Beach erosion and rip channels

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Bar morphology

On large alongshore scale (10 km) and on long term (years), the behaviour of the outer and inner bars at Egmond is 2-dimensional in the sense that the bars are continuous and of the same form in alongshore direction and show the same overall migrational pattern (onshore and offshore migration). On small scale (1 km) and on the short time scale of a storm month, alongshore non-uniformities may develop as local disturbances which are superimposed on the overall straight base pattern yielding a 3-dimensional morphological system. Examples of these local disturbances are the development of depressions (rip channels), crescentic and meander patterns, introducing an alongshore wave length of the bar system (in both plan form and crest/trough lines) of the order of 500 to 1000 m.

A rip channel (with length of 200 to 300 m and depth of 0.5 to 1 m) can be developed in the crest zone of the **inner** bar on the time-scale of a few days during minor storm conditions (Figure 1); the rip channel shows migrational effects (order of 100 m) in both directions along the shore, but the rip channel dimensions remain approximately constant during major storms events.

The **inner** bar shows migration of the order of 20 to 30 m in both onshore and offshore direction on the time scale of a storm month; the maximum cross-shore migration rate of the inner bar crest is of the order of 30 m over five days.

The temporal development of cross-shore profiles (after longshore-averaging) shows significant cross-shore exchanges of sand of about 1 to 2 m^3/m/day at the crests of the **inner** bar in offshore direction during major storm events and about 0.5 m^3/m/day in onshore direction during minor storm events.

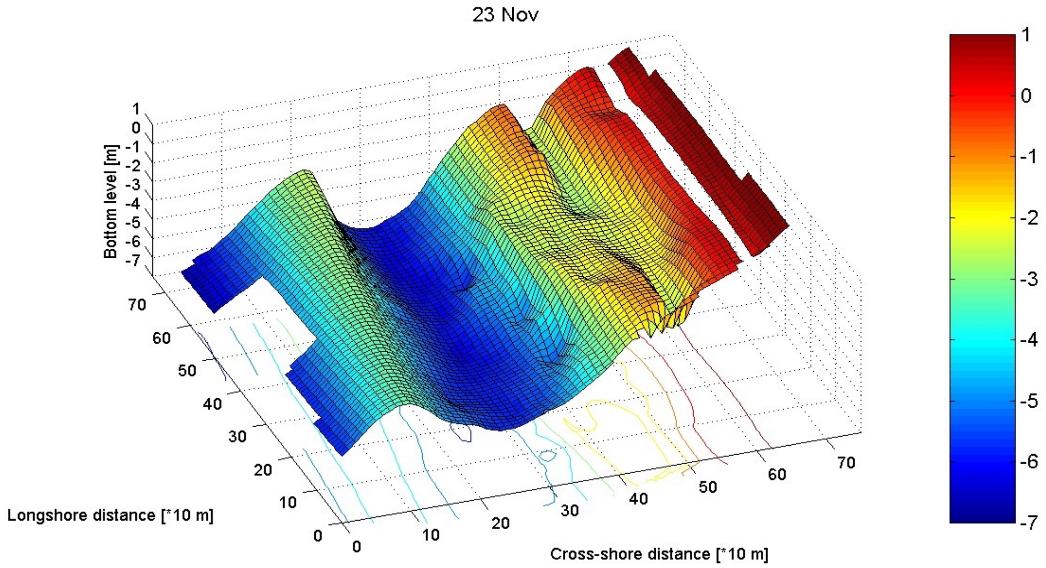

Figure 1 *Three-dimensional plot of bathymetry (to NAP-datum), 23 Nov. 1998*

The temporal development of crest line positions of the **inner** bar reveal the presence of a dominant longshore migrational effect of the inner bar form (plan form). Longshore migration rates of the planform of the inner bar are maximum 150 m/day in both directions.

The **outer** bar shows an overall offshore migration in the main transect of about 30 m, about 50 m in the south and stable in the north of the survey zone, yielding a more oblique orientation of the outer bar crest.
The trough zone between the outer and inner bar remained quite stable at -6 m during the whole storm period of about 6 weeks, which may be an indication that the amount of sand passing the trough zone is relatively small. Based on the sand transport data, the maximum amount of sand passing the trough during minor and major storm events ($H_{s,trough}$ is 2 to 3 m) is estimated to be about 0.5 to 1 m^3/m/day in onshore direction as most of the waves are reforming and shoaling in the trough zone. On a yearly basis the maximum amount of sand passing the trough will be of the order of 10 m^3/m in onshore direction.
The behaviour of the outer bar is of considerable interest for coastal managing purposes, because the outer bar zone is a potential location for shoreface nourishment. Sand nourishments in the outer bar zone may only benefit the inner surf zone and beach zone on longer time scales (5 years), because the annual amount of sand passing the deep trough zone is relatively small.

