

Beach Wizard: Development of an Operational Nowcast, Short-Term Forecast System for Nearshore Hydrodynamics and Bathymetric Evolution

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LONG-TERM GOALS

The long-term goals are to provide accurate and detailed predictions of nearshore hydrodynamics and bathymetric evolution using an advanced process-based model (Delft3D). Observations of dense remotely-sensed and sparse *in situ* data will be assimilated to continuously improve model performance, and where the data is uncertain or absent, the model will be used to fill in the gaps and construct a more complete estimate of current or near-future conditions.

OBJECTIVES

The objectives of the proposed study are to:

- Develop methods for estimating relevant Delft3D model inputs and outputs from airborne and shore-based video and radar observations.
- Develop and implement techniques to assimilate these data in Delft3D.
- Validate the assimilation model by hindcasting with the remote observations and sparse *in situ* data sampled from field experiments.
- Improve numerical model formulations to narrow error bands on model predictions
- Generate nowcasts and forecasts of the nearshore environment

APPROACH

The approach is to develop an integrated nearshore modeling system that can be tested for a few sites where multiple information sources are available. We have brought together a number of research groups with specific nearshore expertise, and experience with observations from different field sites including Duck (NC), Monterey (CA), Egmond (NL), and Palm Beach (NSW). These field sites have distinctly different morphological characteristics and time-scales of response. Correspondingly, these sites have different remote sensing characteristics, which will provide an assessment of our proposed integrated modeling system's ability to nowcast and forecast in practical situations.

The central software in the system is the Delft3D model, which is available at NRL and for other ONR-sponsored institutions. This model is uniquely capable of modeling 2D and 3D hydrodynamics and morphodynamic changes over time-scales ranging from wave groups to several weeks, at spatial scales resolving rip-current cells and breaker bars (Reniers et al., 2004). In particular, model application at Palm Beach, NSW has contributed significantly to our understanding of nearshore morphodynamic processes (Reniers et al, 2001) showing the strong correlation between spatial distribution of computed wave energy dissipation and observed video intensity on a alongshore variable nearshore bathymetry.

The starting point of this work is the estimation of improved nearshore bathymetry via an iterative data assimilation scheme. Assimilation of (forward) model runs with observations is achieved by adding assimilation-based morphological processes to the physics-based morphological processes already in place.

At the start of the project, the assimilation is performed on the basis of the mismatch between remotely sensed (from video) and modelled proxies for wave dissipation. The prediction's sensitivity to the data

is tuned by adjusting the both the time scale of model adaptation and the data de-correlation time scale. A pilot study incorporating spatial variations of nearshore variables derived from Argus video data into the Delft3D model showed good results for both field observations (at Egmond, NL, and Monterey, CA) and synthetic case studies (Roelvink et al, 2003). In the current project, we continue to develop and test this assimilation method for nowcasting and prediction purposes, following a three-step approach:

A. Development and ground truthing of the assimilation model.

Improvement of algorithms to extract video-and radar-derived nearshore variables that can be assimilated with the Delft3D model. An initial focus on hindcasting will use data from Duck that enables the simultaneous incorporation of both video and radar data. Ground truth data were obtained approximately weekly and indicated slowly evolving bathymetry in a complicated wave environment.

B. Nowcasting of coastal evolution.

Application of the assimilation model to quantify the evolution of nearshore processes at a diverse set of morphodynamically active sites including Duck, a nourished beach at Egmond (NL), a rip-channelled beach at Monterey, and Palm Beach, Australia. Model performance will be evaluated against regular bathymetrical surveys at the various sites. The Beach Wizard will be expanded to assimilate an increased diversity of information sources, such as dense surface velocity estimates using video particle image velocimetry.

C. Forecast of coastal evolution.

Model-based forecast of hydrodynamic processes and coastal evolution at the time scale of a single week to extrapolate the hindcast and now cast predictions. We assume that the predictability of coastal evolution is primarily limited by the uncertainties associated with the process-based morphological model. Forecasts will be improved by recursively iterating on model parameters or model formulations, through comparison with real-time remote observations.

