2DH-QUANTIFICATION OF SURF ZONE BATHYMETRY FROM VIDEO

Stefan Aarninkhof[1], Kathelijne Wijnberg[2], Dano Roelvink[1,3] and Ad Reniers[4]

[1] WL | Delft Hydraulics, Marine and Coastal Management, P.O. Box 177, 2600 MH Delft, The Netherlands. Stefan.Aarninkhof@wldelft.nl
[2] University of Twente, Faculty of Engineering Technology, Water engineering and management, P.O. Box 217, 7500 AE Enschede, The Netherlands. k.m.wijnberg@ctw.utwente.nl
[3] UNESCO-IHE, P.O. Box 3015, 2601 DA Delft, The Netherlands. d.roelvink@unesco-ihe.org
[4] Delft University University of Technology, Faculty of Civil Engineering and Geosciences, P.O. Box 5048, 2600 GA Delft, The Netherlands, ad@dutcvmm.ct.tudelft.nl

Abstract: Information on the actual state of the nearshore zone – in terms of topographic variability, surface waves, and circulation patterns - is crucial in many naval and civilian applications. Spatial scales of interest generally span distances on the order of hundreds of meters to a few kilometers. Obtaining this information form in situ measurements or model predictions alone is not feasible. This paper presents results of the first efforts in assimilating high-resolution video observations of the surf zone with a 2DH morphological model to map 3D bathymetry in the surf zone. Two pilot applications demonstrate the model's potential, returning a realistic rip channelled beach topography at Monterey (CA, USA) and preserving the characteristic bar-trough configuration at Egmond (NL) throughout the entire 9 month simulation period. Being fully embedded in the Delft3D modelling system, the assimilation model can be combined with any regular hydrodynamic or morphological model run. This sophisticated use of high-resolution video observations in combination with a 2DH morphological model opens the door towards the nowcasting of nearshore bathymetric evolution.

INTRODUCTION

Information on the actual state of the nearshore zone – in terms of topographic variability, surface waves, and circulation patterns – is crucial in many naval and civilian applications, including mine counter-measure strategies, covert military operations, swimmer safety, shoreline management and protection of the hinterland against flooding. Obtaining this information by in situ measurements is often not feasible, for instance because of costs, logistic limitations, hostility of the surf zone, or short notice on which data is needed.

As an alternative, sophisticated numerical models may be used to estimate the actual state. Numerical models that predict the hydrodynamics of these environments are just now reaching the level of complexity and numerical efficiency necessary for them to be used in an operational sense. Coupling the hydrodynamic models with sediment transport and topographic evolution are also nearing operational form. However, state-of-the-art surf zone models have shown insufficient forecasting capabilities sofar at the spatial scales of interest. For typical nearshore processes (including circulation cells, sand bars, and submarine shelf topography) these span distances on the order of 100's of meters to a few kilometers.

Improvement of the models' skill, and hence lengthening of the predictive horizon, may be expected from assimilating field measurements in near real-time. In that sense, of particular interest are remotely sensed data, which can be obtained without interference with the environment and, once the sensor and its platform are in place, with little logistic effort. For the surfzone environment, these measurement capabilities have been developed using primarily video (e.g. Aarninkhof and Holman, 1999; Alport et al., 2001) and radar observations (e.g. Bell, 1997), and include surface current measurements (Chickadel et al., 2003), wave breaking distributions (Turner et al., 2004), shoreline position (e.g. Plant and Holman, 1997; Aarninkhof et al., 2003), sand bar position (Van Enckevort and Ruessink, 2003a,b), and wave phase speeds (Stockdon and Holman, 1998). Although these methods have largely been developed for shore-based applications, airborne platforms have also demonstrated similar measuring capability (Dugan, 2001). In any case, we hypothesize that assimilation of these types of data into currently available models will yield improved hindcasts, nowcasts, and forecasts of the nearshore environment.

As a first step towards such an integrated modelling system, this paper presents a technique to map 3 dimensional (3D) bathymetry from time averaged video imagery using a two dimensional horizontal (2DH) morphological model. The video data are sampled by fully automated Argus video stations (Holman and Stanley, subm), which collect high resolution surf zone observations on an hourly basis. Quantification of surf zone bathymetry is achieved through assimilation of video-observed and model-predicted patterns of wave energy dissipation in the roller. Starting from an arbitrary, best guess initial bathymetry the model calculates a spatial distribution of roller energy dissipation across the bathymetry for the actual wave and tide conditions. The video time exposure image provides the actual spatial distribution of roller energy. The

mismatch between observed and computed patterns is used to 'nudge' the model bathymetry towards one that better fits the observed dissipation pattern. If the observed dissipation exceeds the computed dissipation, sediment is taken from the water column and deposited at the bed, and vice versa.

