<u>MONITORING CHANGES IN BEACH TOPOGRAPHY</u>

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1 Summary

Data covering long (> 100 years), medium (decades) and short-term (monthly) changes in beach topography are used to increase understanding of spatial and temporal changes in beach volume. Long and medium term changes indicate an eastward trend in longshore transport whilst changes on a monthly basis can occur in both directions with only very small annual net changes. Beach behaviour has been examined at a number of key sites. Those at Saltdean, Telscombe, Newhaven and Birling Gap exhibit relatively simple changes in volume whilst at Cuckmere Haven there is a complex exchange of material between the beaches, the river channel and the delta, and this exchange is also influenced by beach recycling. Qualitative analysis of wave conditions provides a partial explanation for beach behaviour. At Cuckmere Haven, however, the more complex and changing topography of the foreshore influences the nearshore waves to a degree that makes this approach questionable since different parts of the beach reveal that longshore transport occurs in opposing directions.

2 Aims

The aim of the work has been to measure changing volumes (absolute and lateral movement) of a representative samples of vulnerable managed and natural beaches in order to assess the influence of forcing factors on short, medium and long time scales.

3 Introduction

Beaches respond to wave attack on timescales that range from seconds in which individual waves move material up or down the beach to decades over which whole beaches may move landwards or along the coast. By integrating data on the long- and short-term changes of a number of representative beaches it is intended to provide an insight into the behaviour of other beaches in the BAR area. Comparison between natural, unmanaged beaches and recharged, managed beaches will highlight in particular the advantages / disadvantages of beach recharging and beach material redistribution.

BAR is establishing long-term beach development using existing data from a variety of sources. Particular attention has been paid to combining map data (from the 1870s onwards), air photographs (from the 1970s onwards) and beach profiles surveyed by the Environment Agency and other organisations. Short-term changes are measured in situ at regular intervals using differential GPS.

4 Long term changes: map data

4.1 Method

The procedure for preparation and digitising paper maps is detailed in the report on cliff retreat measurements. For the purpose of measuring changes to beaches the high water line (HWL), shingle beach toe (SBT) and landward limit of the beach (LOB) have been digitised. Given the steepness of shingle beaches, the position of HWL can be determined by a field surveyor with a positional accuracy of <3 m. The SBT can be located, depending on the foreshore, with an accuracy of ±0.5 m for the shingle/chalk interface and of max. ±5 m for the shingle/sand contact. The LOB is easily traced where the beach is backed by a cliff or structure, but where it forms a barrier in front of low lying land is not readily ascertained.

4.2 Results

Initially available historic Ordnance Survey maps for the frontage from Brighton to Newhaven have been digitised. In a first step, beach planform areas have been calculated together with the number of beaches. In the 1870s, a continuous narrow beach stretched from Black Rock to Newhaven, which was mostly submerged during high tide. The construction of groynes, particularly those built in the 1930s between Brighton and Rottingdean and in the 1960s and 1970s at Peacehaven, has increased the number of beaches though there has been a general decrease in the area covered by beaches (**Figure 1**).

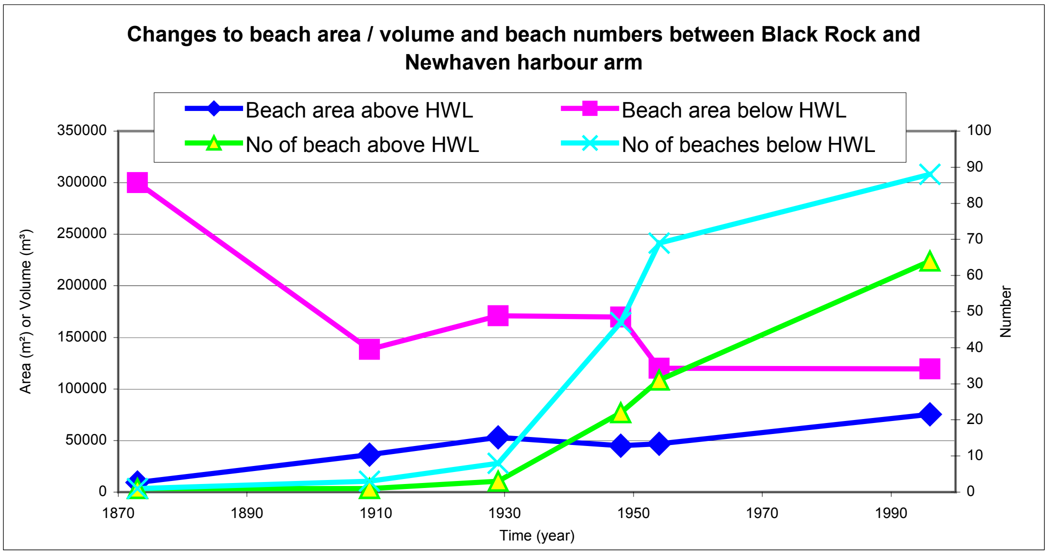


Figure 1: Changes in the numbers of and areas covered by beaches between Brighton and Newhaven between the 1870s and 1990s.

At Newhaven, however, the area of beach above high water has increased due to the construction of Newhaven Harbour arm, which has obstructed the longshore drift allowing beach accretion. This can be seen in the calculated volumes (see section 5.1) shown in **Figure 2**. Most, if not all, the material seems to have accumulated before the 1930s, i.e. in the first 50 years after construction of the harbour arm. If the volumes are converted into annual transport rates, beach material arrived at Newhaven at a rate of ~5,000 m^3/year during the period 1873 to 1909 and at 4,250 m^2/year during the period 1909 to 1929. Changes after 1929 might relate to material extraction and the slight increase in the second half of the 20th century may relate to shingle input from the cliff trimmings at Peacehaven.

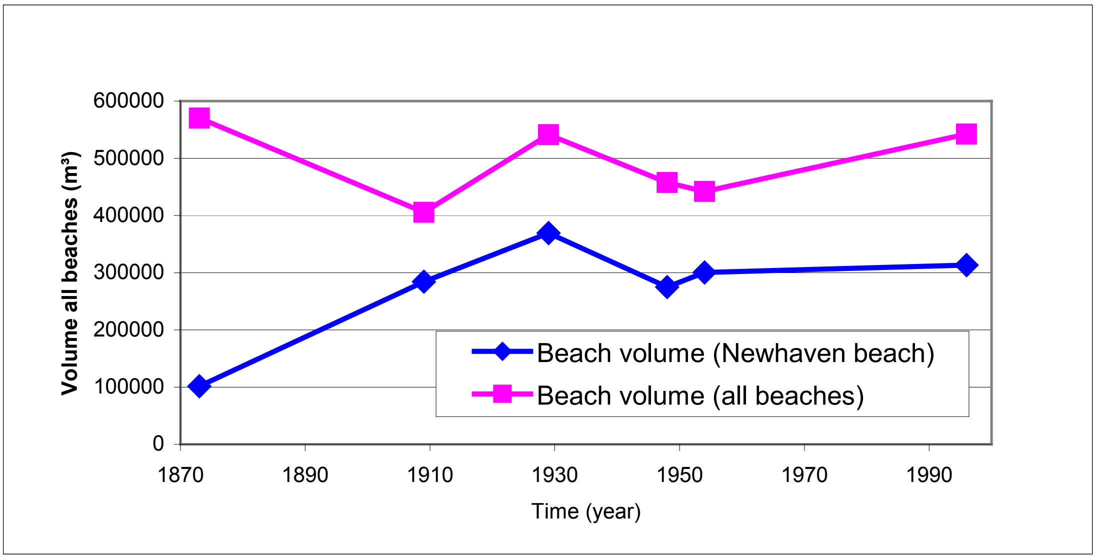


Figure 2: Changes in beach volumes between Black Rock, Brighton and Newhaven Harbour Arm from the 1870s to the 1990s.

5 Medium term changes: air photograph data

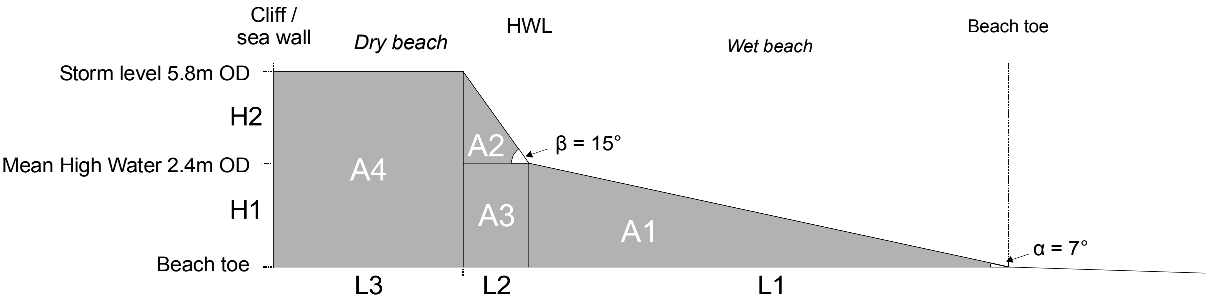
5.1 Method

Orthophotos flown in 2001 by the Environment Agency have been used to digitise the position of the SBT. The positional error is somewhat lower than for maps though the problem of defining the SBT at a shingle/sand interface can be as difficult using air photographs as in the field. The HWL position for 2001 has been digitised using the Environment Agency 2001 Digital Elevation Model (DEM) with the values for the HWL given in **Figure 3**. The position of the calculated HWL has then been compared with the orthophotos and edited to fit the geomorphology as necessary.

Location	HWL in m OD
Brighton	2.4
Newhaven	2.38
Eastbourne	2.8
Hastings	2.85
Rye Bay	2.95
Dungeness	2.7
Folkestone	2.65
Dover	2.33
Deal	2.2
Ramsgate	2.02

Figure 3: Heights for HWL calculated from UK Hydrographic Office data (2004).

In addition to measuring positional changes beach volumes have been calculated for beaches where the LOB could be defined from maps based on simple assumptions about the beach cross profile geometry (**Figure 4**).



$$H1 = \tan\alpha \times L1$$

$$A1 = H1 \times \frac{L1}{2}$$

$$H2 = \tan\beta \times L2$$

If the width of the dry beach is ≤ 12.7m than L2 = dry beach width; if the dry beach width is > 12.7m than L2 = 12.7m and L3 = dry beach width – L2.

$$A2 = H2 \times \frac{L2}{2}$$

$$A3 = H1 \times L2$$

$$A4 = (H1 + 3.4) \times L3$$

Figure 4: Example heights and gradients and geometric relationships for beach volume calculations. (The calculations assume that the shore platform beneath the beach is horizontal. If this is not the case, which is likely, then the calculations will overestimate the beach volume, especially on larger beaches.)

Beach slope angle for the calculation is based on field measurement and the storm level height / height of the dry beach has been taken from the EADEM (**Figure 5**).

Because the EA DEM has only a few points on the beach the resulting beach volumes will be less accurate in comparison with those obtained by more detailed photogrammetry or ground surveys (see below). To obtain more accurate information on the volumetric change of beaches during the past 30 years some stretches of coast have been selected for detailed investigation by photogrammetry. The 2001 photographs will be compared with the earliest air photos from the Annual Beach Monitoring Survey (1973 for Sussex and 1978 for Kent). Digital photogrammetry will be carried out using Geomatica Orthoengine for which ground control points are collected by the BAR project using differential GPS, tied in with the EA E1 and E2 network.

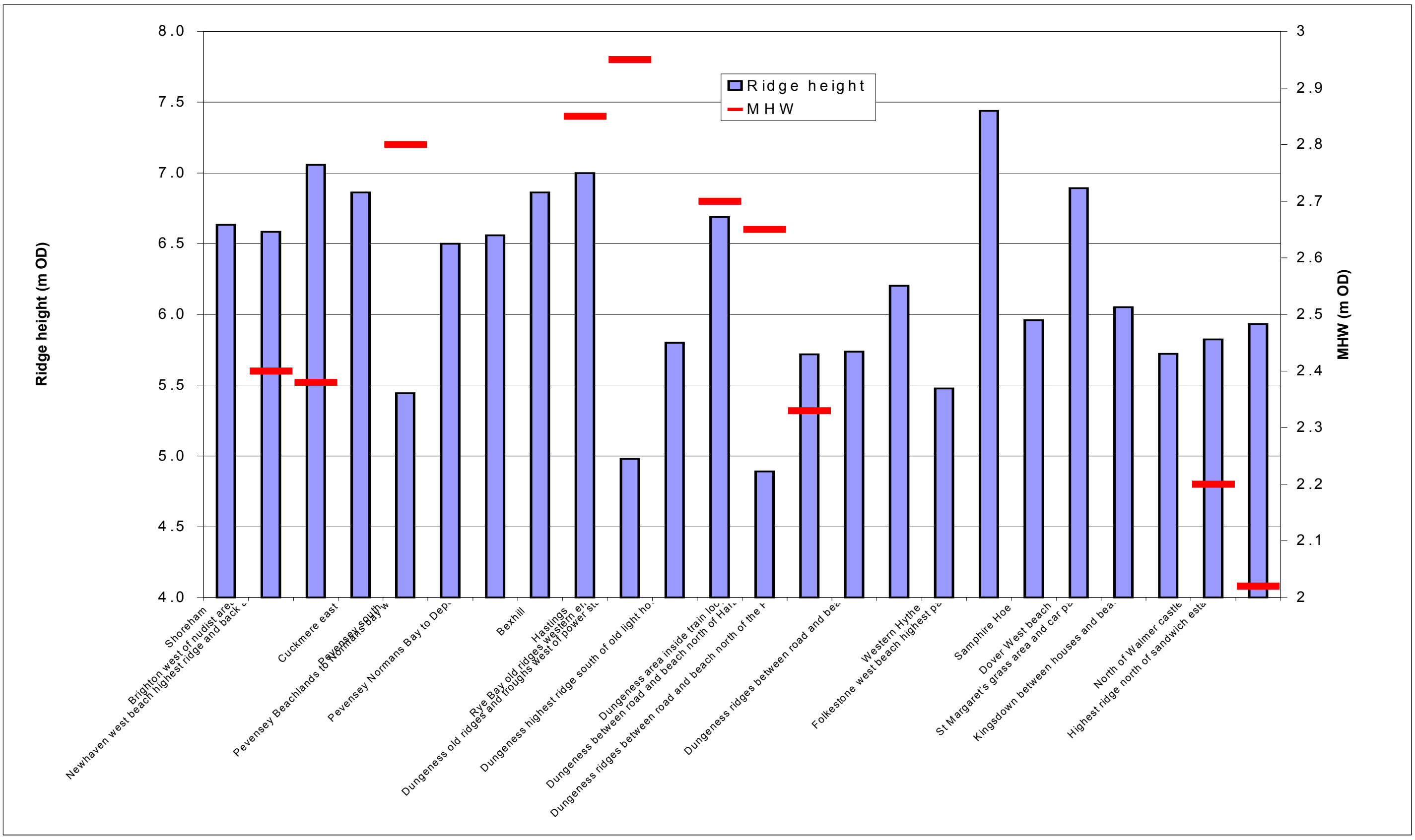


Figure 5: Mean height of storm berms and back beach areas plus HWL (mean high water MHW see **Figure 3**) in East Sussex and Kent, viewed from west to east.

5.2 Results

To date only preliminary work has been carried out to test the methodology. All the air photos necessary have been scanned, and photogrammetry will be carried out in Phase 2 of the BAR project.

5.2.1 Medium term changes: other existing data

Other data that are being utilised are mainly in the form of profile surveys carried out by agencies other than BAR. Whilst using these data every care has been taken to ascertain levels of accuracy and reference heights to comply with data generated by BAR. In addition, qualitative data, such as repeat-photography has been used to record changes. One example of such data was provided by Posford Duvivier in the ‘Beach Status Report October 2003’ for Eastbourne Borough Council. Two types of surveys had been carried out following major recharge works along the Eastbourne frontage. One was a traditional topographic survey (carried out in January 1999 and November 2001) and the other a study of beach levels in relation to groyne heights (carried out in August 1999 and December 2002). Both surveys cover slightly different periods but divide the frontage into the same 5 sections. These are from south to north: (1) from the beginning of the groyne field to east of the Wish Tower, (2) from there to the Redoubt, (3) from the Redoubt to the Tanhouse groyne, (4) from this groyne to the treatment works and (5) from the works to the harbour entrance (Figure 6). For each cell, net volume changes are reported as averages which have been converted to transport rates (Figure 6). Based on both surveys, similar rates of transport can be calculated. Sediment movement is characterised by losses from section 1 which are then transported through section 2 (no net change) and section 3 where some deposition occurs, slowing down the rate of transport. Most of the material from the previous sections then ends up in section 4 where the high rate of deposition means that little material is passed into section 5. The transport out of section 5 is actually a loss due to shingle extraction at Sovereign Harbour.