WORK COMPLETED AND RESULTS

During this first year assimilation techniques, presently based on differences between video-based and computed dissipation, were incorporated into Delft3D and calibrated with data from the 1994 Duck94 field experiment. The model with the calibrated coefficients was used to perform a hindcast assimilation based on video data from the 1997 SandyDuck field experiment. Hydrodynamic simulations of the NCEX experiment were also performed. Inverse data reduction techniques to schematize either 1-D or 2-D bathymetry were developed and have been incorporated into the Beach Wizard system. The results of the first year were presented at a joint workshop in Ypsilanti, MI in November 2006 and reported in the annual report of 2005.

During the second year the assimilation technique was modified and based on a gradient method. This was necessary in order to expand the number of remotely-sensed sources and reduce the number of free tunable parameters from two to one per source. The remotely-sensed sources of intertidal bathymetry (as observed from Argus video) and wave celerity (as observed by radar) were included in the assimilation routines. The modified model was validated against a long-period data set taken at Egmond, NL and a short-period data set (radar data courtesy of Dr. M.C. Haller, Oregon State) taken at Duck, NC. In collaboration with Dr. N.G. Plant of NRL-Stennis/ONR uncertainty bands in the model predictions are computed in the model and presented in the output. The results have been presented by Cohen et al. (2006).

The new assimilation model within Delft3D was validated against two field cases, one at Duck and one at Egmond (Aarninkhof et al., 2005; Cohen et al. 2006). The Egmond results show the improved model capability to predict the characteristic bar trough configuration, while considerably reducing the vertical deviations which were still present in the “old” approach by Aarninkhof et al. (2005). This simulation was run based on assimilation of video-derived wave dissipation and intertidal bathymetry (see Fig. 1).

The model was also used for a hindcast of the morphological evolution in September 2005 at Duck, NC including the above video sources and radar-derived wave celerity, courtesy Dr. M.C. Haller of Oregon State. The computed bottom profile (red solid line) has migrated from a starting bathymetry (red dashed line) to the ground-truth measurement (blue solid line). The rms-error in the measured versus computed bathymetry is reduced from about 1 meter to about 0.4 m. over the course of the simulation period which included one storm. The radar-derived celerity data was used in the shoaling zone region (outside of the breaker zone) because the data was most reliable there and other information (based on dissipation) was lacking in that area. The celerity data was taken in the latter part of the period and improves the shoaling zone estimate. (see Fig. 2).