Beach morphology

The beach zone landward of the -1 m depth contour is characterized by three-dimensional features such as swash bars, beach bars, low tide terraces, beach cusps, ridges and runnels and rip channels. Dominant processes on the beach are onshore mass transport of water by shoaling/breaking waves and wave runup followed by offshore recirculation through runnels and rip channels.
Longitudinal (alongshore) profiles of the beach surface near the waterline show the presence of sand waves with maximum variations (high and low areas on the beach) of about 1 m over a distance of about 500 m during the survey period.

The morphological processes on the beach are strongly affected by the water levels (neap-spring tidal cycle and the storm surge levels), the offshore wave conditions and the crest level of the inner subtidal bar.

The beach volume per unit width increases for increasing crest level of the inner bar. The daily beach volume changes (erosion/accretion) vary between 1 and 3 m^3/m/day in a storm month with wave heights up to about 5 m; the daily accretion is maximum if the crest level of the inner bar is at -0.5 m NAP; the daily erosion is maximum if the crest level of the inner bar is at -2.5 m NAP.

Beach volume changes of about 30 m^3/m can occur over a period of about 10 to 15 days in a storm month (maximum storm surge level SSL of about +2 m above MSL); the beach volume is almost continuously adjusting to a new equilibrium, if the bar crest level is continuously changing.

The overall beach erosion in a storm month can be of the order of -30 m^3/m (between inner bar and dune foot). Large scale beach restoration by cross-shore processes would require the supply of about 30 m^3/m over considerable alongshore lengths. Given a maximum supply rate of about 0.5 m^3/m per day (maximum onshore transport), this would take about 2 months of fair weather conditions. In practice it may take a full spring and summer period to restore the eroded beach after the storm season.

Rip currents

The cross-shore velocities (average value over 10 minutes) at the inner bar strongly depend on the local wave height, local mean water depth, tide level and the presence (position) of a rip channel (depression) in the bar crest. The largest cross-shore current velocities (up to -0.65 m/s offshore-directed) have been measured on the seaward flank of the outer bar during storm conditions with an offshore significant wave height of about 4.5 m (storm waves from southwest with angle of 20 to 30 degrees to shore normal), see Fig. 4. Similar values have been measured at the crest of the inner bar inside a rip channel (local depression) during major storm events. Offshore-directed currents are almost absent in the outer bar zone during minor storm events with significant offshore wave heights smaller than 3 m ($H_{s,o}$<3 m), see Figure 4.

During the ***pre-storm period between 20 and 22 Oct. 1998*** with minor storms ($H_{s,off}$ between 1 and 3 m) the cross-shore current velocities at 1C (also at 1A, 1B and 1D) were between 0 and -0.4 m/s and exhibited the typical behaviour of the undertow with velocities dependent on local wave height and tide level (Figure 3):

- *low tide:* rel. small wave height and rel. small velocity; U_{cross}= -0.1 to -0.15 m/s, h=0.5 to 1 m, H_s=0.3 to 0.5 m, H_s/h=0.4 to 0.6, $H_{s,off}$=1.5 to 2.5 m (21 Oct. t=12 and 23 hrs);
- *high tide:* rel. large wave height and rel. large velocity; U_{cross}= -0.4 m/s, h=2.0 m, H_s=0.9 m, H_s/h=0.4, $H_{s,off}$=2.3 m (21 oct. t=18 hrs).

This behaviour of the cross-shore current during the pre-storm period is most probably related to the position of the main transect with stations 1A to 1D just south of the rip channel (outside rip channel). The water depths at locations 1C and 1B were between 0.5 m (low tide) and 2.5 m (high tide) up to 22 Oct. After that date the water depths at 1C and 1B did increase by about 1 m due to erosion of the bar crest (development of depression/rip channel) and the main transect was situated in the rip channel zone.

During the ***storm period between 27 Oct. and 1 Nov. 1998*** ($H_{s,off}$ between 3 and 5 m) the cross-shore current velocities at 1B and 1C (inner bar) exhibit some typical features of circulation cells, which are shown in Figure 2 Top.

