the six transects, together with the observations for comparison. The simulation results show that the overall trend of either beach-face erosion or accretion is well captured for all transect locations. The model seems to miss the beach profile evolution above the water line, most likely because the model is not a phase-resolved model and cannot physically simulate the sediment transport in the swash zone.

It is also remarked that if the wave-related transport was not considered, the agreement between the simulated and observed results is less satisfactory: transects 1, 4, and 5 fail to capture the observed trends and profile shapes (Hardy, 2017).

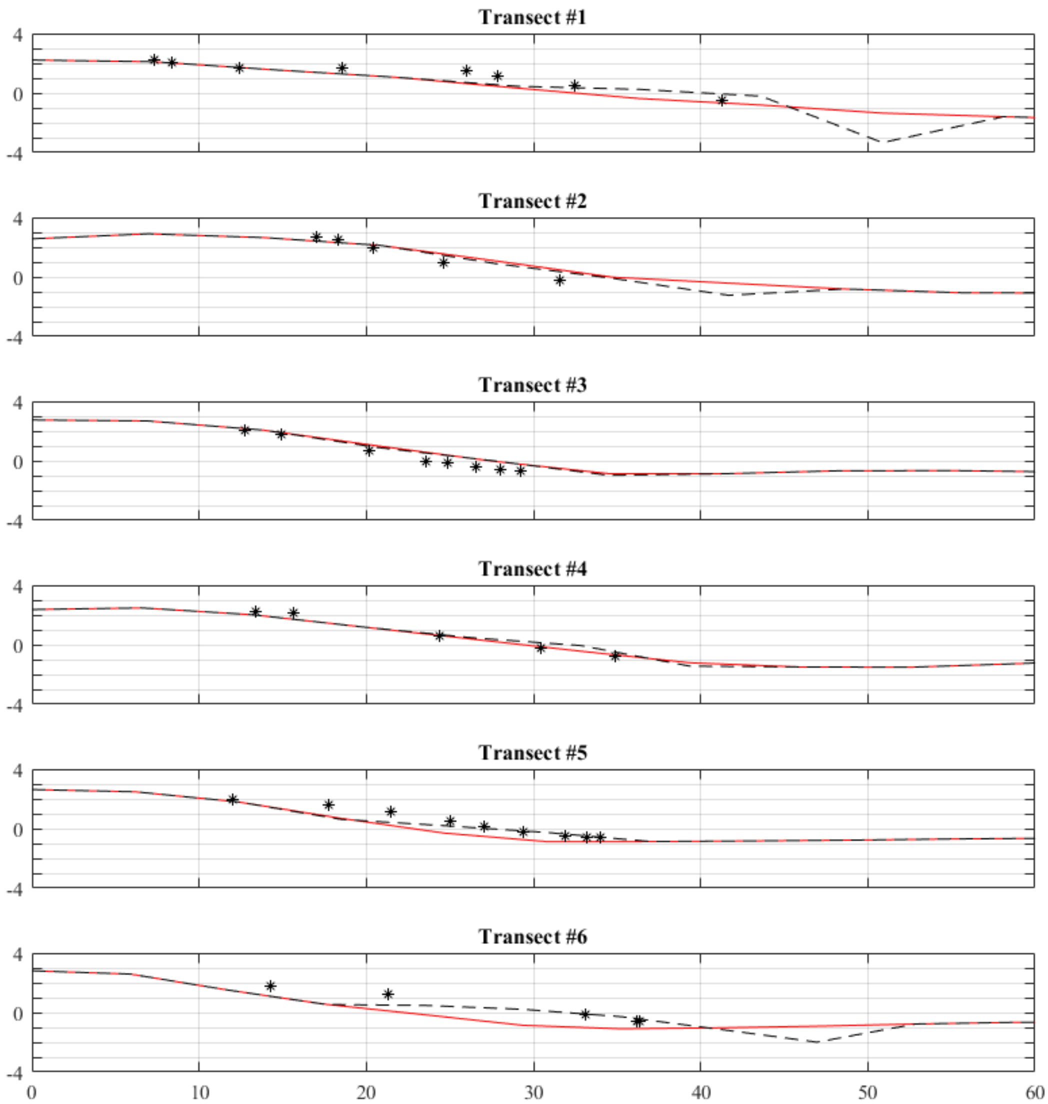

Fig. 14. Initial beach profile (-) and modeled beach profile (- -) for each transect compared to surveyed beach profile (*) (Note: all dimensions are in meters and the vertical datum is MSL). The initial beach profile was obtained on November 1, 2015 and the final profile on February 1, 2016. Elevations are in meters relative to MSL and distances are in meters

If the wave-related bed load and suspended load transport factor was set to 0.05, the results overall slightly differ than those obtained with 0.1; the general trend of erosion or accretion would be still captured while the upper beach face profile change could not be captured well (Hardy, 2017).

4. Discussion

The results from this case study show some potential for the use of Delft3D as a modeling tool for Ka'anapali Beach. For a period of about one and a half months (from January 3, 2016 to February 14, 2016), both the modeled shoreline motion and beach profile agree with observations reasonably well. Historical beach surveys at the HLC show that the general beach profile shape does not change significantly over time and instead shows a migration of the same profile shape either seaward or landward. With further model parameter validation/calibration using historical volume change for the site, the Delft3D numerical suite could potentially be used to simulate future nourishment scenarios at the HLC, which has a fringing reef fronting the beach. The outcome of these scenario studies can provide insight into how the nourished beach face would react to various types of wave conditions and how the shoreline may adjust in the short-term and long-term time scales. It is recommended that further model validation using data collected over a longer time frame (a 6-month to a year period) be performed.

To ensure reasonable computational time, the wave climate could be characterized into statistically representative conditions and morphological scaling factors could be utilized to simulate decadal sediment transport and morphological changes at Ka'anapali Beach, especially when assessing potential effects of sea level rise on shoreline change at Ka'anapali Beach.

5. Conclusions

Ka'anapali Beach is located on West Maui and experiences very dynamic beach morphological changes. A case study of the sediment transport and morphological changes at the Hanakaoo-Littoral-cell portion of Ka'anapali Beach on the island of Maui, Hawai'i, was reported here. For historical winter months, the results show that the Delft3D wave module (SWAN) can provide adequate wave results for the site. Sediment transport and morphological changes at the Hanakaoo-Littoral-Cell portion of Ka'anapali Beach was studied using Delft3D's coupled FLOW-WAVE module. The results suggest that the wave-related transport factor should be an important tuning parameter for the problem under consideration. With the wave-related transport factor being set to 0.1, satisfactory agreement between the simulation results and the observations can be obtained in terms of the overall trend of beach face accretion or erosion as well as the the motion of the beach profiles at six transects at Ka'anapali Beach. Reasonable agreement was also found between the simulated and observed MSL shoreline position. The numerical model does not capture the upper beach face change (above the water line) well, most likely because the numerical model does not physically account for swash zone mechanics which drives the sediment transport and morphological changes there. With further model parameter validation/calibration using historical data for the site, the open source Delft3D numerical suite could potentially be used to simulate future nourishment scenarios at Ka'anapali Beach, Maui, Hawaii.

Data availability statement

The datasets generated during and/or analysed during the current study are available from the first author (ihardy@seaengineering.com) or the corresponding author on reasonable request. The technical report (Sea Engineering, 2020) can also be found at `http://oeqc2.doh.hawaii.gov/EA_EIS_Library/2020-08-23-MA-DEIS-Kaanapali-Beach-Restoration.pdf`.

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