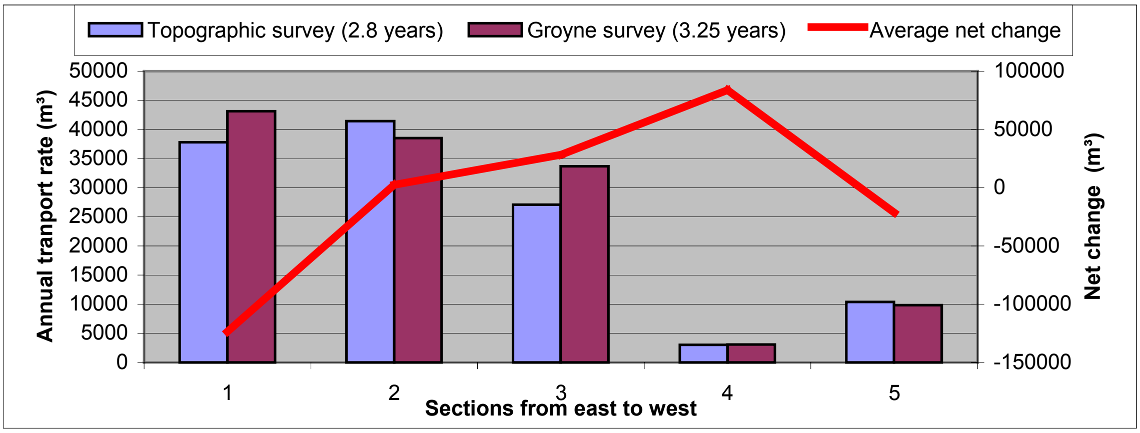


Figure 6: Annual transport rates along the Eastbourne frontage 1999 to 2001 / 2002.

6 Short term: GPS surveys

Following very limited repeat profile measurement during the Interreg II BERM (Beach Erosion in the Rives Manche) project at Telscombe (Figure **7**) and Saltdean it was found that both beaches, which essentially form closed systems, show dramatic changes in profile shape and profile height over relatively short time periods, which may indicate longshore transport. Profiles such as those shown in **Figure 7**, however, can only show the amount of material moving into or out of the profile without any information as to where the material has come from or its direction of movement.

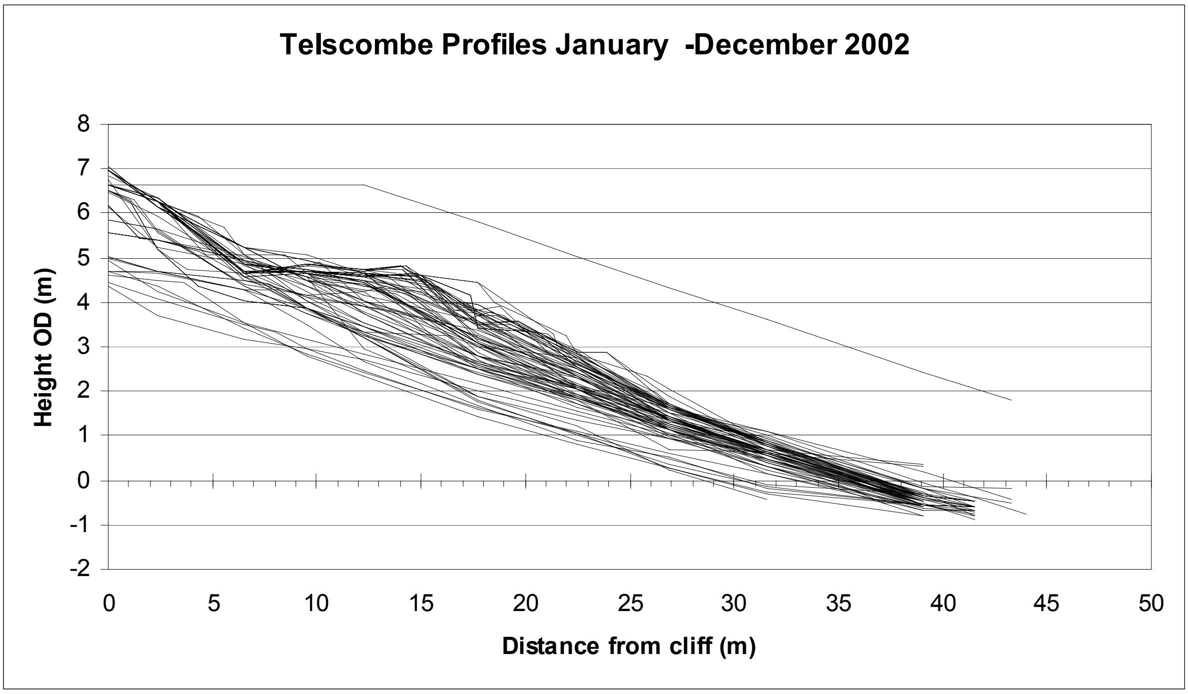


Figure 7: Superimposition of 40 profiles measured against the sewage outfall groyne at Telscombe between January and December 2002.

To obtain a more detailed and precise assessment of volumetric changes of shingle beaches (total volume and volume displacement) additional spatially detailed surveys have been carried out from which accurate beach surfaces can be created to form the basis for calculating volume changes.

6.1 Method

Short-term changes are surveyed using differential GPS. Using TOPCON® receivers allows data collection in close proximity to cliffs due to the added reception of the GLONASS satellites. On Pevensey beach, a Trimble system is used to fit in with other surveys carried out on this beach by Pevensey Coastal Defence Ltd. All beaches are surveyed on a monthly basis around spring tide to minimise surface change effects in relation to different tide levels, but some beaches are surveyed more frequently and in response to individual storms to provide a closer link between wave forcing and topographic change. All surveys are linked to base stations whose position is tied in with the Environment Agency E1 and E2 network points.

The following methodology has been developed following detailed tests (Dornbusch, 2003a; 2003b) on how best to utilise GPS for beach surface surveying taking account of the mapping software used to create surfaces from the measurements and the ultimate objective of comparing different surfaces with each other (Dornbusch, 2003c). Parts of the survey method differ depending on the equipment used.

Survey protocol:

- Surveys use differential GPS in auto-topo or continuous mode with points taken every 0.3m (1 second at Pevensey).
- The rover antenna is mounted on a wheel with a small diameter of 30 cm (Pevensey 42 cm) to reduce the effect a slope of >15° could have on the distance between antenna and beach surface.
- Survey paths follow cross shore profiles and have an average spacing of 20-30 m depending on the size of the beach and longshore variation of the profile. Where necessary, profile spacing has to be much smaller. In case of rhythmic long shore variations (e.g. beach cusps) profiles run halfway between cusp and embayment.
- Profile paths should be as straight as possible.
- Profile start points should always be sufficiently inland of the currently active beach to allow for a comparison of the survey error on unchanged topography between two surveys and to have a reference surface in case the beach erodes prior to the next survey.
- Especially on steep beaches it is recommended to record the profile surveying down the profile as it is more difficult to hold the rover vertical while surveying up the profile. However, this is not always possible, especially in front of cliffs, and every care is taken to ensure that the pole is held vertical at all times.

Surface generation and comparison:

- Survey data is imported into ArcView.
- For each beach or groyne section snap lines along groynes are created to which the profiles closest to the groyne are snapped to ensure that surveys cover the same extent of the beach. The snapping distance should be <2 m.
- Generate a TIN from the edited point set. Check the TIN by displaying all lines if the triangles are slope parallel. If not, this is likely to be due to curves in the survey path. Straighten the survey path by generating a temporary line theme and snapping the survey points to that line; again the snapping distance should be <2 m.
- After an acceptable TIN has been generated the TIN is converted into a grid using a

suitable spacing (this may vary from beach to beach but remains constant for surveys carried out on the same beach). The grid cell size should be < 0.5m to retain detail. The GRID bounds should be a polygon theme that is used for all surveys of a particular beach to make sure that all grids exactly overlay.

- GRIDS can then be compared with others using the map calculator within ArcView to produce surface change maps. The final surface change map should be clipped with a polygon theme that covers the survey extents of all surveys. When subtracting grids, the younger should be subtracted from the older.
- Absolute volume changes can be calculated using the cut & fill function.

6.2 Site selection

The site selection has been based on finding a representative sample of managed and unmanaged beaches but also takes into account accessibility to beaches and previous research.

The following sites have been selected:

Saltdean: At Saltdean (**Figure 8**), 6 beaches composed of the same recharge material exist which differ in position in relation to groynes and groyne types, length along the shore and composition / height of the foreshore. Given that wave conditions over this 500m frontage can be assumed to be uniform, differences in beach behaviour may be attributed to one or a combination of these factors. Beach behaviour (cross shore profile and crest rotation) has previously been modelled by Posford Duvivier and their results can be compared with monitored beach behaviour. Previous research during the BERM project has measured field abrasion of beach material in one of the groyne compartments and measured beach profiles over more than a year, which provides additional data for analysis.

Beach 1 is partially separated by a comparatively low and short groyne that allows sediment bypassing around the seaward end and over landward part. Because of the significant exchange between the two parts they are treated as one beach. The beach terminates on a deeply dissected shore platform with the beach toe at ~-0.5 - -1 m OD. Beach 2 consists of somewhat coarser beach material than the other beaches which leads to a steeper beach. The effect of the Saltdean dry valley is shown on the foreshore which is split into the western part, consisting of a chalk platform that is >1m higher than the eastern part which is mainly covered by sand, though occasionally the chalk is exposed. Beach 3 occupies the centre of the former dry valley and the foreshore at the beach toe is always covered by sand. Chalk only crops out in the south-western part. Due to the obliqueness of the groynes, the beach opens landward. The shingle beach toe is at ~-1.6 m OD which means that the sandy foreshore can only be surveyed during a relatively short time period around spring low tide. Surges coinciding with the surveys have a significant effect on the extent to which the sandy foreshore of beach 3 and 4 can be surveyed. On the foreshore of beach 4 chalk crops out again on an almost permanent basis in the eastern half. However, the platform there appears to erode rapidly by block removal leaving a relatively smooth rock surface. The western part is almost always entirely covered by sand but on one occasion in 2002 the total disappearance of sand from this sector was observed. In contrast to beach 4 the beach opens seawards. The shingle beach toe is located at ~-1.9 m OD. Beach 5 lacks a sandy foreshore and terminates directly on the shore platform with the beach toe at ~-1.3 m OD. Beach 6 is a small triangular shingle accumulation that is probably least susceptible to longshore movement due to its sheltered position behind the eastern rock groyne. The beach toe is at ~-0.6 m OD.

There is little potential for shingle exchange between the beaches 2, 3, 4 and 5. The only transport can occur over the groynes from west to east but observations would suggest that the annual volume is less that a few m³. Because the groynes extend far seawards, it is highly unlikely that shingle moves around them and no traces of such movement have been observed. However, sand can move freely around the end of the groynes. From observations of wave shoaling at low tide it appears that a sand bank, that could provide sand to the foreshore, lies ~100 m offshore from the end of the groynes over the length of the Saltdean frontage.

Telscombe: The beaches at Telscombe (

Figure 9) are only 1 km east of Saltdean and are thus influenced by the same waves. However, they are very different in character. The western beach at Telscombe may be classed as a natural beach. It consists predominantly of grey flint from the cliffs and shore platform and has a significantly larger mean grain size than the beaches at Saltdean. The set of three beaches allows a comparison of behaviour between similar beaches and comparison with those at Saltdean.

Cuckmere Haven: The east beach at Cuckmere Haven (**Figure 10**) is the last unmanaged and largely natural shingle barrier beach in East Sussex and Kent. Together with the groyned and highly managed west beach and the shingle delta it forms a sediment cell that is shaped by natural processes until a certain threshold is reached at which point managerial intervention takes place.

Birling Gap: The natural fringing beach at Birling Gap (**Figure 11**) is the remnant of a continuous fringing beach that up until the early 20th century lay at the foot of the cliff along the whole of the Seven Sisters. Its position is exposed to longshore drift, but, despite this, the beach seems to remain in its position most of the time, though reports exist of its temporary disappearance.

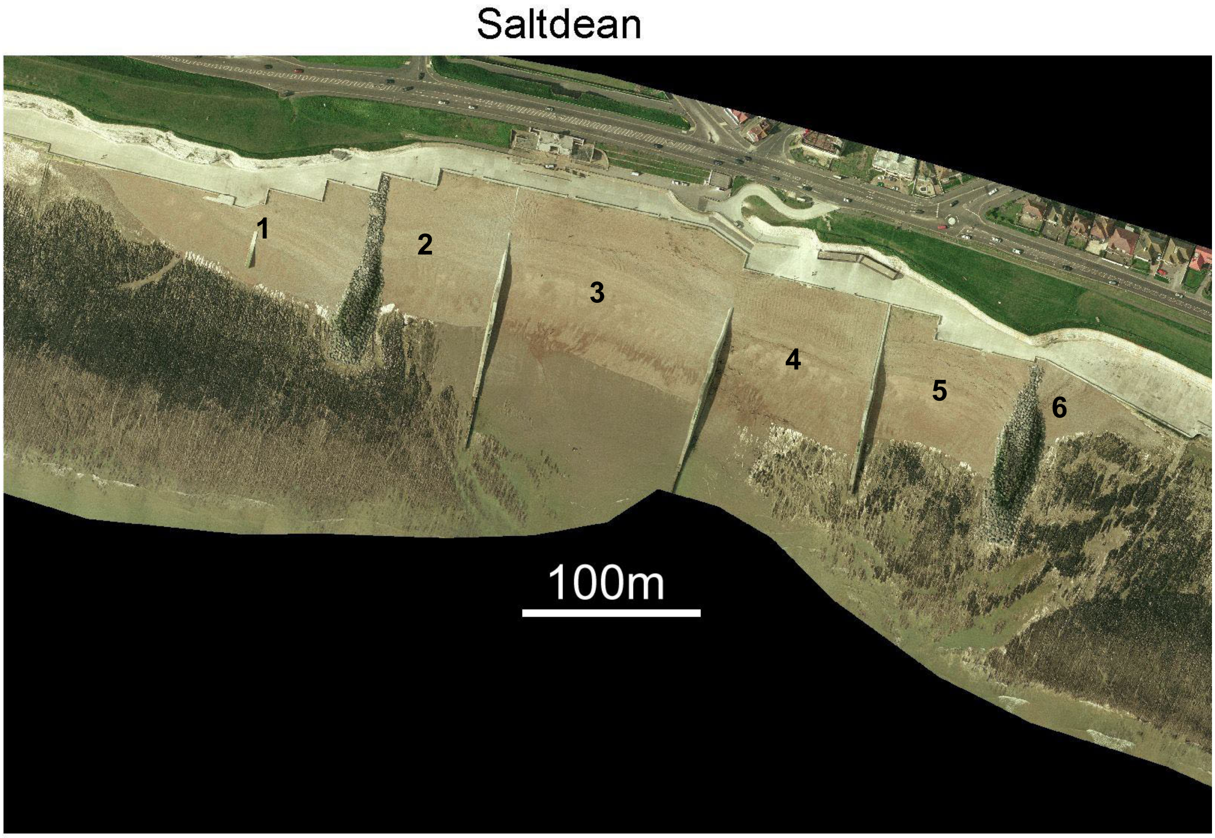


Figure 8: Saltdean beach

Figure 9: Telscombe beach.

Figure 10: Cuckmere Haven beach.

Figure 11: Birling Gap beach

6.3 Results

Analysis of the results will be carried out in different forms. At Telscombe, total volumes for each beach were calculated using a subsurface. Subsurface creation needs to be fine-tuned so that negative areas are as small as possible but are unlikely to be avoided where beaches are shallow, such as the eastern beach at Telscombe and along beach toes. The subsurface was finally generated from measurements of the chalk were it is exposed at the cliff toe or otherwise in the beach and by extrapolating this surface under the beach. However, interpolation of beach surfaces may cut across small rises in the platform and thus create negative areas. Comparing the volumes between surveys for beaches that are assumed to be closed systems provides an indication of the error margin that is associated with the survey and surface generation which then makes it possible to calculate the amount of surface change necessary in the surface comparisons to indicate a true surface change. Similarly, the net change in closed systems (e.g. the groyne compartments at Saltdean) gives an indication of the error margin.

For all beaches, each survey surface is compared with the preceding survey to assess changes that can then be related to waves and tides. Because all surveys are carried out around spring high tides, cross-shore changes reflect changes in wave energy rather than tidal level. **Figure 12** shows an example from Telscombe where a clear cross-shore change can be seen that may be attributed to a summer storm event. However, these comparisons may also be used to calculate longshore transport rates by dividing the beaches into smaller compartments for which the net volume change is calculated. This method disregards the substantial cross-shore changes to filter out the longshore component (see the example in Figure 14). From the net volume changes between each cell the amount of material moving from one cell to the next can be calculated (equates to the longshore transport rate; **Figure 14**). In this example, the longshore transport rate indicates that the west beach is an open system and has lost ~150 m³ to the east, whilst the central and eastern beaches are more closed systems with the transport rate approaching 0 in the final cell. However, the apparent loss of 150 m³ on the east beach can also be attributed to the summation of errors and is likely not to indicate transport off the beach. To compare surveys through the year, the net change between successive surveys is shown for each cell in diagrammatic form (e.g. **Figure 20**).