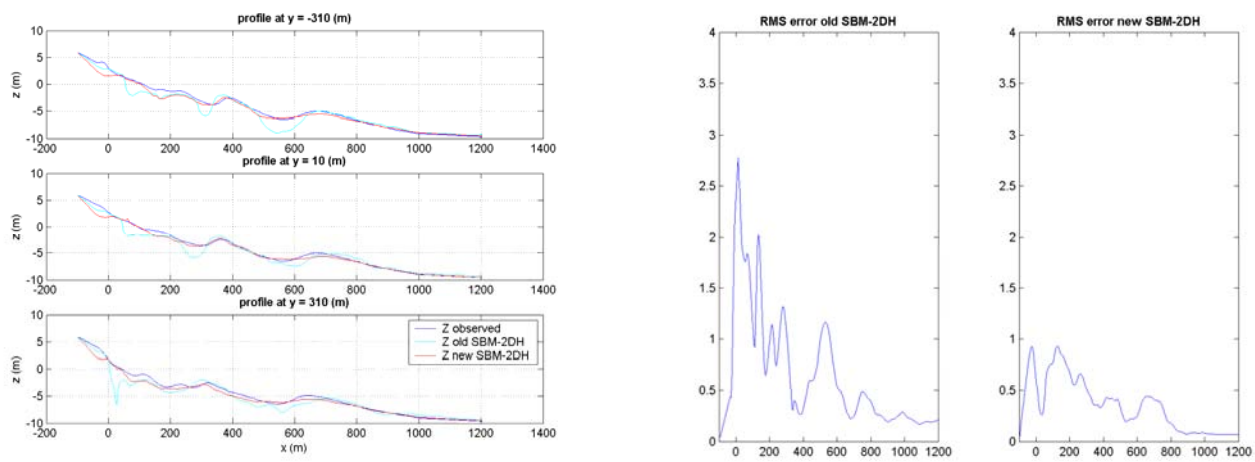


Figure 1 Left panel: Egmond NL results from model simulations for the period September 1999 – April 2001 with the old version (light blue lines) and new version (red lines) of the SBM-2DH. Computed and measured (blue lines) profiles are shown at $y = -310$, $y = 10$ and $y = 310$ m. Measured bathymetry is of 15/04/2001 and computed results are shown at 05/04/2001. Right panel: Rms-errors from model simulations for the period September 1999 – April 2001 with the old version (left figure) and new version (right figure) of the SBM-2DH, this time with intertidal bathymetry data included in the assimilation. The rms-errors are computed with respect to a measured bathymetry over the area $y = -1000$ to $y = 1000$ m (in Argus coordinates). Measured bathymetry is of 15/04/2001 and computed results are shown at 05/04/2001.

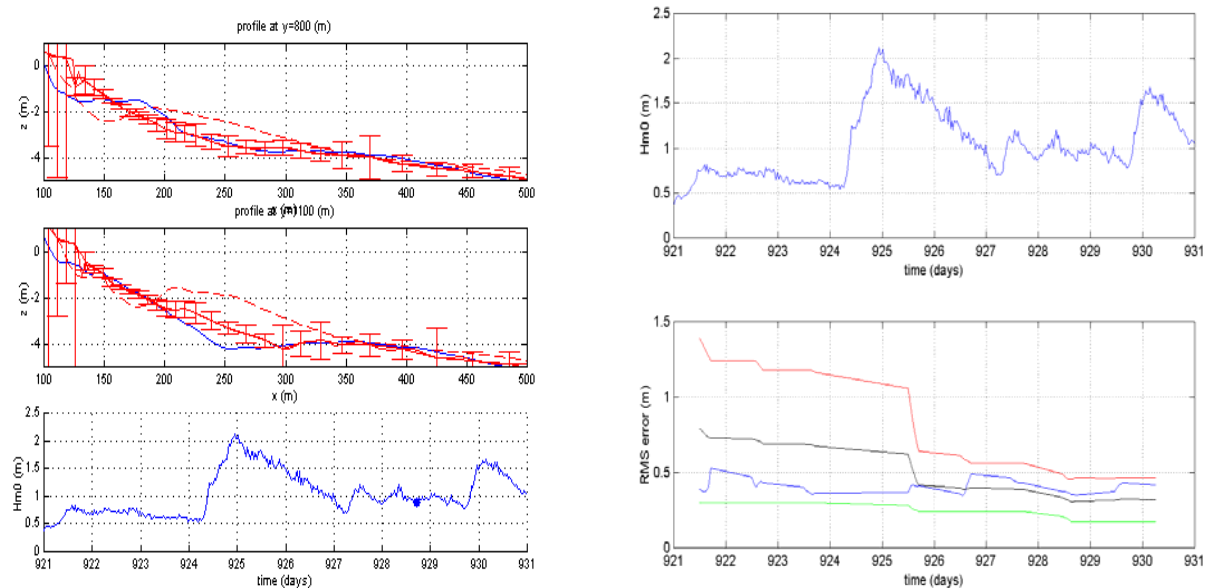


Figure 2: Duck NC 2005 results. Left panel: computed (red line), initial bathymetry for computations (red dashed line), measured (blue line) at two cross-sections in Duck coordinates at 900 m (top panel) and 1100 m (middle panel). The uncertainty bands are shown as the vertical bars. The time history of the offshore wave height is shown for reference in the bottom panel. Right panel: The time history of the wave height (top panel) and the rms-error (black: total; blue: inner surf zone; red: outer surf zone; green: shoaling zone) .