In a 1D cross-shore approach, Aarninkhof et al (2005) demonstrated that such a model is capable of reproducing the dominant morphological changes during the first year after placing a shoreface nourishment at a multiple barred beach at Egmond. The *rms* error of the vertical deviations along the entire beach profile typically amounts to 40 cm for the two arrays considered. Deviations in the order of 10 to 20 cm were found at the seaward face of the bars, which increase up to 20 to 40 cm near the bar crest. Maximum deviations up to 80 cm were found in the trough regions, owing to lack of wave dissipation information. The 1D approach by Aarninkhof et al (2005) lacks spatial extent required for use in a 2DH nearshore nowcasting system. The extension towards a 2DH version of this model is presented here.

2DH QUANTIFICATION OF 3D SURF ZONE BATHYMETRY FROM VIDEO
To enable 2DH quantification of 3D surf zone bathymetry, the assimilation approach according to Aarninkhof et al. (2005) has been implemented in the Delft3D modelling system. This model is capable of modeling 2DH 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 (e.g. Reniers et al., 2004; Lesser 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 overall flow scheme of the resulting assimilation model is shown in Fig. 1.
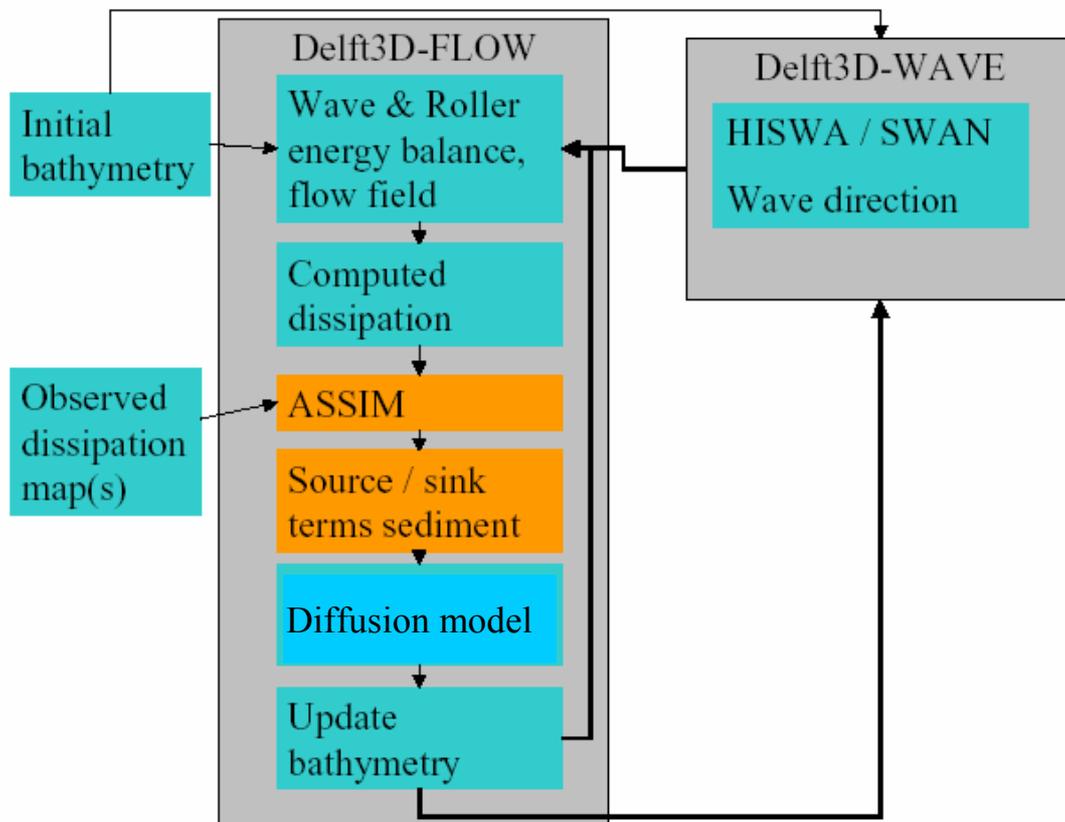
Fig. 1: 2DH Quantification of subtidal bathymetry through assimilation of video-derived and model-predicted wave dissipation maps.

The assessment of nearshore bathymetry starts from the application of a directional wave model to simulate the shoreward propagation of waves (particularly the evolution of wave direction) across the surf zone. Next the balance equations for wave and roller energy are solved along these directions with the help of a 2D roller model, to generate 2DH roller dissipation maps. Note that adopting a simpler approach by determining wave refraction from Snell's law would probably do well in the region of the outer bar, but certainly not in the inner surf zone.