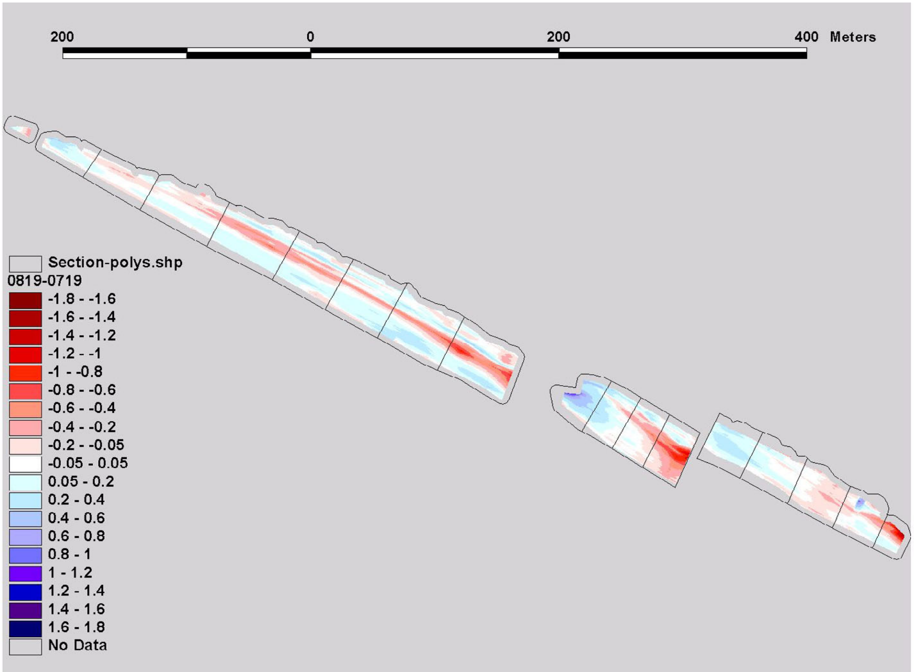


Figure 12: Surface elevation changes between surveys carried out on July 19, 2004 and August 19, 2004. The polygon overlay divides the area down into smaller sections for which the net change can be calculated.

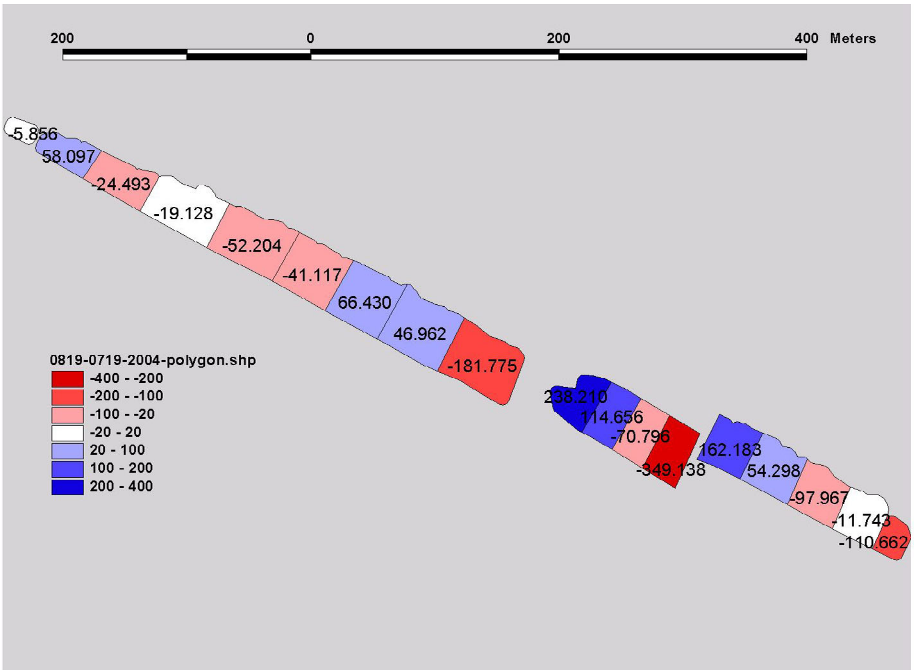


Figure 13: Net volume changes for each cell.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Net change	58	-24	-19	-52	-41	66	47	-182	238	115	-71	-349	162	54	-98	-12	-111
Rate	-147	-205	-181	-162	-110	-68	-135	-182	-67	-305	-420	-349	-4	-166	-220	-122	-111

Figure 14: Net change and calculated rate of sediment transport for each cell shown in **Figure 13**. The direction of transport may be obtained from the net change with negative values indicating westerly and positive values easterly transport.

In a final step, all surveys are averaged and all individual surveys are recalculated in units of standard deviation from the average surface. This method makes it possible to identify different ‘beach states’ that may be linked to seasons. However, given that to date data have been collected over only one year, both the averaging and identification of ‘beach states’ are of limited statistical robustness.

6.4 Saltdean

At Saltdean, surveys for beach 4 (**Figure 8**) go back to July 2003. Other beaches have successively been added and from December 2003 all 7 beaches have been surveyed.

6.4.1 Net volume changes

Figure 15 shows the net surface elevation changes for each survey on each beach. Based on the assumption that the beaches are closed systems for shingle, the variations provide a scale for the error associated with the surveys and the data analysis. Most changes are in the order of ± 2 cm. The exceptions are beach 1 where changes are two to three times this value. This is because the assumption of a closed system does not apply to this beach which is open to the west. The large variations for beach 3 in May and July relate to beach material movement in relation to groyne repair. To allow for heavy machinery to work near the groynes, shingle was taken from the beach and deposited alongside the groyne. This material migrated back onto the beach in July (see **Figure 17**).

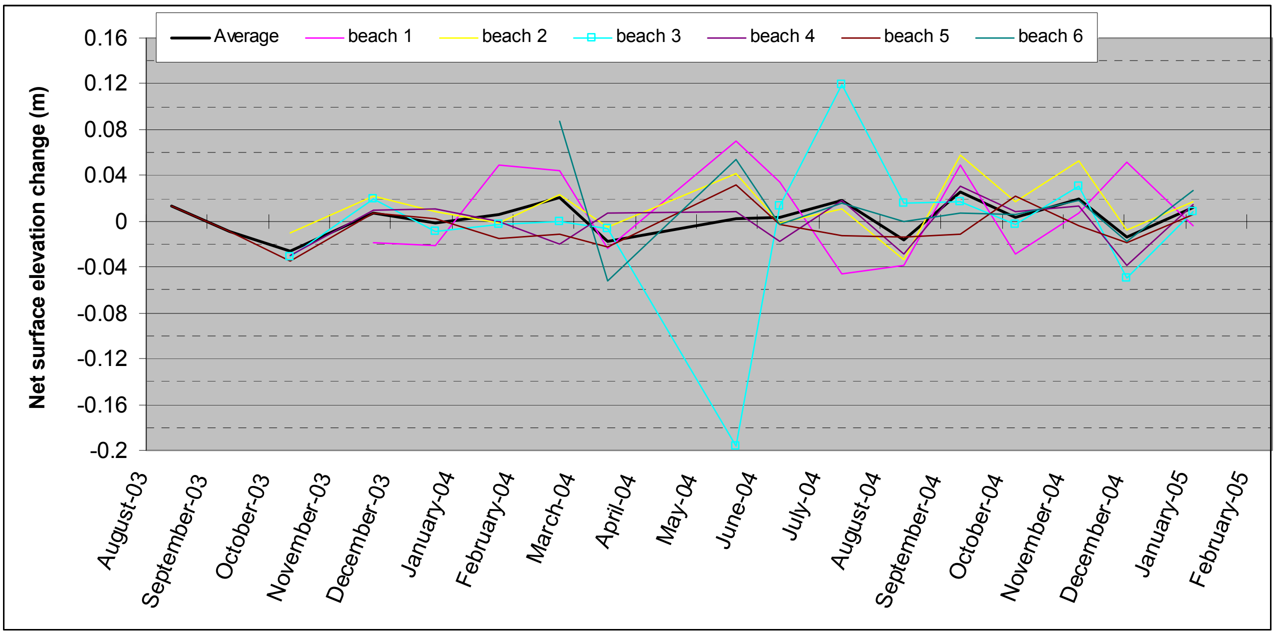


Figure 15: Net surface elevation change for each survey and each beach. (Values have been calculated from changes in volume divided by the beach area; for beach number please refer to **Figure 8**).

While the changes between monthly surveys are small, they may in some cases mask longer term changes. Comparing the surveys carried out in January 2004 and January 2005

(**Figure 18**) and calculating the net surface elevation change (**Figure 16**), beaches 1, 2 and 6 show changes well above the error margin while beaches 3, 4 and 5 show changes in line with those measured on a monthly basis. The increases in beaches 1 and 6 can be easily attributed to their openness for sediment transport. Especially west of beach 1 small pockets of beach material can be found below the seawall that are able to move on and off the beach. More puzzling is the material gain on beach 2, which corresponds to 500m³. Such a gain is also confirmed in the comparison between the surveys carried out in December 2003 and December 2004 and therefore does not relate to the selection of the surveys. It might be possible that some of the shingle that was placed next to the groyne between beach 2 and 3 was moved into the beach 2 section during works or moved around the end of the groyne after the works were finished. In addition, some material might have moved from beach 3 into beach 2 over the groyne top prior to the Survey in November 2004 when a large accumulation against the eastern side of the western groyne of beach 3 is shown in **Figure 17**. However, material movement in the order of a few hundred m³ does not seem to have been likely in both scenarios.

beach 1	beach 2	beach 3	beach 4	beach 5	beach 6
0.140751	0.172217	-0.03096	0.003983	-0.03334	0.131765

Figure 16: Net surface elevation changes (in metres) between the surveys in January 2004 and January 2005.

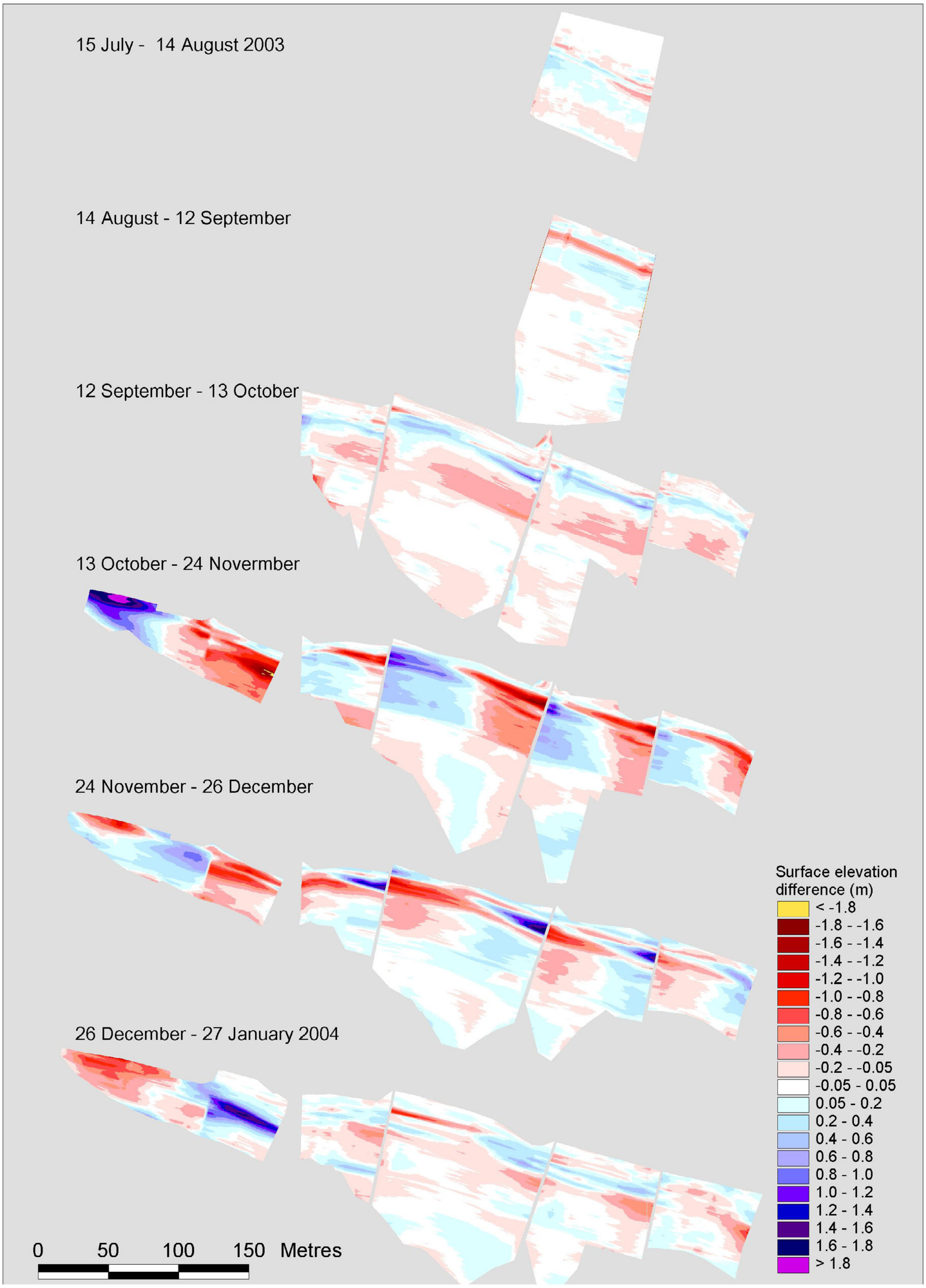


Figure 17: Changes in surface elevation between surveys.

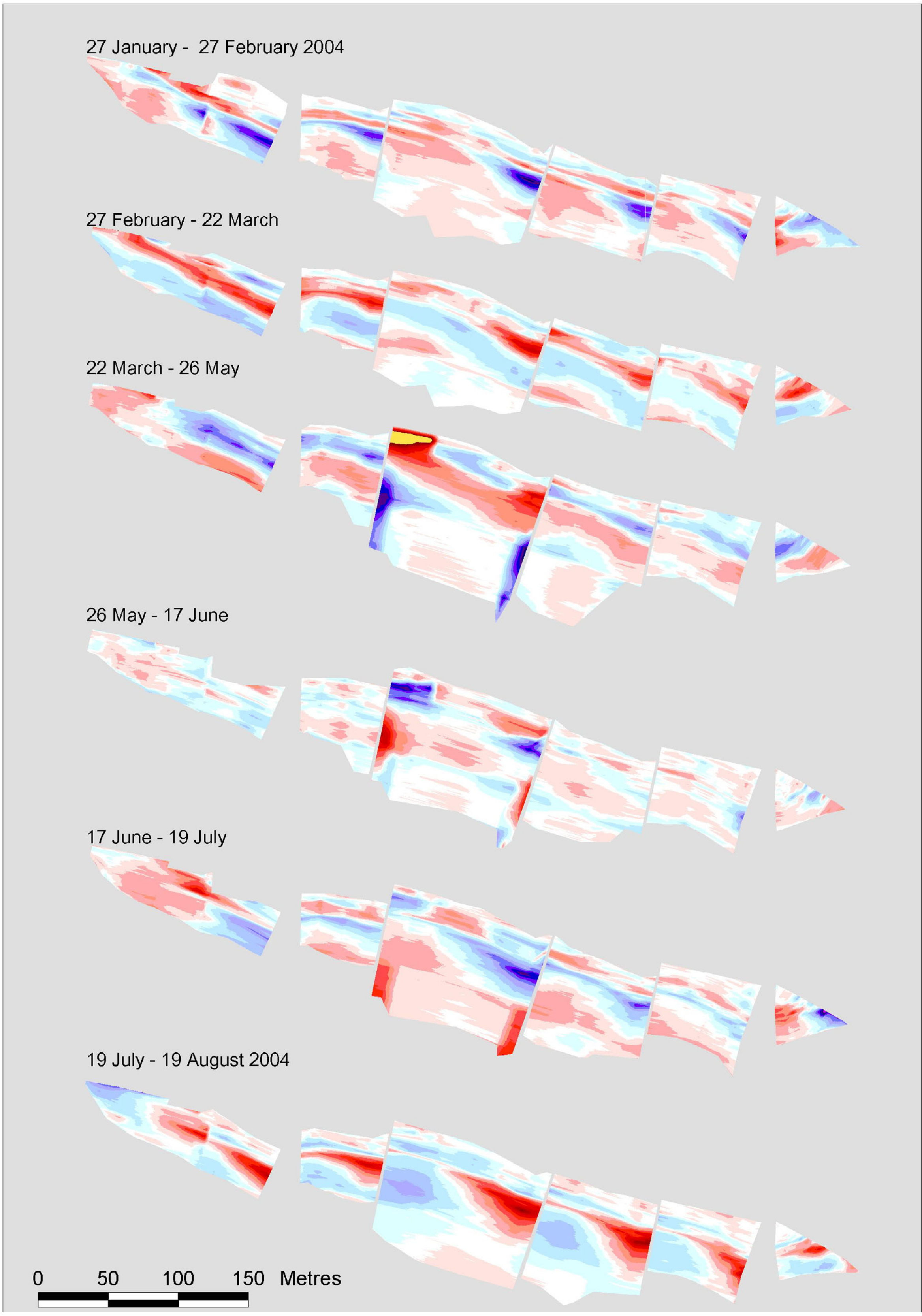


Figure 17 continued: Changes in surface elevation between surveys.