The updated version of the Beachwizard model, based on the gradient method, has been used to estimate the underlying bathymetry on beaches with strong alongshore variability. Two data sets for verification have been used: RIPEX (Monterey, USA, MacMahan et al., 2005) and RDEX (Palm Beach, Australia, Reniers et al., 2001). The updated method to estimate bathymetry from a sequence of ARGUS-intensity images (Cohen et al., 2006) has led to an improved estimation of the actual bathymetry (see Figure 3) compared to the old method (Aarninkhof et al., 2005).

In addition to RIPEX and NCEX the Beach-Wizard model has been calibrated for RDEX by comparing computed and measured wave and flow conditions during RDEX (Smit et al., 2006). The calibrated model was subsequently used by Ad Reniers to hind-cast a sequence of bathymetries based on daily averaged ARGUS images of Palm Beach (see Fleft panel of Figure 4 for an example) which were used as input for the morphodynamic computations described below.

Marije Smit visited CSIRO Marine and Atmospheric research for the period February 20 to August 23, 2006. During this time she worked on setting up Delft3D to simulate morphological evolution on Palm Beach as observed in the Argus images. One purpose of this exercise was to assess how well we can simulate morphological evolution without data assimilation. An example of her results is shown in Figure 4. In the upper panel are daily time exposure images from the Palm Beach Argus camera for the period April 28 to May 2, 1999. The simulated morphological evolution, starting with bathymetry derived from the first Argus image, is shown in the lower panel, where day 4 corresponds to the last Argus image and the computation was continued for three more days. The model produces

characteristics of the morphology which are qualitatively similar to the Argus images, in particular the non-rhythmic longshore bar and rip channels.

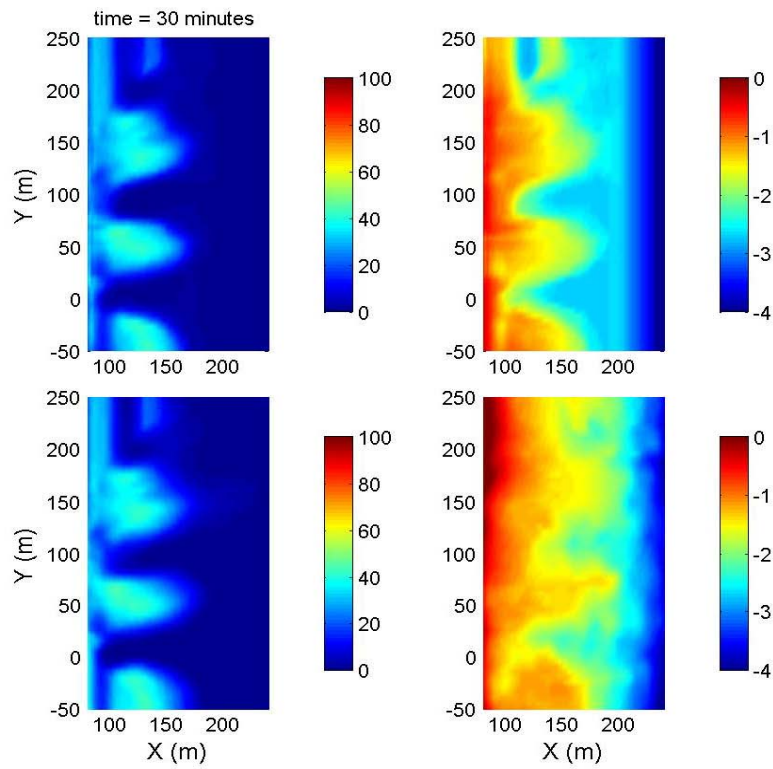


Figure 3. Upper panels: Beach-Wizard estimated roller energy dissipation (left, in W/m²) and bathymetry (right, in m). Lower panels: corresponding observed dissipation and bathymetric survey.