Changes to the Delft3D code are limited to a routine named ASSIM that reads the video-derived dissipation maps, interpolates them to the Delft3D grid (which may or may not be the same as the Argus grid) and updates model bathymetry on the basis of deviations between observed and computed roller dissipation rates. The implementation in Delft3D is such that the assimilation with Argus data can in principle be combined with a regular morphological run.
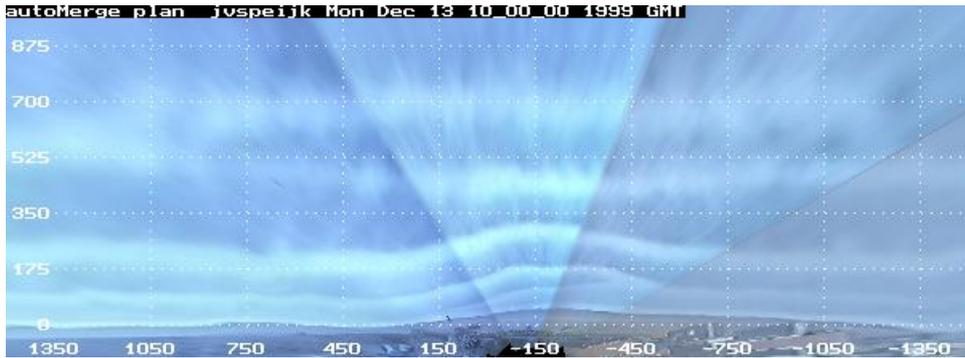
Fig. 2: Merged, plan view image of Egmond station Jan van Speijk dd. 13/12/1999 at GMT 10:00 hr.

The 2D assimilation model operates on plan view images, obtained from merging and rectifying oblique time exposure sampled from one or more video cameras that cover the area of interest (Fig. 2). To obtain a roller dissipation map from these merged plan view images, a three-step approach is followed. First a background intensity level is removed, because an area with no wave breaking should map to no wave dissipation, hence the video intensity should be set to zero there. This is achieved by determining the average image intensity in the region from 800 m to 1800 m offshore (i.e. well outside the surf zone), for each vertical image line in the oblique image (Fig. 3a). Before transforming the oblique image to a plan view image this value is subtracted from each vertical image line. In addition, this approach was found to correct for cross-image variations of optical intensity characteristics and sharp transitions between camera views (cf. Fig. 2), caused by different camera orientations with respect to the position of the sun and the non-simultaneous collection of video data.
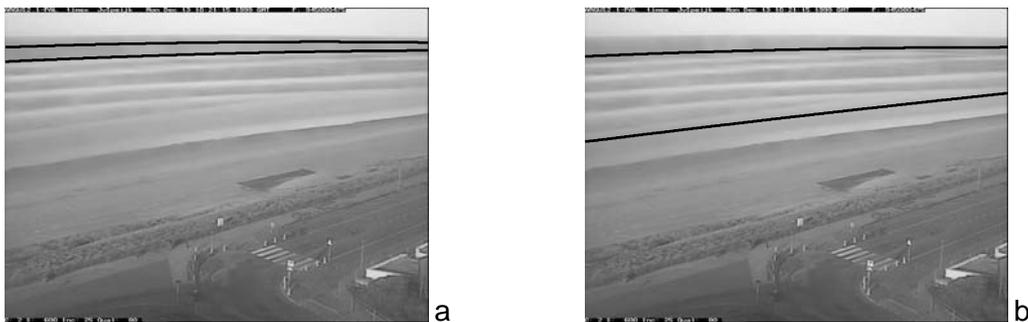

Fig. 3: Visualization of the deep water region used for the cross-camera removal of background illuminations (a) and the surf zone region used for the determination of image contrast (b).

To obtain smooth wave dissipation maps covering multiple cameras, we further take into account differences in image contrast levels between cameras, because an area represented by a low contrast image will result in unrealistically low wave dissipation levels in that area. This is achieved by adopting the standard deviation σ_{sz} of surf zone

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pixel intensities as an indicator for image contrast. An image-specific σ_{sz} is determined from pixel intensities sampled from a nearshore region enclosed by shore-parallel lines at 100 m and 1000 m offshore (Fig. 3b). Breaking-induced image intensities collected from different cameras are corrected according to

$$I_{c,i} = \left(\frac{\sigma_{sz,\min}}{\sigma_{sz,i}} \right) I_i \qquad (1)$$

where $\sigma_{sz,i}$ is the standard deviation of surf zone pixel intensities of camera i, $\sigma_{sz,min}$ is the minimum σ_{sz} of all cameras involved and I_i is the breaking-induced image intensity map of camera i (after correction for background illuminations) and $I_{c,i}$ is the breaking-induced image intensity map after correction for variable image contrast. The ratio $\sigma_{sz,min}/\sigma_{sz,i}$ typically varies between 0.5 and 1. Merging the individual camera views after correction for background illuminations and variable image contrast yields a plan-view, wave dissipation map I_v, which typically covers a coastal stretch up to a few kilometers alongshore.