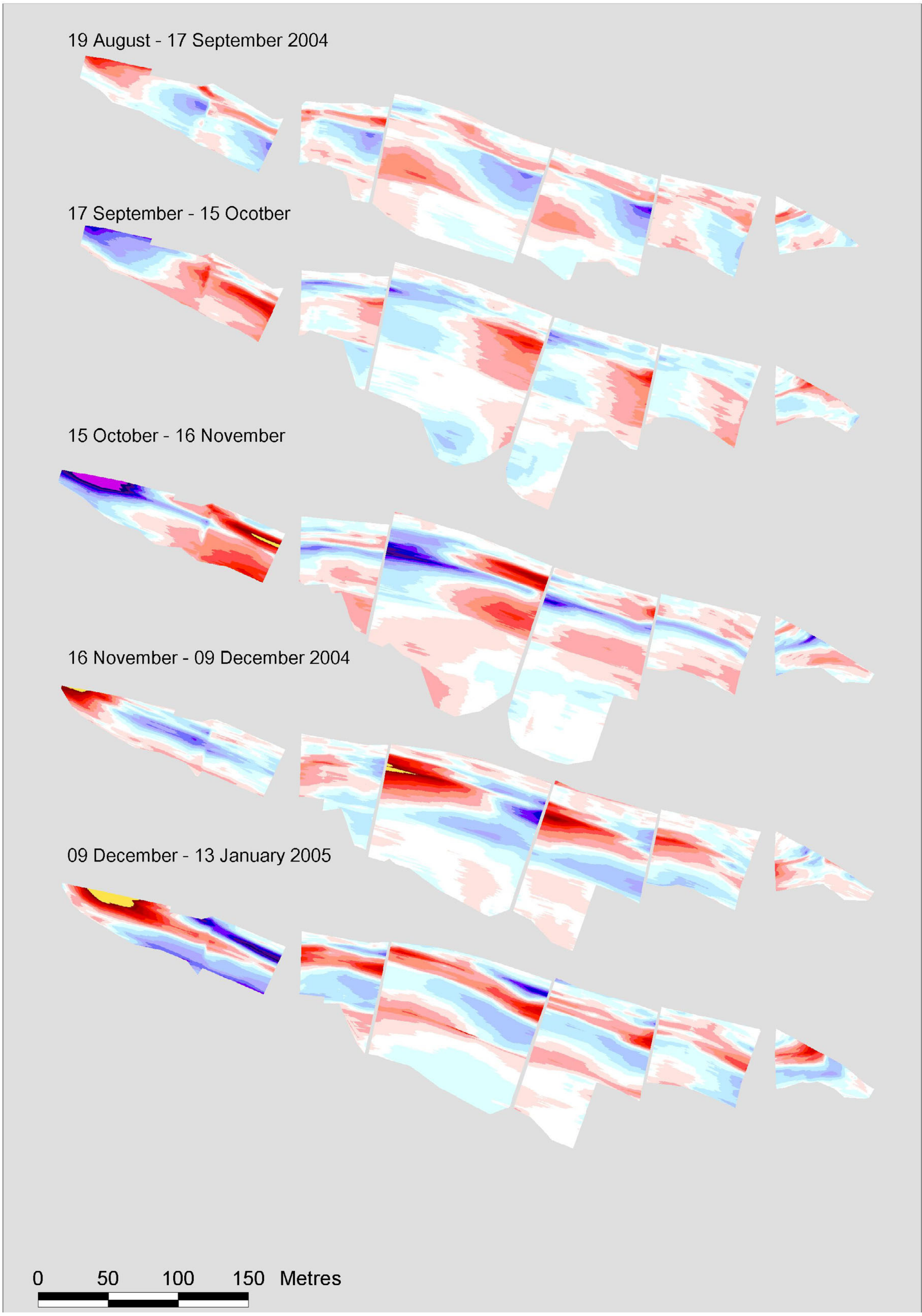


Figure 17 continued: Changes in surface elevation between surveys.

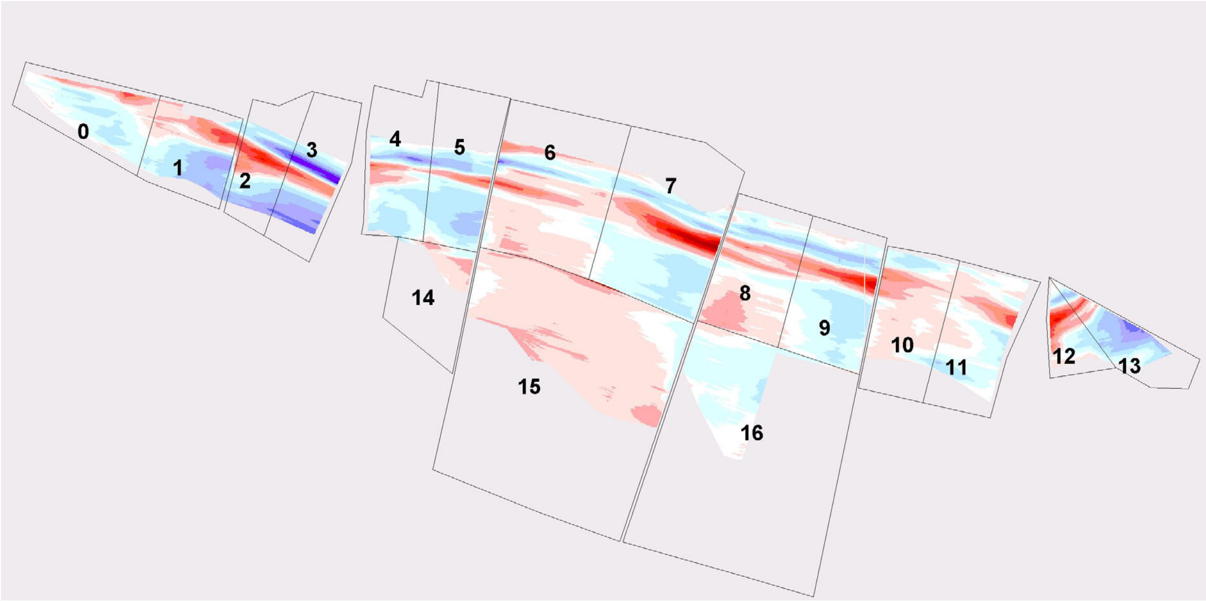


Figure 18: Changes in surface elevation between the surveys in January 2004 and January 2005. Also shown are the beach segment numbers relating to **Figure 20**.

6.4.2 Longshore movement

Despite the restricted width of the beaches between the groynes, significant changes in the longshore direction can be observed (**Figure 17**). Only the surveys in August, September and October 2003, May and June 2004 and January 2005 are characterised by limited longshore movement. The surveys in November and December 2003 and from July to December 2004 show large oscillations of the beach material.

The magnitude of the changes, i.e. the amount of material moved, depends on the volume available (as shown in **Figure 20**), where the changes on beach 3 (sections 6 and 7) during larger events is always more than that for beaches 4 and 5. However, if the length of the beach is taken into consideration and the volume change per metre of beach is calculated, the amount moved on beach 4 (sections 8 and 9) is ~70% and on beach 5 40% of that on beach 2. This is not surprising as the greater length of beach 2 would result in less interference from groynes so that oblique waves are less refracted and therefore lose less of their longshore transport capabilities.

Within the constraints of groynes the maximum transport rate is ~1300 m^3 between the surveys in October and November 2004 on beach 2. The maximum on beach 3 is 700 m^3 and 360 m^3 on beach 4 (both between October and November 2003). Though unconstrained on the western side the maximum transport rates on beach 1 reach only 1400 m^3 (November 2003 and 2004). The magnitude and direction of change can to some degree be related to the offshore wave conditions at the Rustington buoy (**Figure 19**). For example the large scale eastward movement of material prior to December 2004 most likely related to the storm just following the November survey that coincided with wave directions between ~10 and 50° from the west. The large movement of material to the west prior to the October 2004 survey is likely to relate to conditions at the beginning of October when over a few days wave heights were ~1.5m but the direction 70° to 90° from the east.

However, the wave buoy data does seem to show some difference between the recordings prior to and after the down-time in spring 2004 with a much greater spread of directions in the period prior to the down-time.

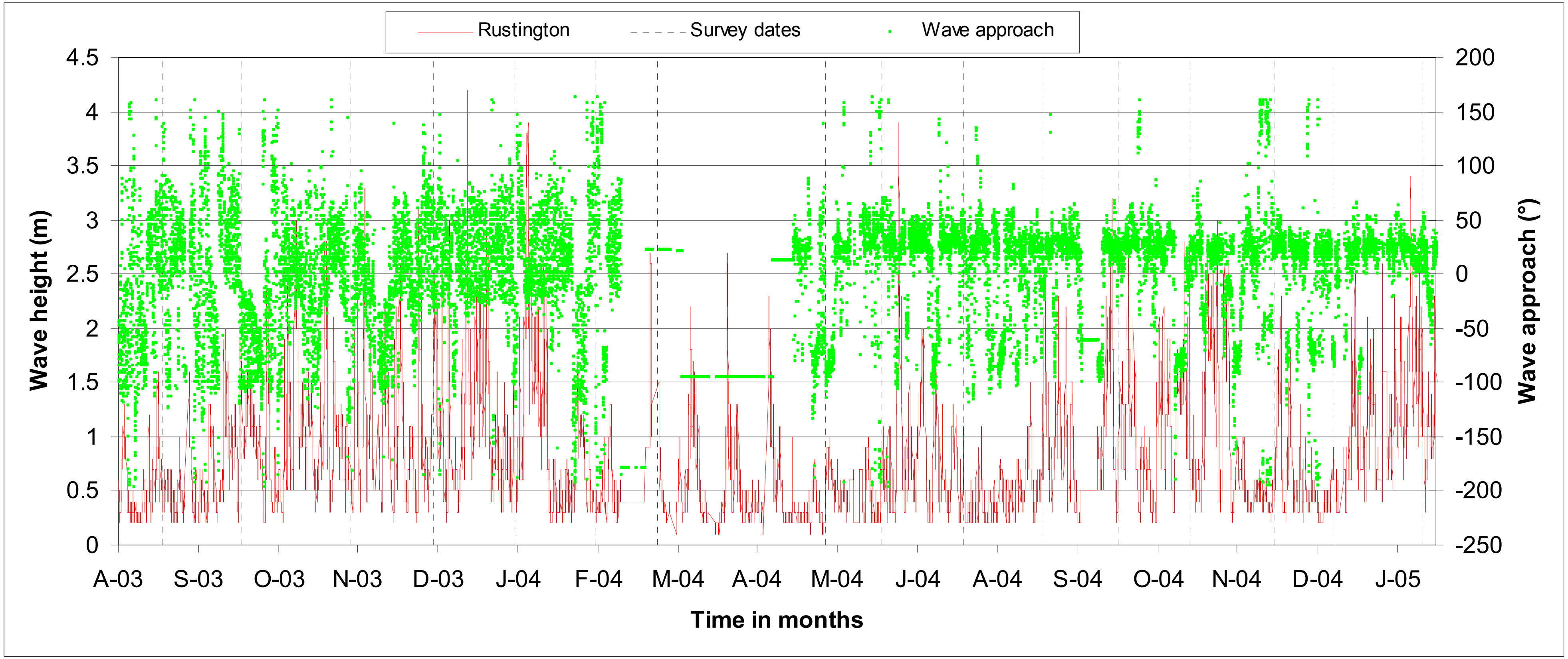


Figure 19: Wave data for the survey period from the wave buoy at Rustington. 0° wave approach would be orthogonal to beaches 3, 4 and 5. A direction of +18° would be orthogonal to beach 1, one of –20° orthogonal to beach 2 and one of –36° orthogonal to beach 6. However, offshore wave direction does not take inshore wave refraction into consideration.

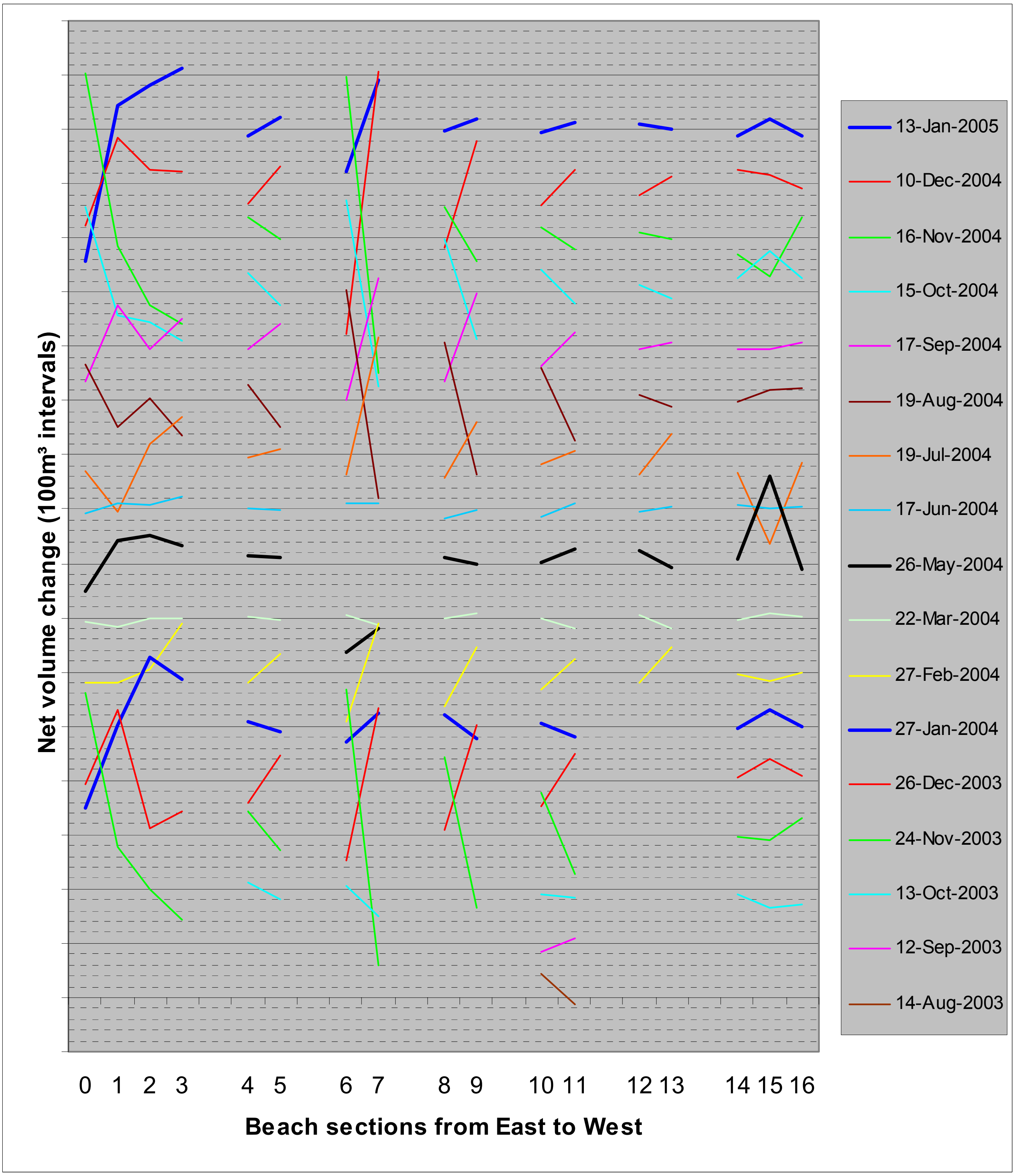


Figure 20: Net volume changes for each beach segment. For a location of the segments see **Figure 18**. Segments 14, 15 and 16 are the sandy foreshores of beach 2, 3 and 4 respectively.