The most typical results are:

- *lag effects;*
  offshore velocities are about -0.2 m/s during beginning of storm (28 Oct.) increasing to about -0.5 m/s after 1 day;
- *onshore-directed and offshore-directed velocities;*
  offshore-directed velocities prevail, but onshore-directed velocities do also occur; for example Ucross is about 0.05 m/s on 28 Oct. t=17-19 hrs (h=2.3 m, $H_{s,off}$=4 m, H_s/h=0.65);
- *pulsating character with large and small velocity fluctuations due to tidal variations;*
  - offshore velocities are relatively large at low tide: U_{cross}=-0.55 m/s, h=2.1 m, $H_{s,off}$=3.9 m; H_s/h=0.65 (29 Oct, 17hrs),
  - offshore velocities are relatively small at high tide:U_{cross}=-0.2 m/s, h=3.2 m, $H_{s,off}$=3.9 m; H_s/h=0.63 (29 Oct, 21 hrs).

Thus, the cross-shore current during major storm events has a pulsating character at the inner bar with large and small velocity fluctuations between -0.2 and -0.5 m/s due to tide level variations.

During the ***post-storm period between 7 and 10 Nov. 1998*** with low wave conditions ($H_{s,off}$ between 0.5 and 1.5 m) the cross-shore current velocities at 1C (also at 1A, 1B and 1D) vary between 0 and -0.6 m/s and exhibit a typical pulsating behaviour related to low and high tide levels (see Figure E-2 Bottom):

- *Low tide:* rel. large velocity U_{cross}= -0.6 m/s, h=1.6 m, H_s=0.6 m, H_s/h=0.4, $H_{s,off}$=1.25 m;
- *High tide:* rel. small velocity U_{cross}= -0.1 m/s, h=3.0 m, H_s=0.9 m, H_s/h=0.3, $H_{s,off}$=1.0 m.

The relatively large offshore-directed velocities at low tide generated at the inner bar crest during relatively low offshore waves are most probably related to circulation effects inside and outside the rip channel. At low tide there is strong wave breaking on the relatively high bar crests at the northern and southeren sides of the rip channel and hence substantial mass transport of water towards the shore, which is flowing back at relatively large velocities through the deeper rip channel passing locations 1C and 1B.

Thus, the cross-shore current at the inner bar during low wave conditions also exhibits a pulsating behaviour related to low and high tide levels; offshore current velocities can be as large as -0.6 m/s for fairweather conditions (local waves of 0.5 to 1 m) at low tide. These conditions may easily occur during normal summer conditions.

The maximum cross-shore current velocities of about 0.7 m/s observed in the rip channel through the inner bar at the Egmond field site are quite comparable to those measured in the rip channel at the Duck field site during the Sept-Oct. 1994 campaign. The maximum cross-shore current velocities under storm conditions with offshore wave heights of about 2.5 m at a depth of about 8 m were in the range of 0.6 to 0.7 m/s at the

Duck site (Grasmeijer et al., 2000). These values generally were observed just seaward ((20 m) of the bar crest, which was about 2 m below MSL. The period to establish the rip current was about 6 hours.