Finally, the corrected image intensities are scaled such that they are a quantitatively correct measure of roller dissipation. To that end, I_v is normalized such that $\iint_{x\,y} I_v dxdy = 1$ and scales the normalized intensity map with the incoming wave energy flux to obtain a video-derived measure of wave dissipation D_o that quantitatively matches the model-computed roller dissipation:

$$D_o(x, y) = \int_y Ec_g \cos(\theta) dy \left(\frac{I_v(x, y)}{\iint_{x\,y} I_v dxdy} \right) \qquad (2)$$

In Eq. 2, E is the wave energy at the seaward end of the surf zone according to $E = \frac{1}{8} \rho g H_{rms}^2$, c_g is the wave group velocity and Θ is the wave angle of incidence with respect to shore normal. Wave conditions measured at deeper water are transformed to the seaward end of the surf zone with the help of a standard parametric wave model (Battjes and Janssen, 1978) including bottom friction, to account for the modification of wave height and direction due to wave refraction and bottom friction along the deeper part of the coastal profile. The roller dissipation map D_o thus obtained is used for assimilation the dissipation map computed from the Delft3D model.

PILOT APPLICATIONS
To assess the feasibility of our approach, the assimilation model was tested against two field cases. The first test was based on data from the RIP current Experiment (RIPEX, MacMahan et al., 2004) at Monterey Bay, carried out in spring 2001. The application is

based on a single time exposure image (dated May 6, 2001, GMT 21:00 hr). The *rms* wave height at the time of image collection was 0.7 m, with a peak period of 10.7 sec and a direction approximately shorenormal. The measured profile along the central array Y=50 m was used to create an alongshore uniform initial bathymetry.
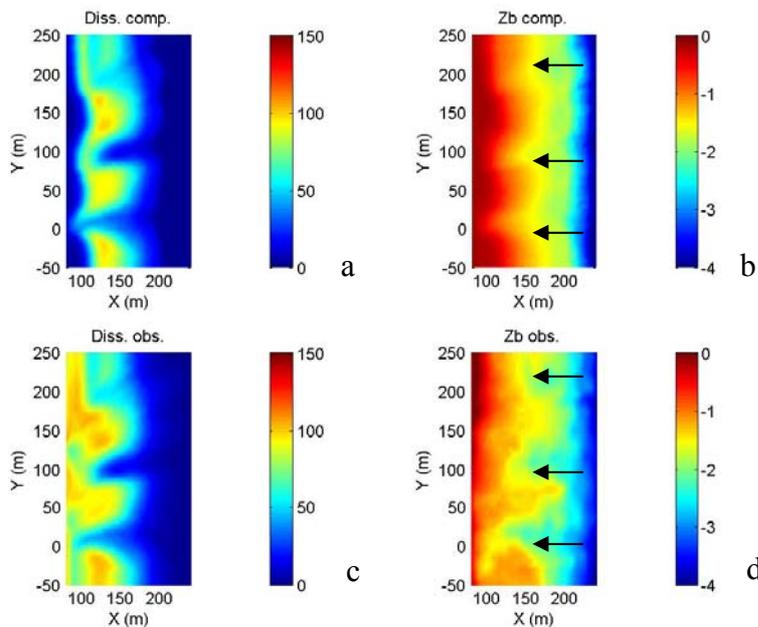

Figure 4. Upper panels: Computed dissipation pattern and corresponding computed bed-elevation after 12 minutes of simulation time. Lower panels: Observed dissipation obtained from video observations and underlying measured bathymetry. Position of rip-channels indicated by arrows.

Morphological updating started after 5 minutes of initialisation time, mainly needed to spin up the roller model. The measured bathymetry (Fig. 4d) shows very well developed rip channels, which are clearly reflected in the video-derived measured dissipation map (Fig. 4c). The resulting subtidal bathymetry obtained from assimilating measured and computed patterns of roller dissipation is shown in Fig. 4b, together with the computed roller dissipation (Fig. 4a). The pattern of dissipation matches the target pattern very well, except in the very nearhore. The adjusted bathymetry shows rip channels at roughly the same locations as in the measured bathymetry. Computed beach profiles (Fig. 5) sampled every 50 m alongshore confirm the realistic nature of the results. The transects roughly coincide with rip channels and bar crests. The area seaward of X=150 m, with a depth between 1 and 4 m, shows a remarkably good match, with deviations in the order of tens of centimeters. At very shallow water, the agreement is not good. Despite the large deviations at shallow water depths of less than 1 m, we conclude that the results are promising, particularly given the fact that only one image was used up till now.
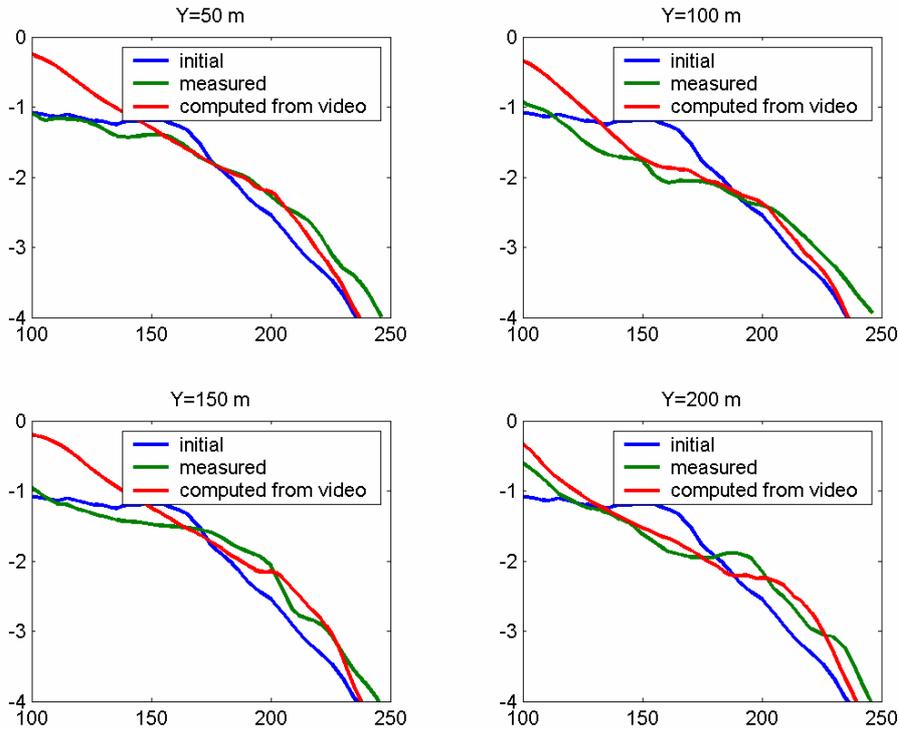
Fig. 5: Comparison of initial, computed and observed cross-shore profiles