6.4.3 Changes on the sandy foreshore

The analysis has so far focussed only the shingle beach, but the sandy foreshores fronting beaches 2, 3 and 4 have also been included in the surveys. The extent to which the foreshore can be surveyed depends to a large degree on tidal conditions but also on wave conditions as these determine how far into the water the surveyor can wade. From surface comparisons in **Figure 17** it is apparent, that in many cases only smaller parts could be surveyed. The gentle changes and the lateral extent, together with the general small changes in surface elevation, make it difficult to ascertain real changes in many cases. In general, surface elevation changes are less than ±10cm. The deposition of a mixture of sand and shingle next to the two groynes of beach 2 in May 2004 has left the sandy foreshore in between unaffected. Towards the end of 2004, larger changes can be seen between the surveys in September and October with accumulations of >20cm in front of all three beaches. All other changes except for those between December 2004 and January 2005, when widespread accumulation took place in front of beach 3, are too weak to be interpreted as significant changes. The small amounts of change observed could be due either to a relative stability of the geometry of the sand accumulation or to the surveys not coinciding with situations when the sand level has changed more dramatically due to the mobility of sand (see observations described in section 6.2). It is possible that changes may occur for example during a storm, but that recovery takes place in one tide and the foreshore reverts back to an equilibrium profile situation.

6.4.4 Beach states

Figure 21 shows each survey surface in the number of standard deviations from the mean surface. Comparing all surveys, there does not seem to be pattern that can be attributed to any seasonality on the beaches except on beach 1. On this beach higher than average beach levels occurred on the western half from November 2003 to January 2004 and between October 2004 and January 2005. During May 2004 to September 2004 the western half was characterised by beach levels below the average. On the remaining beaches, positional changes of the material from one side to the other or from higher up the beach to lower down on the beach occur almost on a monthly basis.

However, comparing changes between the beaches illustrates that beaches 2, 3, 4 and 5 behave very similar, displaying almost identical states on many occasion. This would indicate that beach behaviour within the range of the variation found at Saltdean (see section 6.2), is independent of groyne type (rough rock groynes and smooth concrete groynes), groyne spacing, foreshore elevation and foreshore material. Small variations in grain size (beach 2 is coarser and beach 5 is finer than beaches 3 and 4) also seem to have little influence.

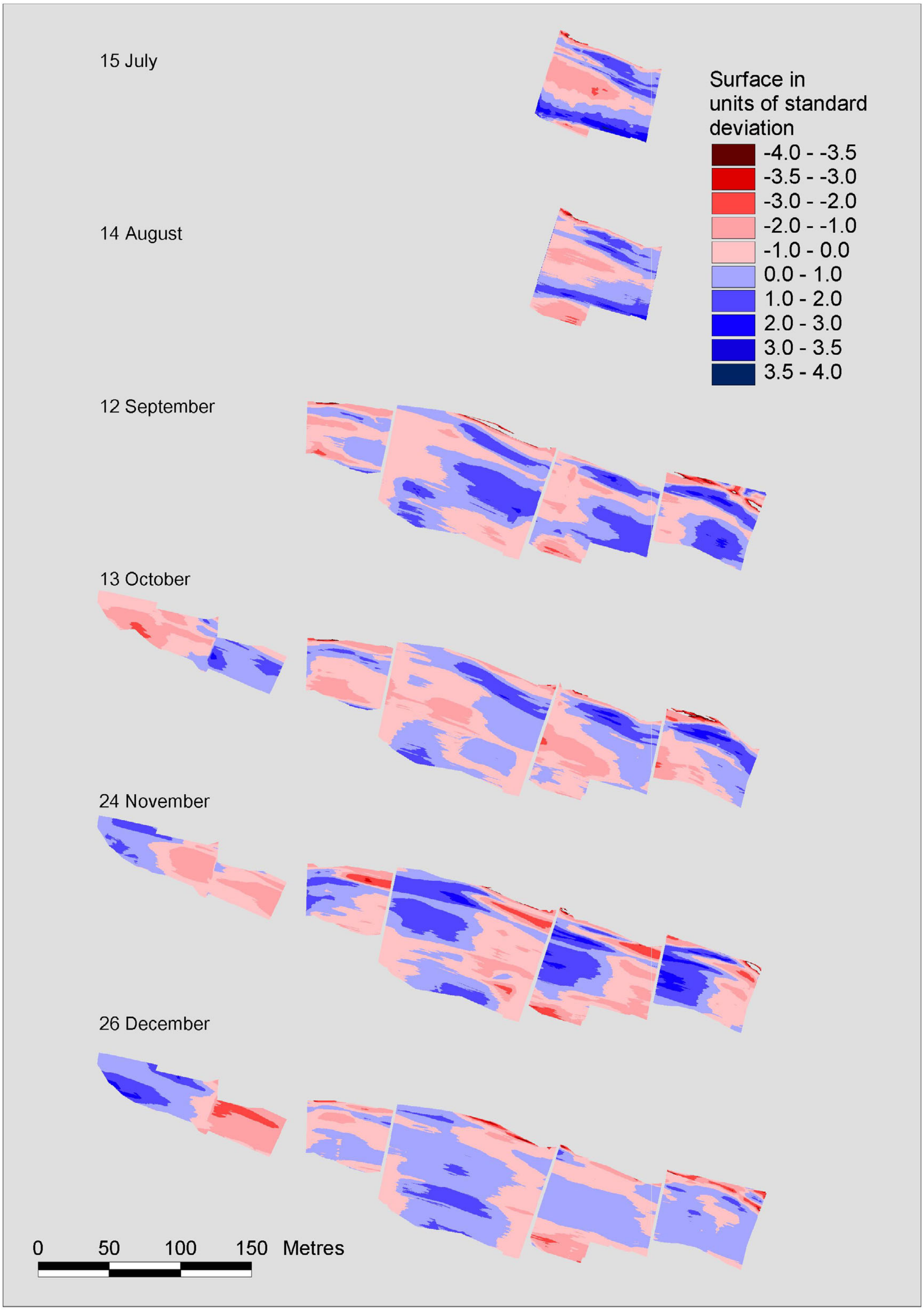


Figure 21: Surfaces of all surveys with heights expressed in standard deviations from the mean surface obtained by averaging all surveys.

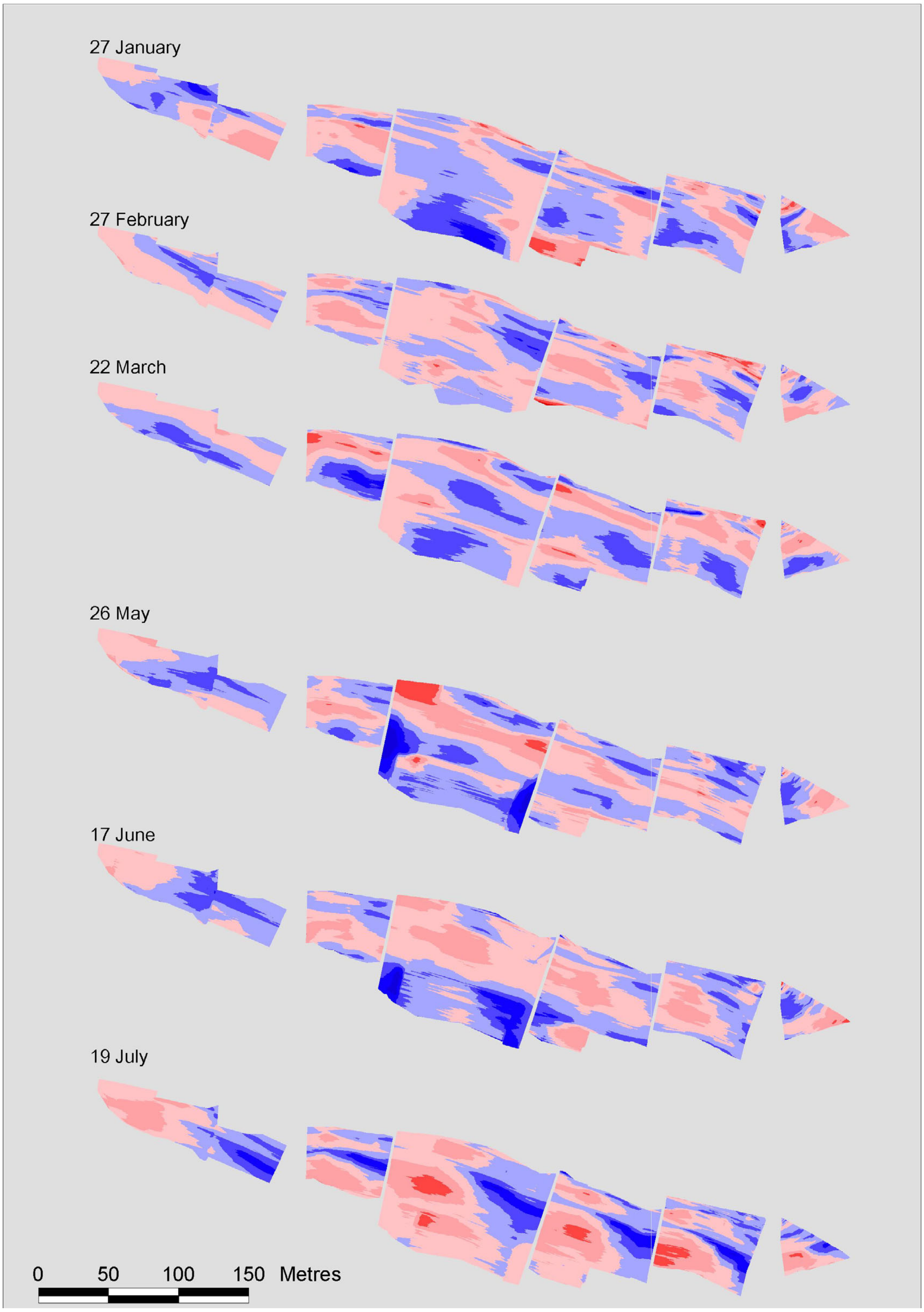


Figure 21 continued: Surfaces of all surveys with heights expressed in standard deviations from the mean surface obtained by averaging all surveys.

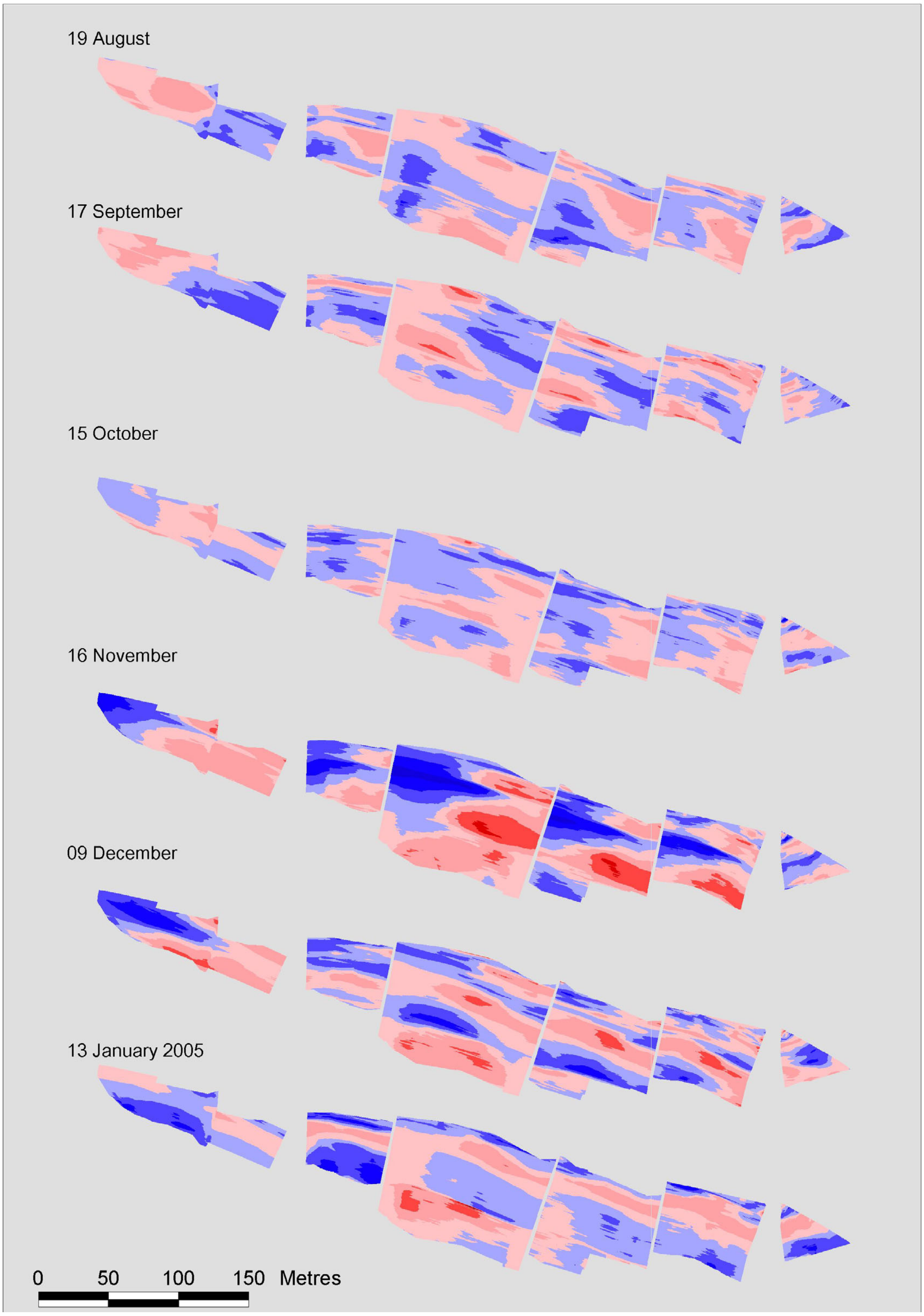


Figure 21 continued: Surfaces of all surveys with heights expressed in standard deviations from the mean surface obtained by averaging all surveys.

A comparison of specific contour lines on the beach (**Figure 22**) shows that for the mean beach topography, the lines on beaches 3 and 4 are aligned in exactly the same way. It is also evident that the beaches with concrete groynes on either side (beaches 3 and 4) seem to have straighter lines that the beaches with one boulder groyne (beaches 2 and 5). This difference in plan shape can be observed on any occasion in the field and may be attributable to the energy absorbing effect of the boulder groynes.

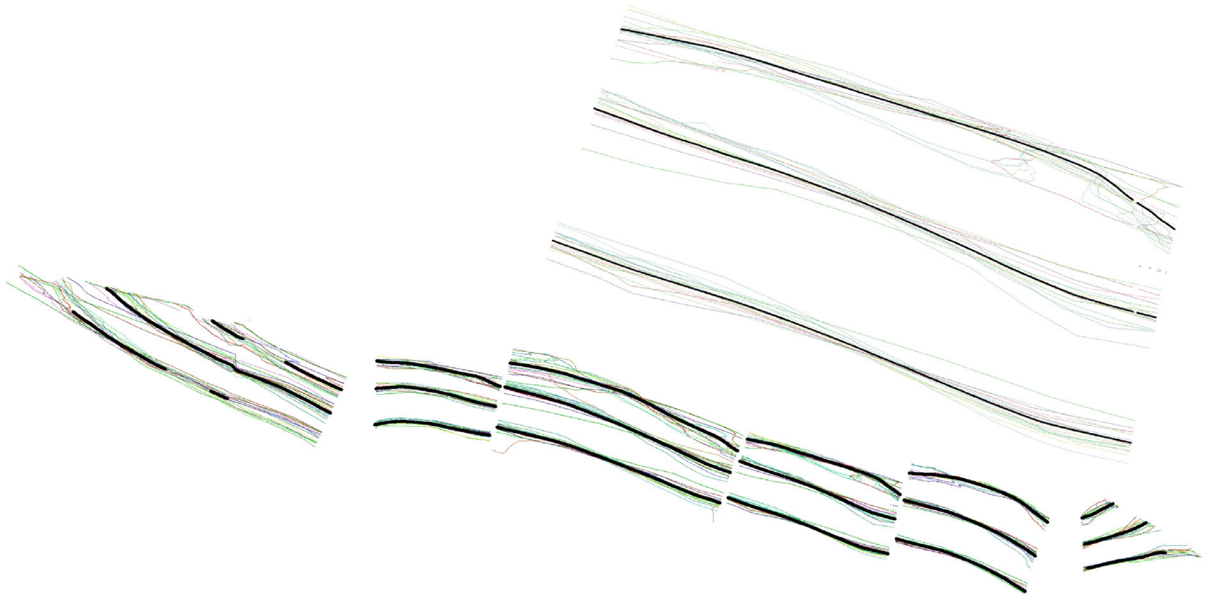


Figure 22: Variation in the position of the 0 m, 2.4 and 4.5 m lines on the beaches. Inset shows the lines on beach 4. (0 m is mean water level, 2.4 m is mean high water level and 4.5 m is approximately the storm berm face. Solid black line shows the mean position.)