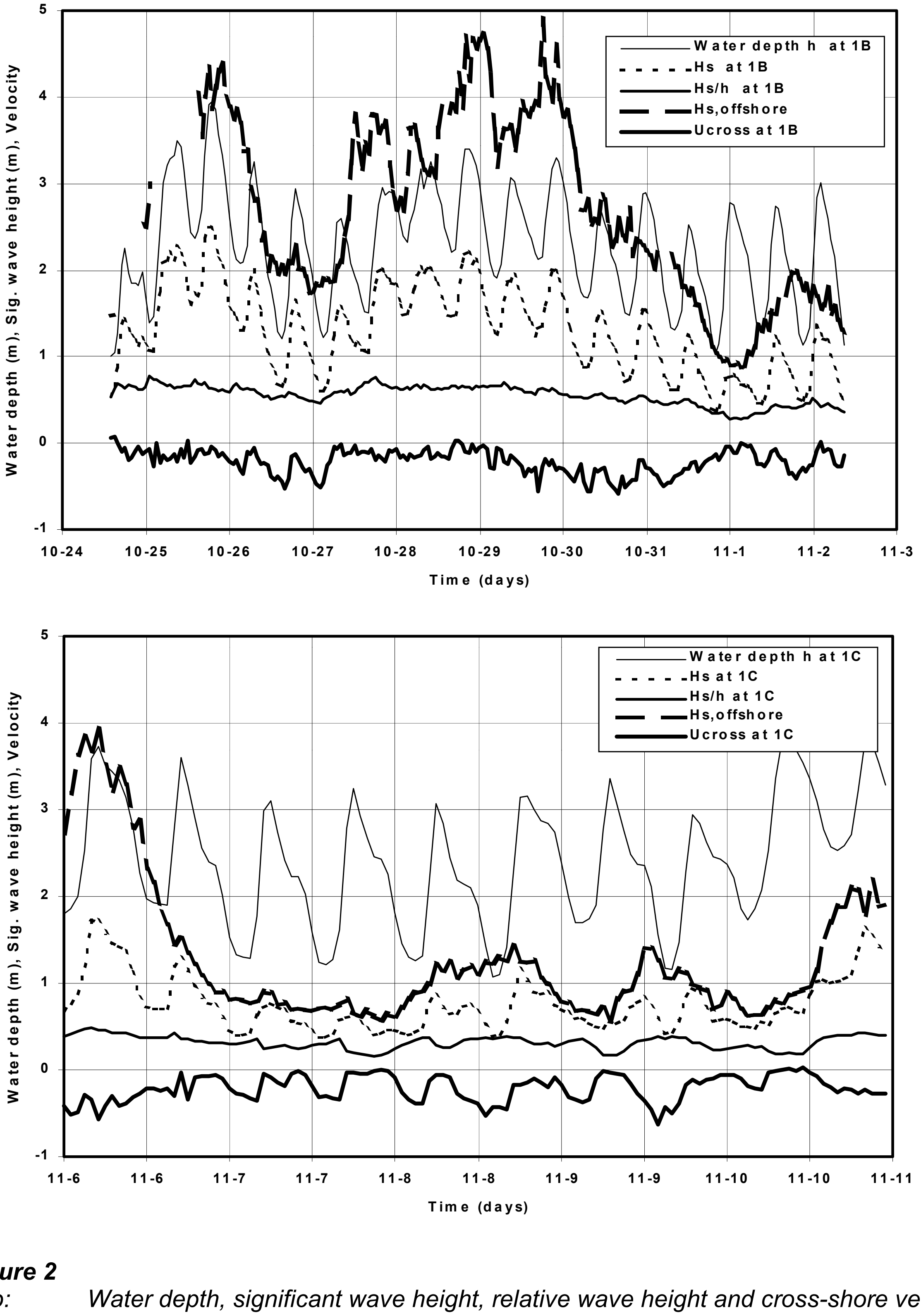

Figure 2

Top: *Water depth, significant wave height, relative wave height and cross-shore velocity at location 1B between 24 Oct and 3 Nov. 1998 (storm period of main experiment)*

Bottom: *Water depth, significant wave height, relative wave height and cross-shore velocity at location 1C between 6 and 11 Nov. 1998 (post-storm period of main experiment)*

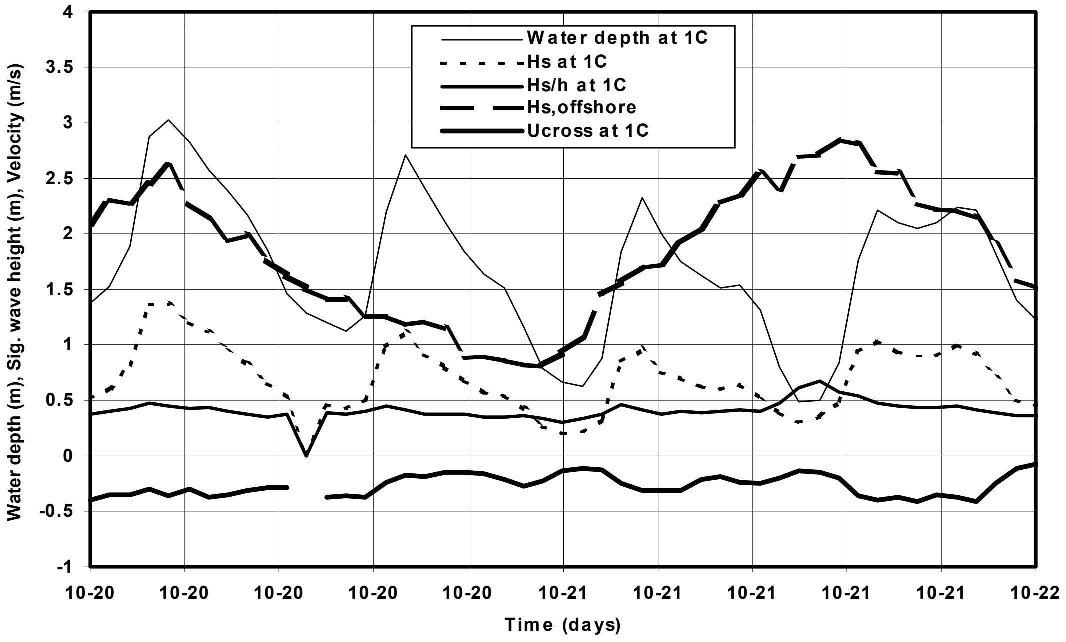

Figure 3 *Water depth, significant wave height, relative wave height and cross-shore velocity at location 1C between 20 and 22 October 1998 (pre-storm period of main experiment)*