The second pilot application involves the assessment of the evolution of subtidal bathymetry along a 2 km coastal stretch at Egmond (The Netherlands), over an 18 month period starting December 1999. During this period, the WESP was used to survey nearshore bathymetry twice per year, typically along 50 cross-shore profiles with 100 m spacing alongshore. The measured depth is estimated to have an error of less than 15 cm. Offshore wave conditions (H_{rms}, T_p and Θ) were measured with a directional wave buoy at IJmuiden, located approximately 15 km to the south of the nourished site. Approximately 50% of the missing data, which occurred during 15% of time, could be replaced by values from an identical buoy approximately 75 km to the north. Offshore tidal levels are found from interpolation in water level data collected at tidal stations located 15 km north and south of Egmond. Subtidal bathymetry is quantified on the basis of 13 hand-picked, merged images of good-quality and sufficient wave breaking, sampled throughout a one-year period.

The computed bathymetry after 9 months is shown in Fig. 6. Clearly, the model is capable of preserving the characteristic bar-trough configuration throughout the entire simulation period. Unrealistically large *rms* deviations are found in the trough regions and near the shoreline. Overall, the sand volume in the surf zone is under-estimated, despite an over-estimate of the accumulation in the inner surf zone in the central part of the area of interest. The middle bar and trough regions generally show an overestimation of the water depth at both the bar crest and the trough, albeit that the relative difference

between both (or 'bar height') is remarkably correct. This particularly holds for the northern and southern end of the area of interest, indicating that video-derived roller dissipation patterns underestimate the actual dissipation rates. This may be induced by relatively poor image contrast for the far-field regions in the outer cameras. At deep water (i.e. seaward of the breaker bars) as well as along the upper part of the beach profile (i.e. landward of the subtidal bars), the model results show a continuous overestimate of the water depth from the first image onwards.
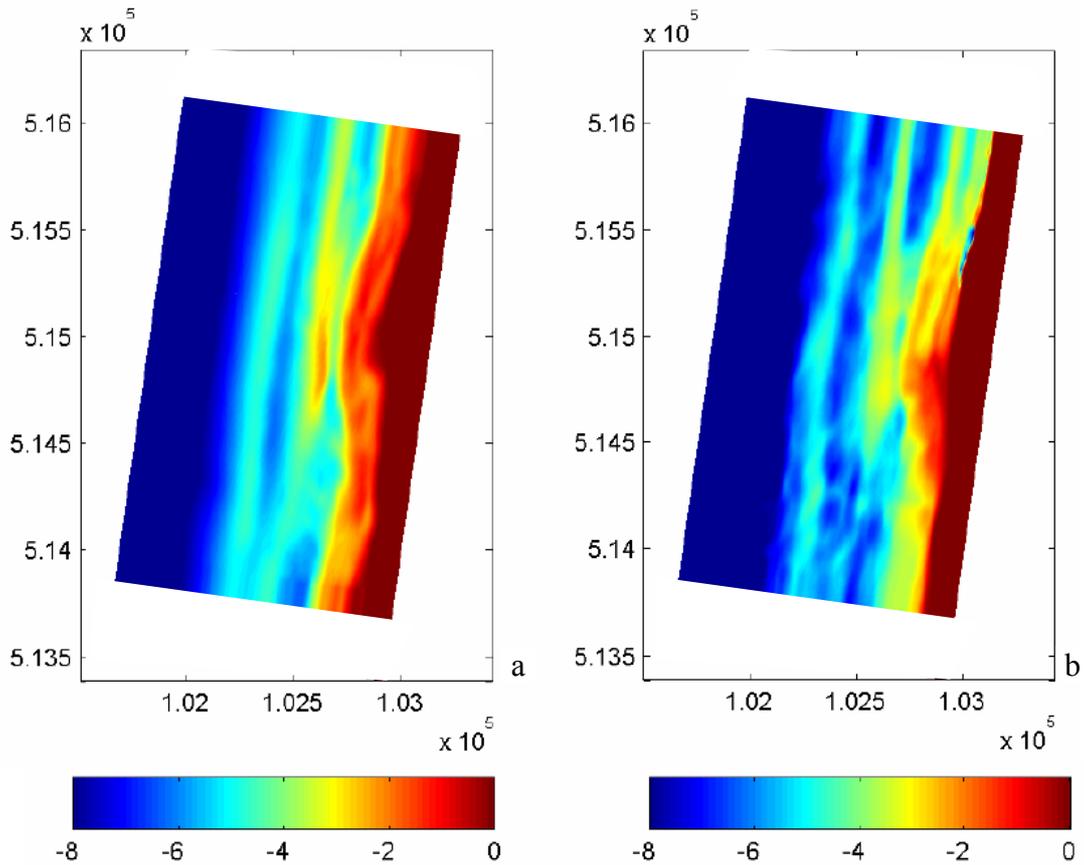