Comparing the beach alignment between surveys shows that the mean high water line changes direction by less than 9° on beaches 2, 3, 4 and 5. On beaches 1 and 6 the mean and mean high water line positions diverge increasingly towards the open sides of the beaches while the position of the 4.5m line does not show a directional bias. Beach orientation and rotation has been modelled prior to recharge activity (Posford Duvivier 1993, 1997). The predicted shoreline orientation of 112° agrees very well with that measured for the beaches 3 and 3 (110°). However, the modelled amount of rotation has a range of 74° for extreme events (Posford Duvivier 1993, Table 6.4) and an average 25° is given (Posford Duvivier 1997). It would appear that the modelling has overpredicted the amount of beach rotation. This might be related to the sediment properties assumed in the calculation. The reports assume that the beach angle would be ~ 1:7, i.e. about 8°. The average angle of the beach below mean high water is shallower (5 to 7°) with the eastern parts of beaches 1 to 5 being somewhat steeper than the western parts (

Figure 23).

The slightly steeper angle on beach 2 reflects the coarser material on this beach. The steepening eastwards on beach 1 is most likely also a function of different grain sizes as the surface material is almost always coarser on the eastern than on the western side. The steepness of beach 6 again reflects the slightly coarser surface grain size.

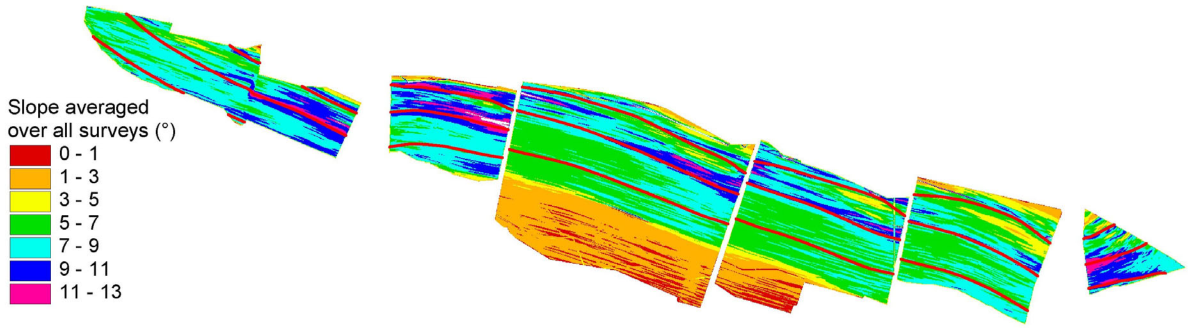


Figure 23: Average slope angle for beaches at Saltdean. (Red lines for orientation correspond to 0m, 2.4 and 4.5m OD.)

6.4.5 Discussion

Despite the restrictions between massive groynes, the beaches at Saltdean show a significant amount of movement in the longshore direction. This movement is quite frequent and does not seem to be linked to any seasonal factors except for beach 1.

Though the net elevation changes between surveys for each beach are usually small, given the area of each beach, these changes amount to up to 200m³, which is the level of accuracy with which the volume can be determined. This accuracy is insufficient to ascertain sand exchange between the mixed shingle beach and the sandy foreshore.

Groyne spacing seems to determine the magnitude of longshore variations while the groyne type (rough rock groynes and smooth concrete groynes) seems to influence the plan shape of the beach contour lines. Grain size appears to have little influence on the beach slope though this would need to be confirmed by sediment analysis other than that obtained from the surface surveys and those carried out for the beach material property report (Dornbusch, 2005).

6.5 Telscombe

The beaches at Telscombe are divided into four main sections. Section 1 is a very small part of the beach at the western end (see detached beach in northwest corner of **Figure 12**). It is usually less than 100m² in area but its volume can vary between 3 and 70m³, serving as an indicator of longshore movement. However, the size and difficulty in surveying it lying directly under the cliffs influences the results significantly and makes interpretation more difficult. Section 2 is the long main beach west of the sewage outfall groyne (

Figure 9). It is unlikely that beach material can travel eastwards around the groyne which makes the beach a semi-closed system. The groyne and sewage outfall provides some shelter from easterly waves. Section 3 lies between the sewage outfall groyne and the eastern groyne. It is backed by a seawall and forms a closed system as material is unlikely to pass around the groynes on either side. Section 4 is the eastern part where the cliffs form an embayment. This part of the coast has retreated rapidly in the past but no retreat has been observed during the survey period. Beach material could move eastwards around the small headland but also material could enter from the east making the beach a semi-closed system. The beach is extremely shallow (quite often the chalk shore platform can be seen when the beach has undergone lateral movement) with an average depth of only 36cm.

6.5.1 Total volume

Figure 24 shows the volume variations for the four sections and the total. Changes are small and within the survey accuracy (**Figure 25**), especially following the first three surveys after which the surveying method has become much more stable. Section 4 is the only one that shows larger fluctuations that may actually represent gains and losses in a longshore direction. However, because the beach is so shallow, total volume is influenced more by the accuracy of the subsurface.

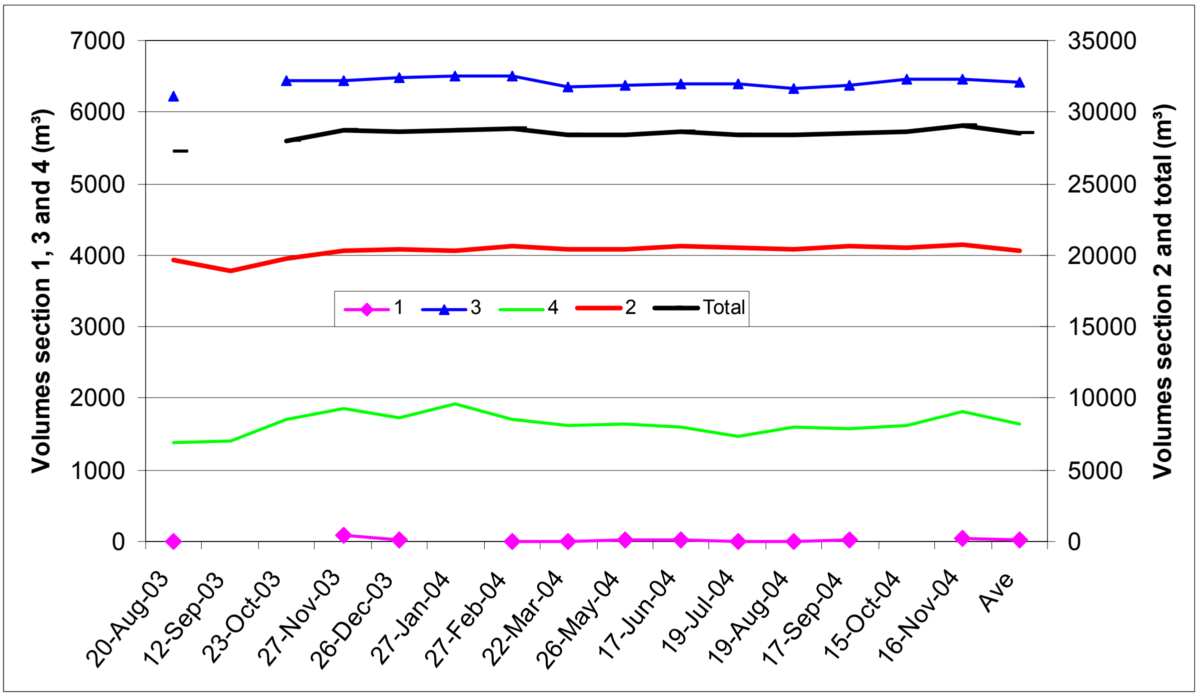


Figure 24: Volumes calculated from each survey for each of the four beach sections and the total.

Figure 25 shows the average volumes for each beach section together with the standard deviation as a volume, a percentage of the total volume and as an elevation difference for each beach section. The highest variation is in section 1 where a small amount of material exists on average that can also disappear. This section is also most difficult to survey and part of the large variation results from this. Section 2 and 3 show similar variations of the volume by 1 to 3% which equates to surface differences of ±2 to ±4 cm. The figures compare well with those obtained at Saltdean. Due to the shallowness of section 4 the accuracy of the underlying subsurface has a large influence and therefore the volume can vary by 10% though the change in surface elevation is in the range of that for section 3 and 4. However, Section 4 is the only one where a gain or loss of material to / in a longshore direction (from the east) is feasible so that larger volume changes could be attributed to actual gains and losses.

For the following comparison between surfaces these figures provide a threshold from which surface changes can be attributed to actual changes rather than to errors introduced from the surveying or surface interpolation processes.

	Volume Ø (m^3)	Volume Stdev (m^3)	Stdev in %	Stdev Height (m)
1	19.67709	22.16581	112.6478	0.259749
2	20286.55	491.8957	2.424738	0.039141
3	6406.711	75.14217	1.172866	0.018573
4	1644.775	153.9242	9.358373	0.032813
Total	28470.46	436.4703	1.533064	0.020683

Figure 25: Table of average shingle volume, standard deviation of the volume and the standard deviation converted into percentage and elevation difference.

6.5.2 Net changes and transport rates

Figure 26 shows the net change over time for each cell. To allow a better comparison, each survey is offset by 500m³ upwards on the y axis. The surveys covering August 2003 to November 2004 indicate that longshore transport is not predominantly in one direction. Some of the largest transport events (e.g. November 2003 and 2004) involve westward transport. Comparison of surveys from October 2003 and 2004 (**Figure 27**) show that, over one year, the three beaches have different net-transport patterns. The western beach shows a net transport westwards and the central and eastern beach shows a net transport in an easterly direction, indicating that average annual longshore transport is small.

To assess the forcing factors that lead to the changes in observed in the monthly surveys **Figure 28** shows wave heights and wave approach. Wave heights are from the Telscombe wave recorder that best represents the waves that actually impact on the beach. Where this data is not available the wave height from the Rustington buoy may be used. Wave approach is based on the wave direction data at the Rustington buoy and modified to the orientation of the beaches at Telscombe. Waves approaching from 210° should not have any longshore transport effect and so wave approach in Figure 28 is negative if waves have approached from east of 210° and positive if from west of 210°. However, as the recorder at Rustington is off shore, wave directions are likely to have been modified by shoaling which will, in most cases, have reduced the angle of approach. The general direction is unlikely to have been modified though this is possible because the shore platform in front of the western beach dips eastwards which could refract waves from westerly approach to an easterly.

Because surveys are carried out at spring tide at one month intervals, the waves most likely to have a major impact on the beach shape are those immediately following and preceding surveys plus those halfway between as these will coincide with another spring tide.

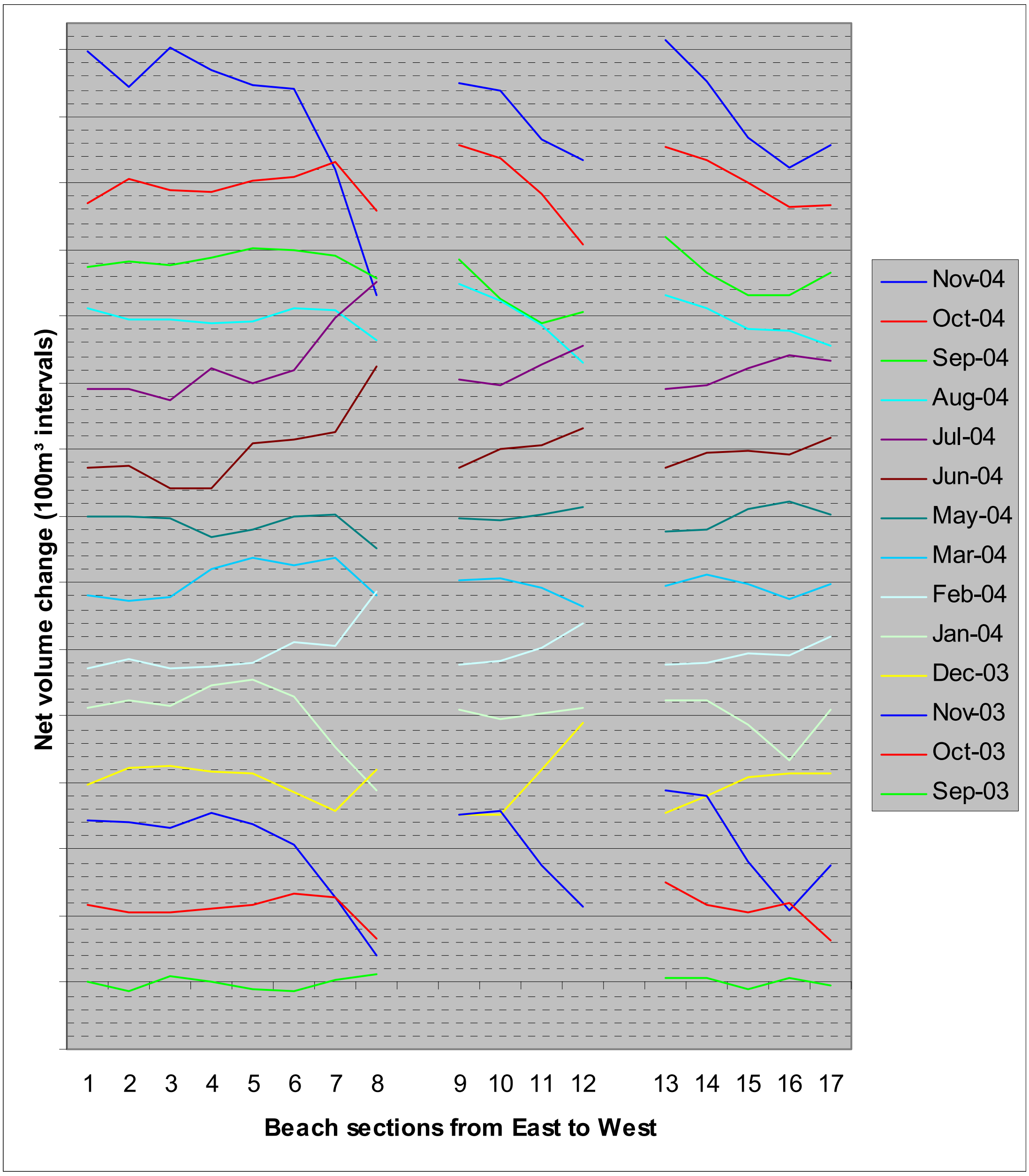


Figure 26: Net change for each cell between two surveys. Legend gives the month of the later of the two surveys. Colour scheme for the surveys is the same for the same months to allow inter-annual comparison. Net changes are shown as positive if above the solid line and negative if below. From the distribution and magnitude of positive (accretion) and negative (erosion) changes transport direction and rate may be calculated. The middle beach (sections 9-12) has not been surveyed in August and September 2004

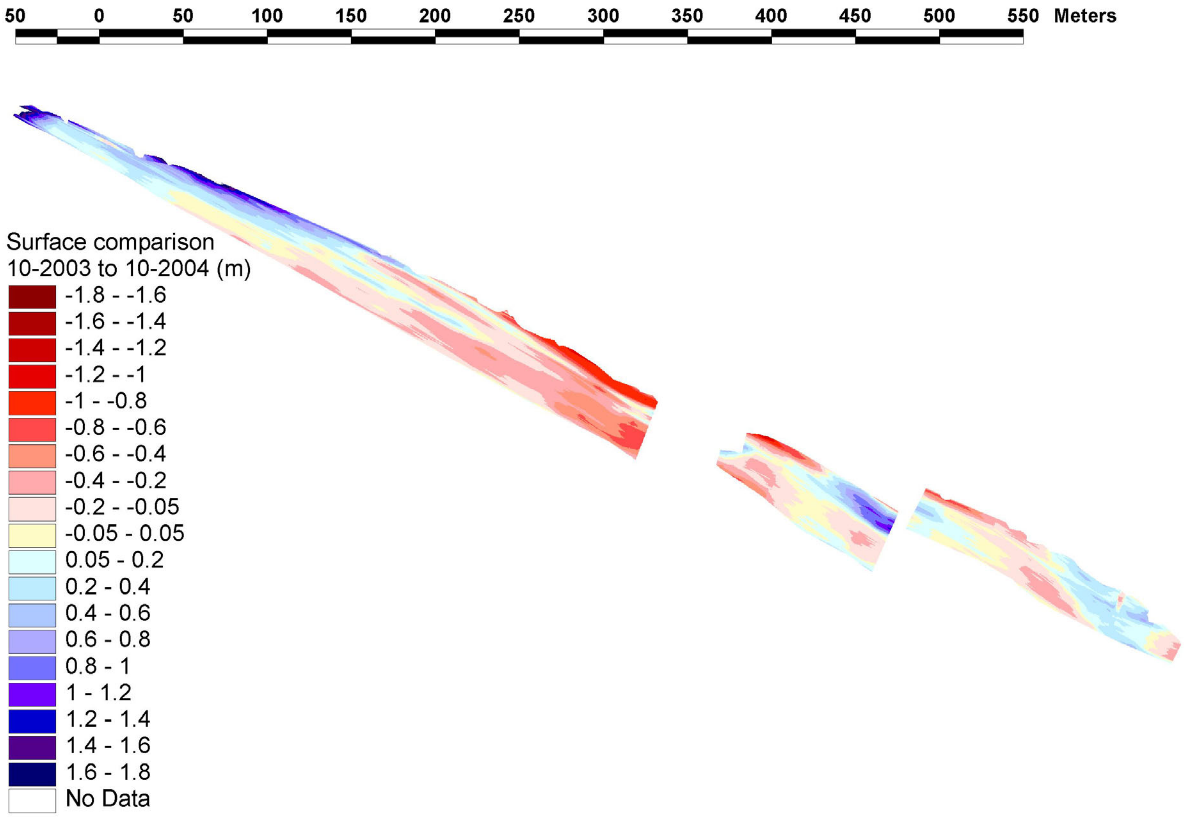


Figure 27: Comparison between surveys carried out in October 2003 and 2004

The period prior to October 2003 saw easterly waves approached during neap tides coinciding with small waves that nevertheless lead to some westward transport of material. Higher waves with an easterly component just prior to the survey in November lead to an increase in westward transport and lead to some severe erosion close to the eastern groynes of the western and central beach. In the period prior to the survey in December, wave heights were moderate and predominantly at right angles to the beach resulting in very little longshore transport, though the central beach shows significantly more westward movement than the eastern and western beach which is likely to reflect differences in local shoaling of the waves. Between the December and January surveys, and coinciding with spring tide, relatively high waves occurred but again with no clear directional bias leading again to a mixed reaction of the beaches. The western beach showed substantial westward transport, the eastern beach some westward transport and the central beach no transport. The changes to the central beach in the preceding month may have changed the beach planform so that it was no longer susceptible to westerly transport. High waves with no clear directional preference following the January survey lead to some eastward movement again. The changes from March to May (the April survey was flawed) show little difference which have proved difficult to interpret as directional wave data from the Rustington buoy is not available for this period. The Telscombe recorder, however, shows only very little wave activity.