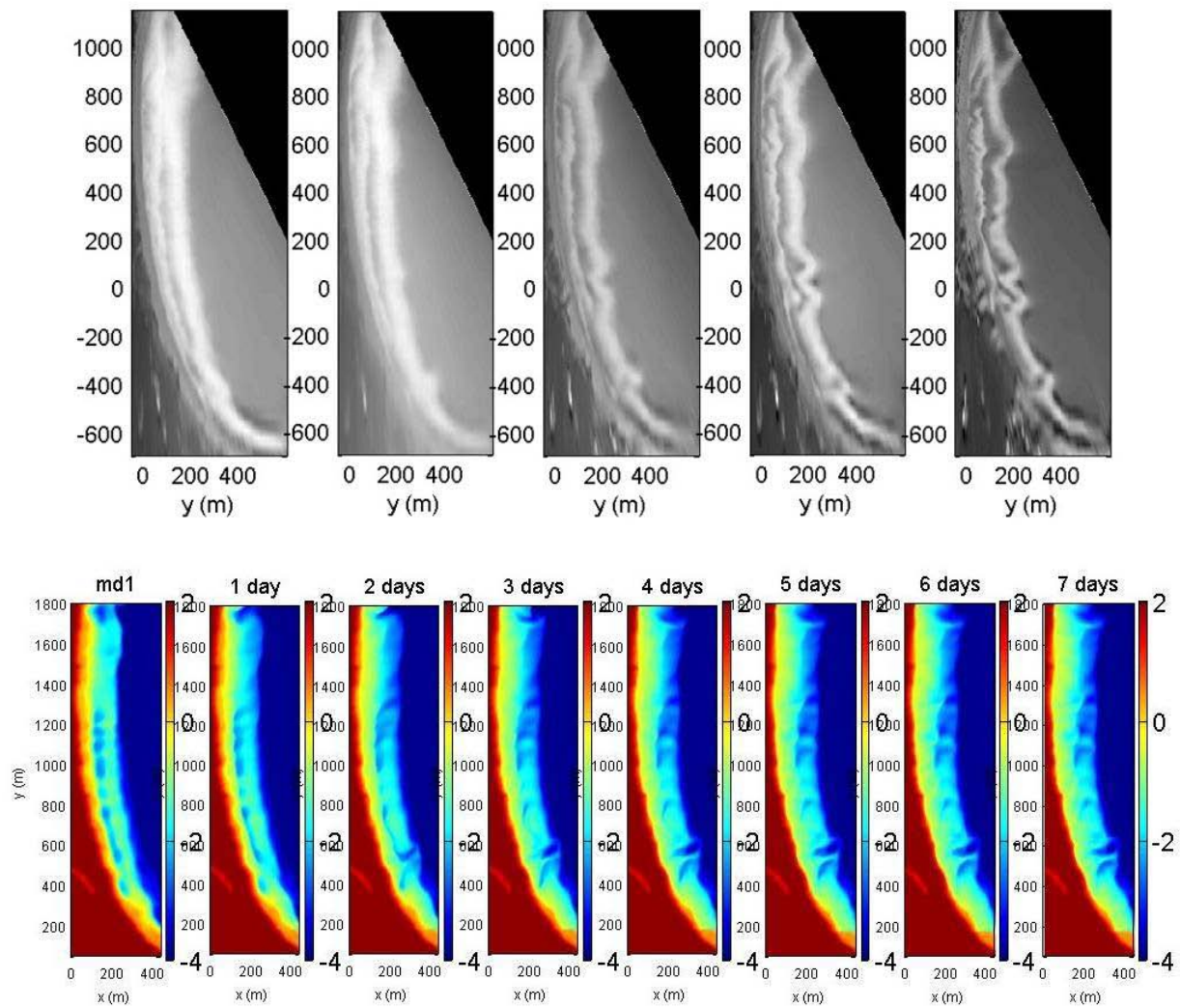


Figure 4. Daily Argus time exposure images for the period April 28 to May 2, 1999 (top panel) and corresponding numerical results (the first five panels match the five observations)(bottom panel).