Fig. 6: Measured (a) and computed (b) Egmond bathymetry in May 2000. The computed bathymetry was obtained from a 9 month simulation with the assimilation model.

Careful analysis of the computed bathymetrical evolution shows that model deviations can be explained either from the occasional inclusion of poor quality video images, or the gradual accumulation of small errors over time. For example, the inclusion of video data sampled at July 12, 2000, induces an abrupt transition from inner surf zone accretion in the central part of the area of interest to an erroneous erosion, which apparently cannot be corrected afterwards. This observation confirms the potentially negative effect of including noisy video data, in combination with relatively large bathymetrical updates per image. At deep water, on the other hand, the model results show a continuous overestimate of the water depth from the first image onwards, which increases over time. This can be attributed to a persistent underestimation of video-

derived dissipation rates. To improve model performance at this point, we need to reconsider the procedure for the correction of background illuminations, which presently assigns zero values to wave dissipation rates at deeper water. As a result, any model-predicted wave dissipation in the region will induce a lowering of the bed elevation. Besides, calibration of the wave model (for instance, an increase of the dissipation parameter γ) may also positively affect model performance in this region.

DISCUSSION

The pilot applications have shown model capability to preserve the characteristic bar trough configuration, albeit that vertical deviations are considerable in absolute sense. Despite these deviations, it should be noted that the availability of this model in itself yields considerable added value as compared to the situation without any regular updates on surf zone bathymetry. Many engineering studies adopt the most recently surveyed bathymetry as a starting point for investigations and assume unchanged bathymetry since the date of survey. Doing so in this case would imply that no changes of bathymetry occur between May 1999 and May 2000, which yields an off-set as shown in Fig. 6a. The resulting off-set after application of the assimilation model is visualized in Fig. 6b. It appears that video-based updating of bathymetry prevails over the common assumption of unchanged bathymetry.
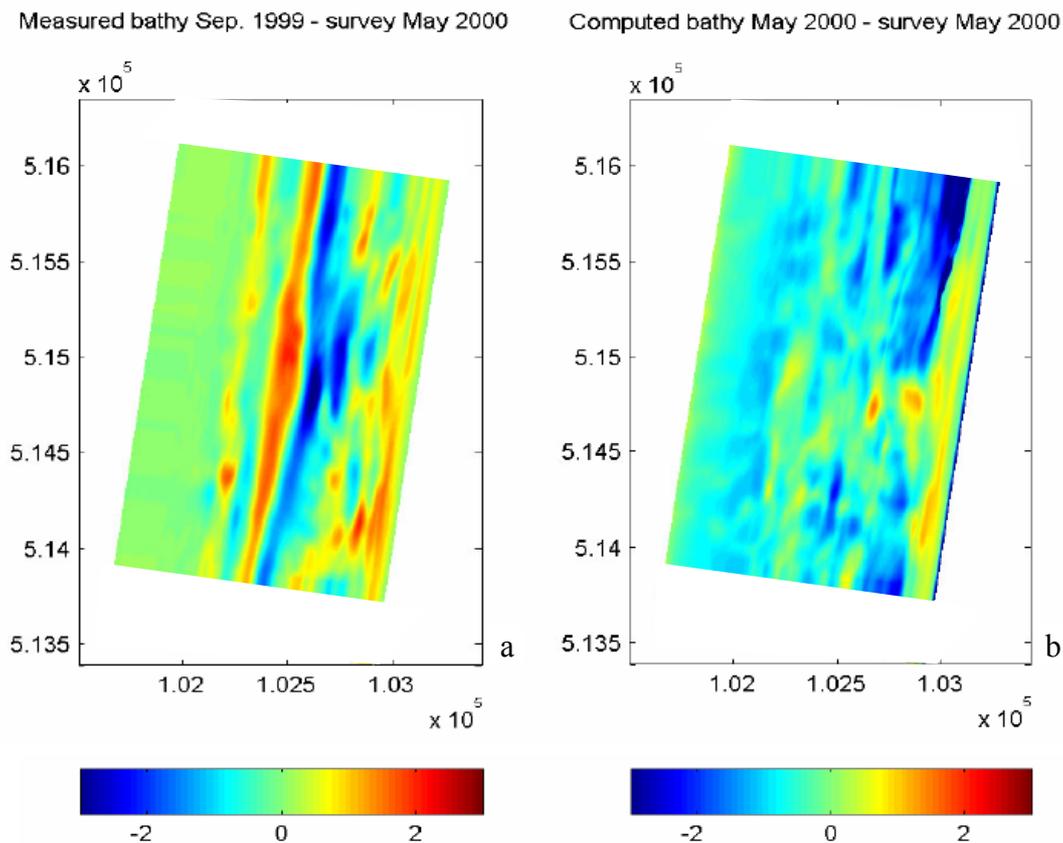