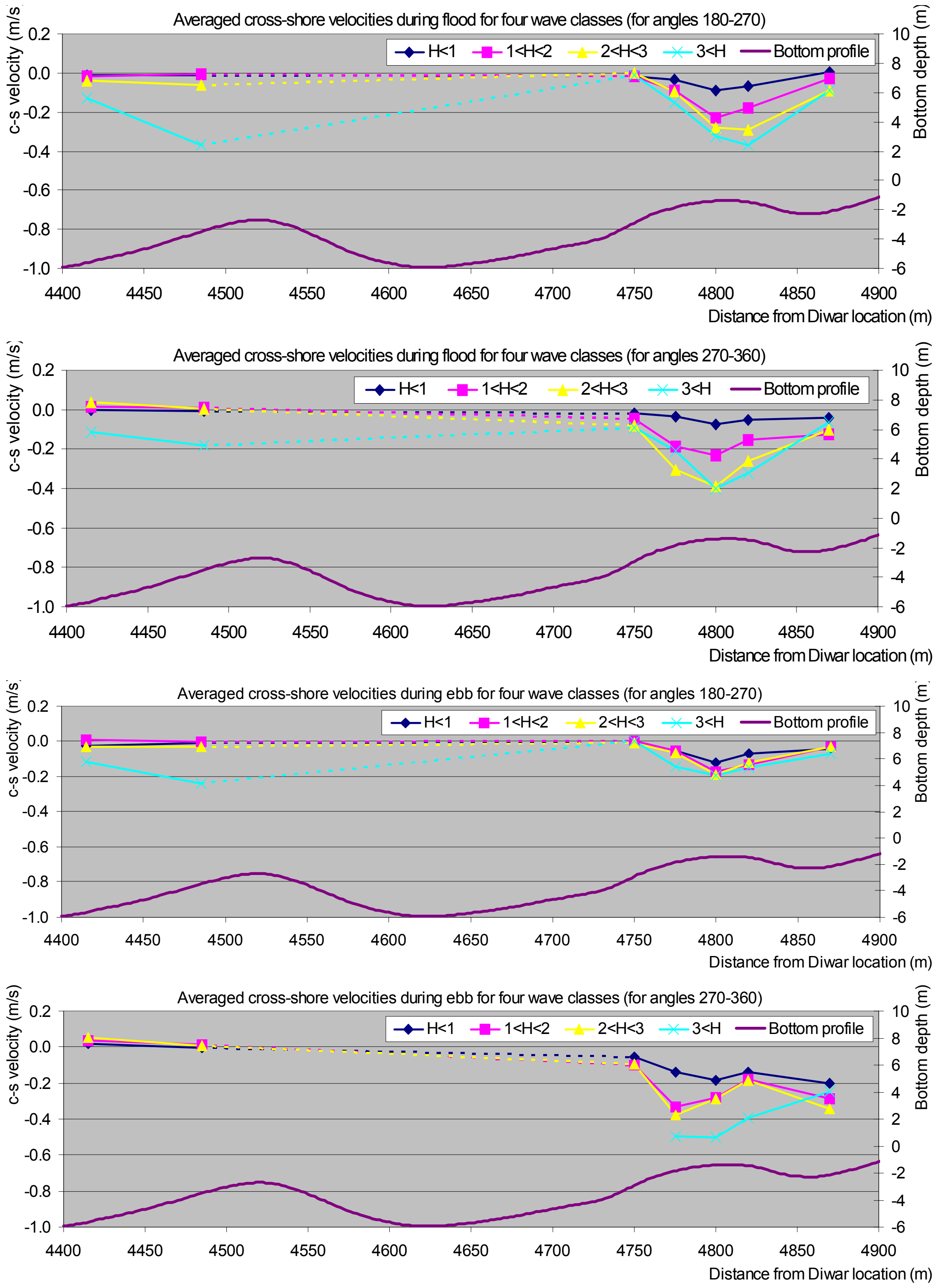

Figure 4 *Cross-shore current velocities along bed profile of main transect (main experiment); flood tide level >MSL and ebb tide level <MSL; four wave height classes H<1 m, H=1 to 2 m, H= 2 to 3 m, H> 3 m; southwest= 180-270 degrees, northwest= 270-360 degrees; positive velocities are onshore-directed; negative velocities are offshore-directed.*