The second half of the year shows a dominance of waves approaching from westerly directions which is reflected in the eastward transport observed on all beaches in the June and July surveys. Between these surveys high waves occurred during the intervening spring tide.

The August and September surveys show mixed changes on the three beaches with westward transport on the central and eastern beach and slight eastward transport on the western beach. Waves were coming slightly from a western direction so that local refraction is likely to be accountable for the different magnitudes. Although the October survey was preceded by relatively high waves with a significant easterly component only the central and eastern beach show an appropriate reaction with significant westward transport. The magnitude for the wave approach and wave height is likely to have been severely influenced by the sewage outfall east of the eastern beach so that it resulted in very little transport. Waves with a lesser easterly component but similar wave height during the springtide in November seem to have been much better suited to induced severe easterly transport on all beaches. Calculated monthly transport rates have reached up to 1700 m³ (east beach between October and November 2004) and are in the order of 400 to 800 m² for the more moderate events.

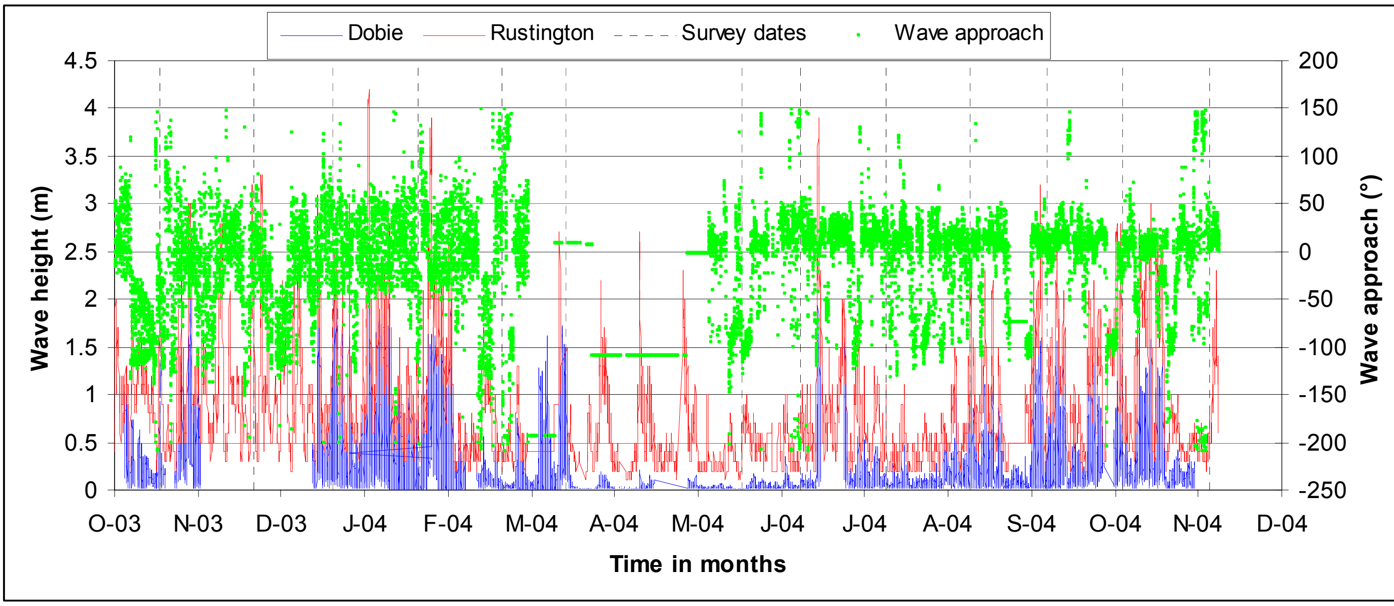


Figure 28: Wave data for the survey period (from the wave recorder at Telscombe and the wave buoy at Rustington).

6.5.3 Beach states

Figure 29A shows the standard deviation resulting from the surfaces of 14 surveys and **Figure 29**B the standard deviation resulting from surveys October 2003 to November 2004. Broadly, all three beaches show a similar pattern with the lowest values (i.e. the lowest variation in surface height between surfaces) towards the centre of the beach. This is indicative of a 'transport' zone where material is moved through without significant surface change taking place. The sides of beach are the places where material is accumulated and eroded by longshore transport and the amount of change increases up the beach in response to higher waves involved with more severe transport. While the western and eastern beach show some symmetry in the distribution of areas with higher values, the central beach shows a distinct asymmetry (**Figure 29**A). This is due to the fact that the central beach was not surveyed during the first two surveys and if these are excluded, the symmetry exists also on the central beach. The influence in the reduction of surveys considered has only limited impact on the east and west beach which would indicate that the number of surveys carried out does provide some statistically robust results.

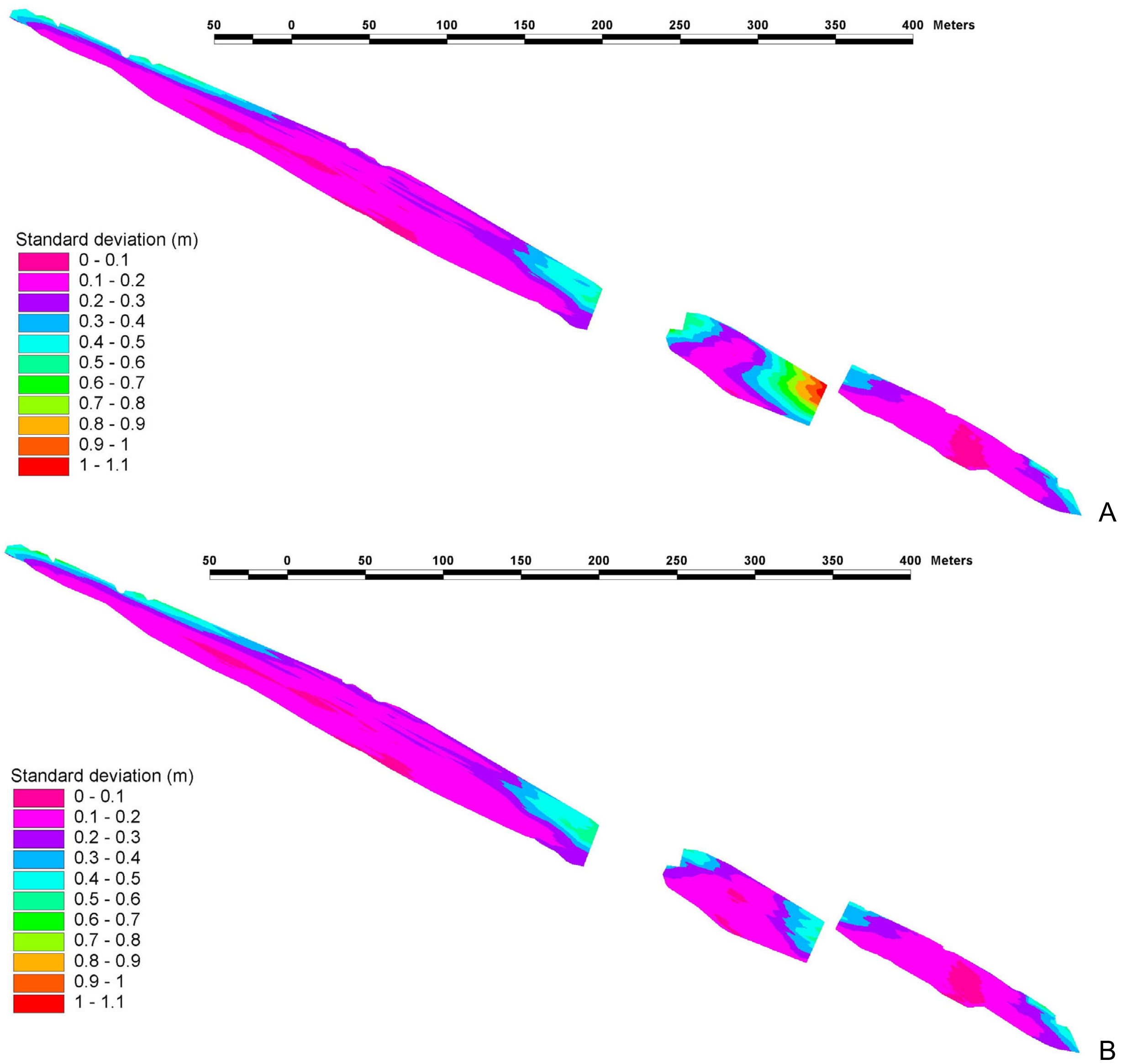


Figure 29: Standard deviation surface based on A) all 14 surveys and B) on the surveys October 2003 to November 2004 excluding surveys were the central beach had not been surveyed.

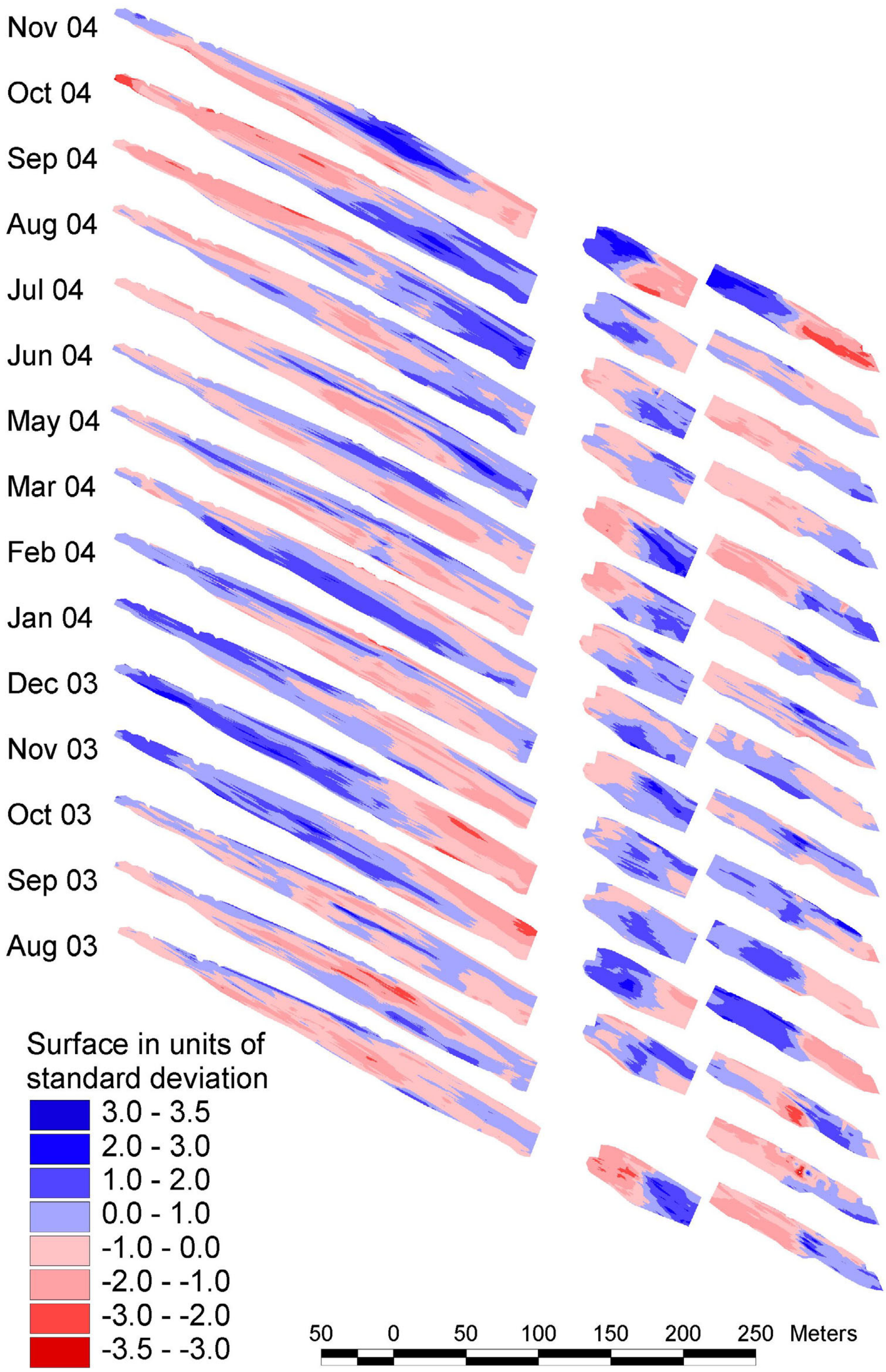


Figure 30a: Surfaces of all surveys with heights expressed in standard deviations (based on 11 surveys) from the average surface of 14 surveys.

Figure 30a shows all surveyed surfaces in units of standard deviation (**Figure 29**) from the average surface. Because the surveys cover only 15 months it is impossible to identify with any certainty patterns, at this stage in the work programme, that are linked to seasonality particularly because all three beaches do not necessarily show the same patterns.However, it would appear that the months November to March are characterized by higher than average beach levels in the western part of the beaches and lower than average levels in the eastern parts. This distribution appears to shift during the summer months to higher than average levels in the east and lower levels in the west. The pattern is best seen on the west and east beach and is less apparent on the central beach.

The average slope angle for the beach below mean high water is very similar to that at Saldean with 5-7° (Figure 30b). A steeper angle on the eastern side of the west beach is in line with frequent observations large pebbles being found on the surface close to the groyne. The slope above mean high water increases on the western and central beach but not on the eastern beach, most likely due to much finer sediment or the shallowness of the beach.

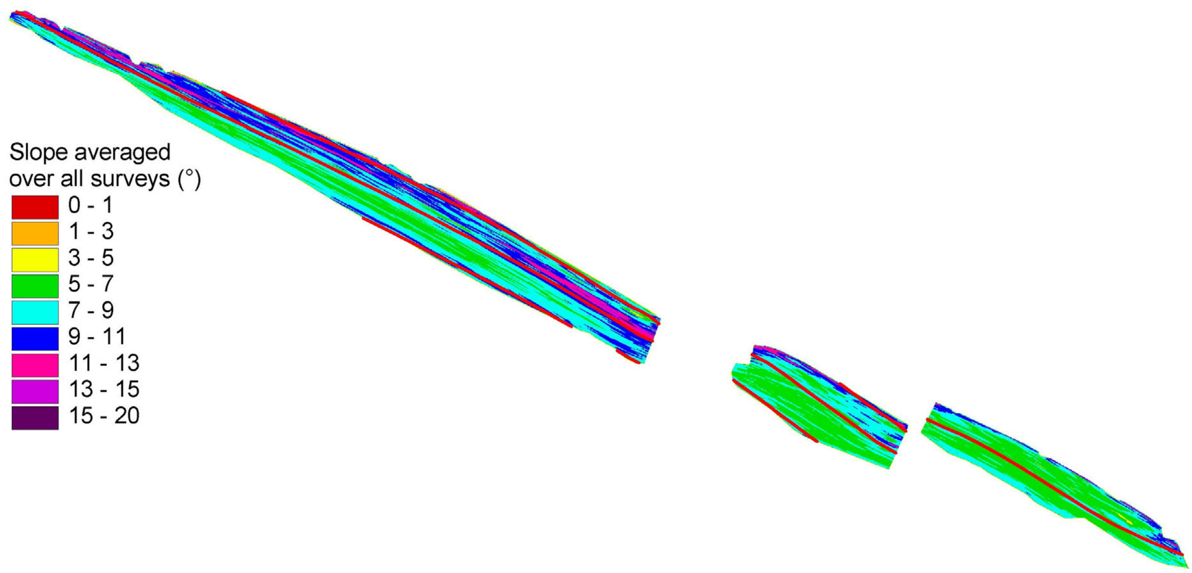


Figure 30b: Average slope angle for beaches at Telscombe. Red lines for orientation correspond to 0m, 2.4 and 4.5 m OD.