Fig. 7: Vertical off-set in bed elevation in May 2000 based on the assumption of unchanged bathymetry (a) and application of the video-based assimilation model (b).

Promising model potential is further revealed from the realistic flow field computed in June 2000 (right panel of Fig. 8), showing a strong rip current crossing the inner bar. The corresponding plan-view video image of June 22 (left panel of Fig. 8) vaguely reveals a depression in the wave dissipation pattern at the same location, which may also reflect the presence of a rip current. The latter observation clearly highlights the potential of the combination of sophisticated models and high-resolution video.
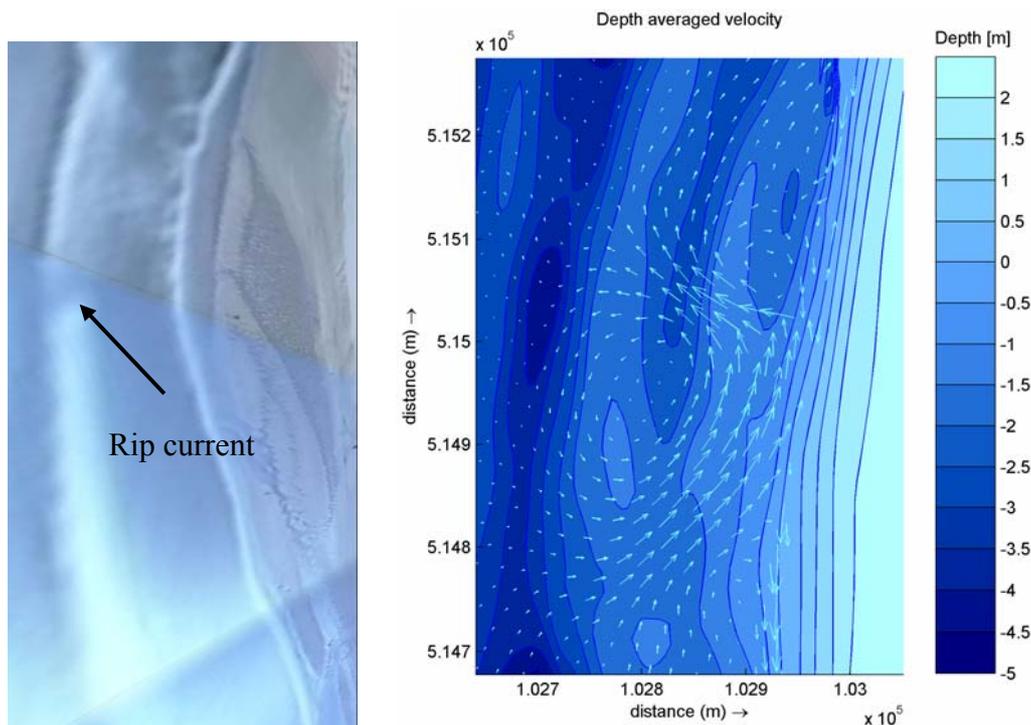

Fig. 8: Plan-view Argus video image and computed flow field at Egmond dd. June 22, 2000. Both figures cover an area of 300 m cross-shore by 600 m alongshore. The video image reveals the presence of a rip channel in the central part of the nourished area, which is confirmed from the Delft3D calculations.