The numerical simulations described above are initiated with bathymetry derived from the Argus images because regular bathymetry surveys are not available. Since the installation of the Palm Beach Argus station in January 1996 only one detailed bathymetry survey was obtained in October, 1999. As part of the Beach Wizard effort at Palm Beach a second bathymetry survey was completed in August 2006. Prior to the bathymetry survey we set-up the pixel array shown in Figure 5 designed to provide the option of deriving bathymetry, directional wave field and longshore currents from the time stacks collected at each pixel location. Starting the pixel collects a couple of months prior to the bathymetry survey allows the possibility of simulating morphological evolution and assimilating image derived bathymetry which provides a quantitative check on the model prediction.

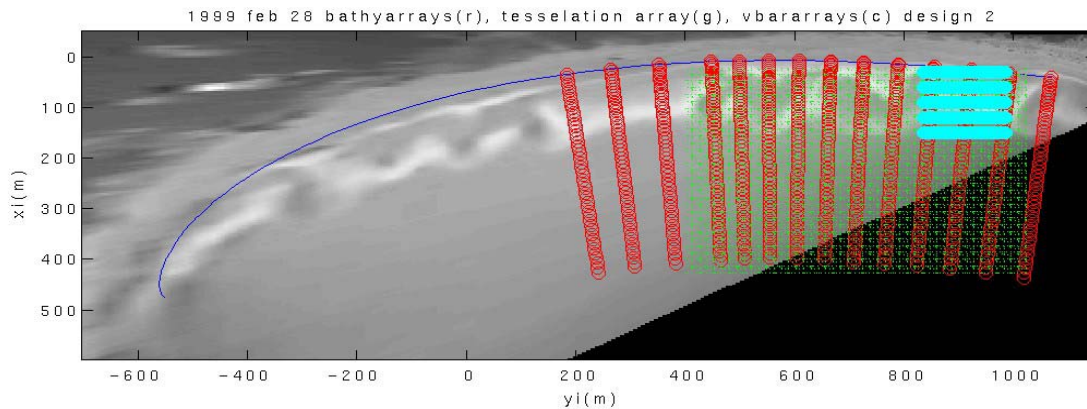


Figure 5: Pixel array showing tessellation array (green), bathymetry transects (red) and longshore current arrays (cyan).

Surface current and wave breaking analysis of an array of 9 shore-based video cameras deployed as part of NCEX was completed and posted to http://www-bprc.mps.ohio-state.edu/ocean/experiments/ncex_2003. These data include spatial maps of time-averaged image intensity and percent wave breaking that will be assimilated into the Delft3D model. Data assimilation methods utilizing Kalman-type filters to adjust model output velocities using a weighted average of modeled and observed mean flows (through a time-distributed averaging process; Oke, *et al.*, 2004) have been developed and tested initially using the OK model (Ozkan-Haller and Kirby, 1999) and observations from NCEX.

IMPACT/APPLICATIONS

In addition to the importance to amphibious and special forces operations on beaches this research has benefits to predicting and mitigating the effects of beach erosion and accretion due to natural causes and coastal development and is therefore useful for coastal management.

RELATED PROJECTS

Bluelink (<http://www.marine.csiro.au/bluelink/>) is a joint research effort between CSIRO, the Royal Australian Navy, and the Bureau of Meteorology, to deliver ocean forecasts for the Australian region. The highly successful first stage of this project is nearing completion with the delivery of a relocatable ocean model to the RAN. Bluelink2 is scheduled to begin in July 2006 with a particular emphasis on forecasting waves and currents in the littoral zone. Bluelink2 aims to combine numerical simulations with measurements of nearshore waves, currents and bathymetry using remote sensing techniques such as radar and video, and in situ instrumentation. The objectives of Bluelink2 are closely related to the Beach Wizard objectives providing the opportunity to apply the assimilation techniques in a more operational environment.

Delft Hydraulics is executing a project in the context of coastal management for the Dutch Dept. of Public Works (Rijkswaterstaat) in the framework of the Ongoing Research Project (VOP). The application focuses on the evaluation of the efficiency of a combined beach and shoreface nourishment in Egmond, The Netherlands. In this project we will co-develop the assimilation techniques that are also used in the Beach Wizard project.

This work is collaborative with Dr. 's Haller and Holman (Oregon State University), Dr. Frasier (University of Massachusetts) and Dr. Plant (NRL-Stennis).

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