So-far, the focus of this study has been on the assessment of the feasibility of this approach. Consequently, no attention has been yet to appropriate model calibration. To investigate opportunities in that respect, model sensitivity to variable settings of the wave dissipation parameter γ (Battjes and Janssen, 1978) and a variable number of video observations of wave breaking has been tested (Fig. 9). Model performance considerably benefits from an increase in γ and an increase in the number of images. With increasing γ, the dissipation of organized wave energy is delayed. As a result, the computed dissipation of roller decreases at deeper water (which is associated with an increase in de computed bed elevation) and increases at shallow water (which yields a decrease of the inner surf zone bed level). An increase of the number of video observations yields better estimates of surf zone bathymetry, particularly at the seaward face of the sand bars and near the bar crest where waves predominantly break. By

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providing additional field observations of wave dissipation, model capabilities to resolve the general trend in coastal morphodynamics improve. In addition, the computed morphological changes per image decrease, which makes the model less sensitive to over-fitting on noisy input data.
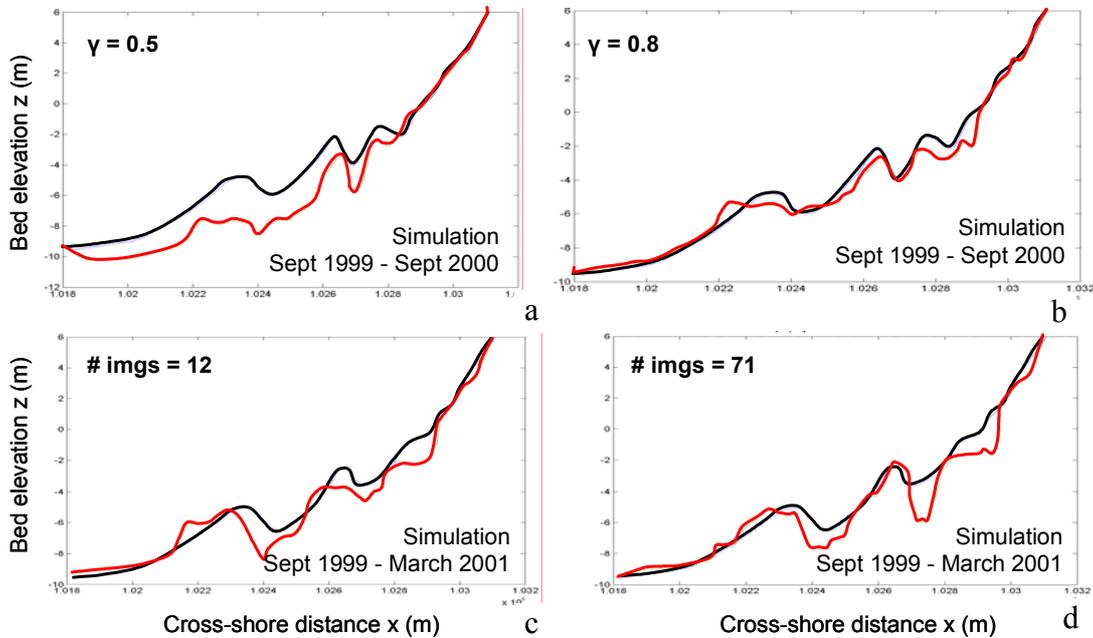

Fig. 9: Model sensitivity to variable settings of the wave dissipation parameter γ (panel a,b) and variable number of input images (panel c,d). The model is applied in 2DH mode. The plots show the computed bathymetry (red line) along a cross-shore section in the central part of model domain in Sept. 2000 (a,b) and March 2001 (c,d), respectively. The corresponding measured profiles in these months are shown in black.

The method presented in this paper appears to converge rapidly and can easily be extended with additional sink/source terms related to other observed and computed parameters, as long as these parameters have a clear (local) link with the bathymetry. For instance information on the wave celerity can be used to improve the bathy-estimate outside the surfzone as celerity is a function of depth. Different spatial weights can be assigned to the various observations and to the real morphological model, reflecting the reliability of each method. Utilizing video-derived shoreline positions to map the foreshore will help the estimation in very shallow depths. Presently, the method does not guarantee convergence towards a minimum mismatch between observed and modeled parameters. Convergence can be improved, and error estimates can be computed if more rigorous inverse methods are developed for this scheme.

CONCLUSION
An innovative model concept provides enhanced opportunities for the 2DH mapping of 3D surf zone bathymetry from nearshore video observations, with high resolution in time and space. The present model updates surf zone bathymetry through assimilation of video-derived and model-computed patterns of wave dissipation. Two pilot applications

reveal the model's potential to map subtidal bathymetries, returning a realistic rip channelled beach topography at Monterey (CA, USA) and preserving the characteristic bar-trough configuration at Egmond (NL) throughout the entire 9 month simulation period. Best results were found in the areas of actual wave breaking. Model deviations can be explained from the occasional inclusion of poor quality video images, or the accumulation of small errors over time. In addition, it was shown that model performance considerably benefits from calibration of the wave dissipation parameter γ as well as the inclusion of a larger number of video observations. Further integration of morphological model predictions and remotely sensed nearshore variables opens the door towards the development of an operational nowcasting system for the prediction of nearshore hydrodynamics and bathymetric evolution, in support of coastal zone management and naval planning operations.

ACKNOWLEDGEMENTS

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