6.5.4 Discussion

The three Telscombe beaches show variations in behaviour whose explanation needs further exploration and which is most likely to be controlled by the nearshore bathymetry and resulting shoaling patterns. The fact that the beaches are quite different with regard to grain size and depth (particularly between the western and eastern beach) does not appear to cause widely diverging patterns of response to the same wave action.

To analyse seasonal trends it is necessary to cover at least 2 full years of surveys, an opportunity that will be provided in BAR Phase 2.

6.6 Cuckmere Haven

Cuckmere Haven is the most complex and largest beach system investigated because of the interaction between the beaches, the Cuckmere Channel and the delta that covers large parts of the bay at low tide. In addition, the western beach is influenced by management activity (recharge) that takes its material from the Channel and the delta. Due to the size of the delta, it is surveyed at a much lower density and coverage has been variable over the year. Because of the size of the system and its degree of openness, no volume calculations have been carried out and interpolation error and values for this are taken from the other beaches. However, the combined error is likely to be larger in the delta area due to the spacing of survey lines and the sometimes quite rough surface topography (the lower parts often feature cobble size material on the surface). An error assumption of ±10cm is reasonable.

Figure 31shows the average height based on 14 beaches. Material on the western beach is accumulated predominantly against the western side of groynes indicating average eastward transport on this beach.

Figure 31 also shows that there is constant accumulation in the western, and to a lesser extent, in the eastern part of the Cuckmere channel.

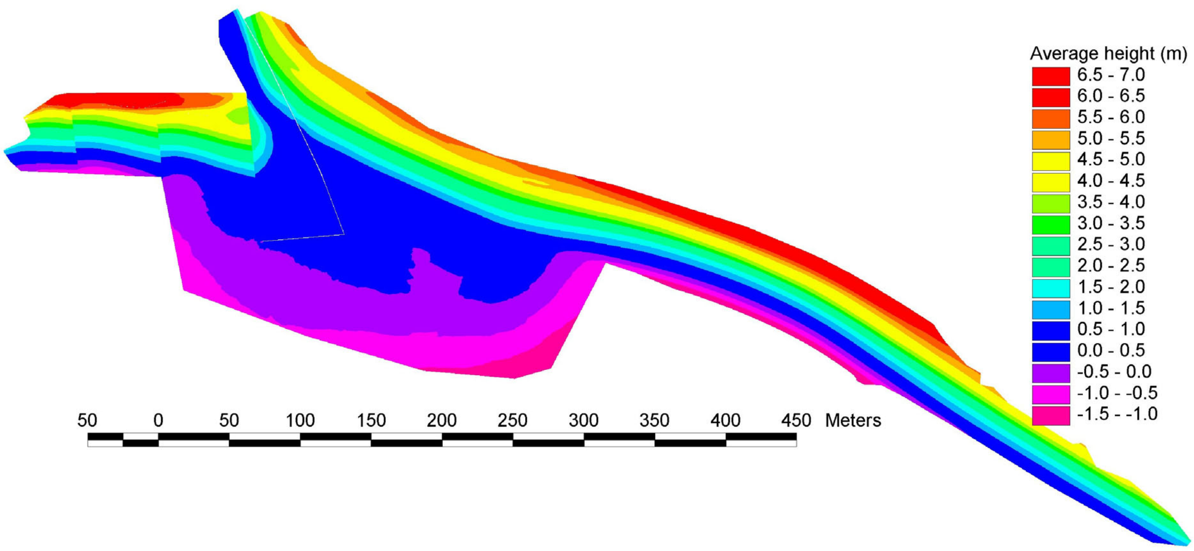


Figure 31: Average topography (14 surveys).

6.6.1 Net changes and transport rates

Figure 32 gives an illustration of the changes measured. To a large extent changes at Cuckmere Haven involve cross-shore profile changes which often mask net changes for different parts of the beach. The net change for the same two surveys is shown in

Figure 33. Volume change in the range of ±100 m³ for beach and channel segments are within the error range and therefore no change may actually have occurred. For the delta area, the error margin needs to be increased to ±400 m³ due to the higher uncertainties in relation to survey density. Consequently the only delta area that shows a true change is the central part (number 26) with an accumulation of almost 1200 m³, mainly in the ramp shaped accumulation at the southern end.

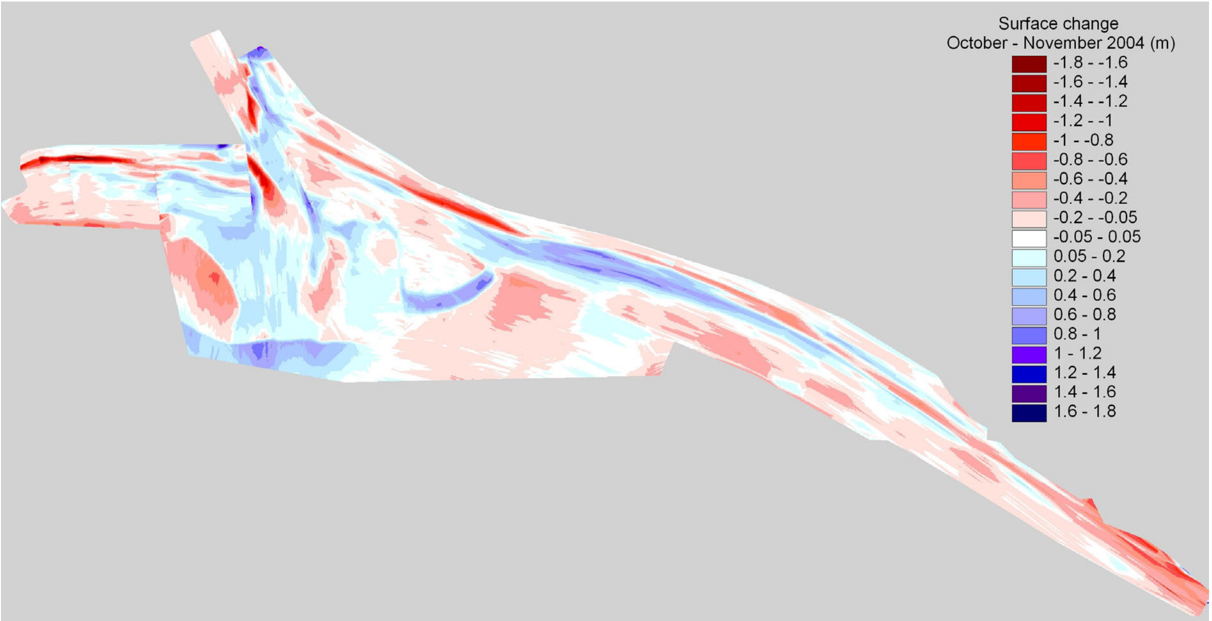


Figure 32: Comparison between surveys carried out in October 2004 and November 2004

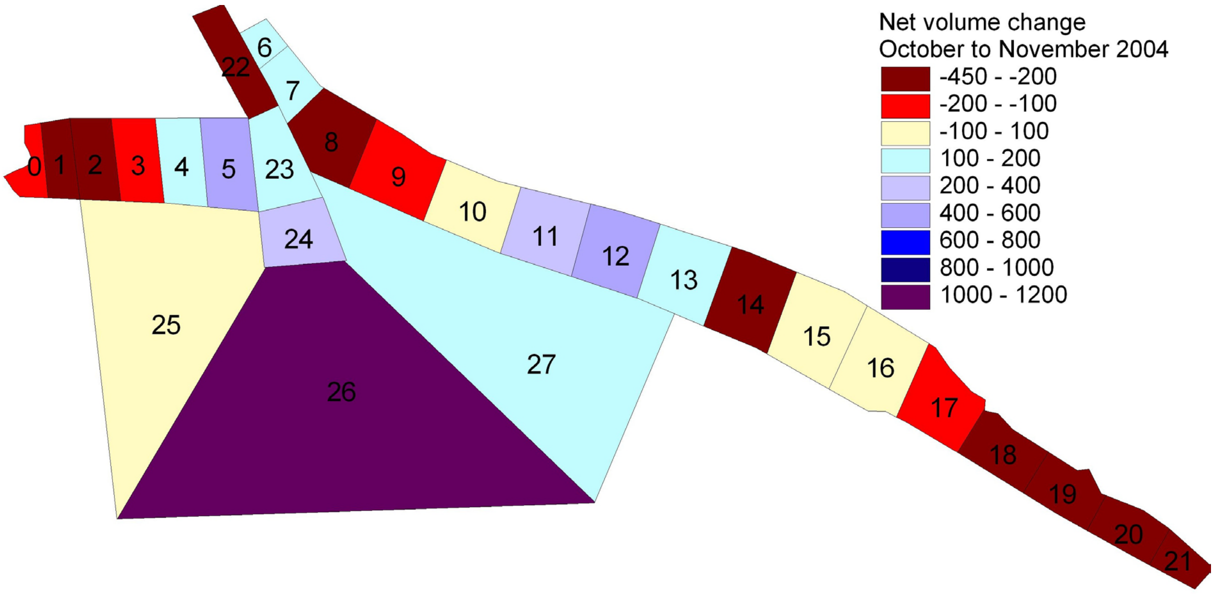


Figure 33: Map shows the net volume change (m³) for beach segments between surveys, October - November 2004. Numbers refer to those in

Figure 34. The western beach comprises numbers 0 to 5, the eastern beach numbers 6 to 21, the Cuckmere channel number 22-24 and the delta number 25 to 27.

The net transport shown in

Figure 34 is dominated by a management event between January and February 2004. While October 2003 saw little change in the beach material distribution, November shows easterly transport on the western beach (cells 0-5) but westerly transport on the eastern beach (cells 6 to 21). This transport towards the Cuckmere channel leads to a volume increase in the channel (cells 22 to 24) with some material being pushed onto the western and central part of the delta (cells 25 and 26). The same longshore transport pattern occurs up to the survey in January 2004 with net erosion from the western beach, westerly transport on the eastern beach leading to more accumulation in the channel and the western and central parts of the delta. The transport pattern on the eastern beach is similar to that observed on Telscombe beach.

The beach material recycling prior to the February survey added more than 7,000m³ to the western beach, taking the material mainly from the central and southern part of the channel and the western and central part of the delta. During the same interval, the eastern beach showed predominantly eastward transport but westward transport in its western part. This transport split on the eastern beach can be seen in almost any survey in 2004, indicating that the regional wave direction (illustrated in **Figure 28**) is strongly modified in relation to the topography of the delta. The local foreshore topography is depicted in

Figure 31 where it is shown that the beach toe (and consequently the foreshore) is lowest in sections 13 to 16. From section 17 eastward, the foreshore is composed of chalk shore platform and is higher. This is also reflected in the general beach planform of the eastern beach that shows the most landward bend behind the lowest part of the foreshore which would facilitate a longshore transport divide in the centre of the beach.

March shows some eastward transport on both the western and eastern beach, but the western beach is dominated by net loss that again enters the Cuckmere channel. April to June show little transport following the generally quiet wave conditions in summer.

Eastward transport characterises the eastern beach but westward transport the western beach in July. Material from the central part of the eastern beach (cells 10 to 13) is removed in July and September with transport into these sectors again in October and November.

The survey in December shows little change on the beaches but the delta area loses material that is pressed into the Channel. Following storms and rainfall events before the January 2005 survey the west beach shows some further erosion and displacement of beach material from the centre of the east beach to either side has occurred. The most significant change is the movement of >1500 m³ into sector 24, effectively blocking the Cuckmere Channel resulting in beach recycling being carried out again in the second half of January 2005.

Transport rates are quite comparable with those found at Telscombe, however, the more complex pattern makes it difficult to identify the transport direction and the magnitude may also be influenced by net transport from the beach to either the Cuckmere channel or the delta.

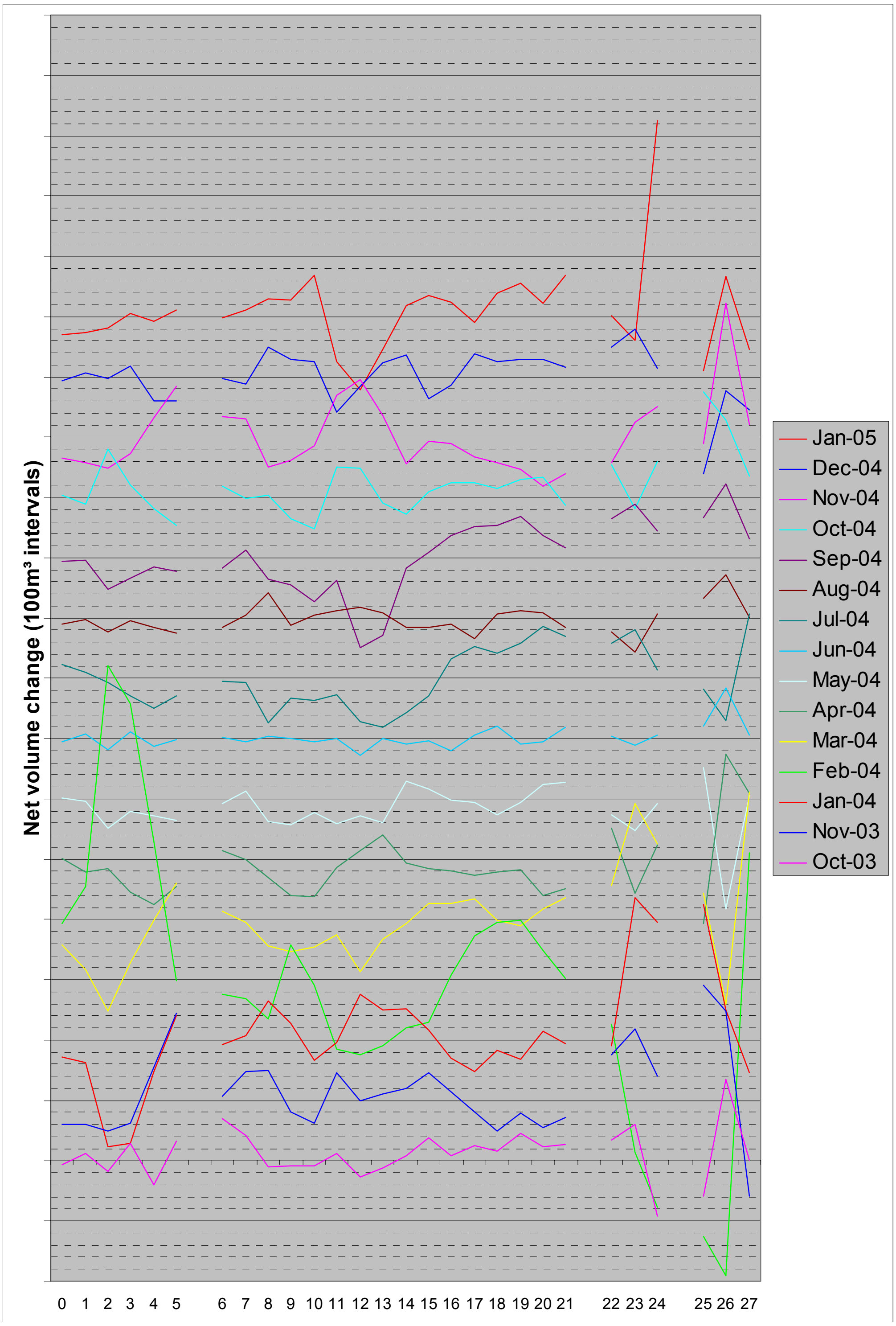


Figure 34: Net change for each cell between two surveys. Legend gives the month of the later of the two surveys. Net changes are shown as positive if above the solid line and negative if below. Section numbers correspond to those in

Figure 33.

6.6.2 Beach states

The standard deviation map (**Figure 35**[1]) shows a rather different picture from that for Telscombe. There are no clear areas of higher values at the eastern and western side indicating an 'oscillating' beach, however, the larger values are found higher up on the beach, as at Telscombe. The pattern instead shows higher values in the central compartment of the western beach, in the Cuckmere Channel and in the central and eastern part or the eastern beach. In addition, areas of the delta exhibit quite large values. Small values for the standard deviation are found between the central and eastern part of the eastern beach and indicate an area where mainly transport occurs. Given that the overall pattern is more complex, the surface elevation expressed in units of the standard deviation from the mean surface shows some clear patterns (**Figure 36**). The best-developed feature seems to be the higher than average surface in the eastern half of the eastern beach from July to November 2004, which is a feature that was also observed at Telscombe.

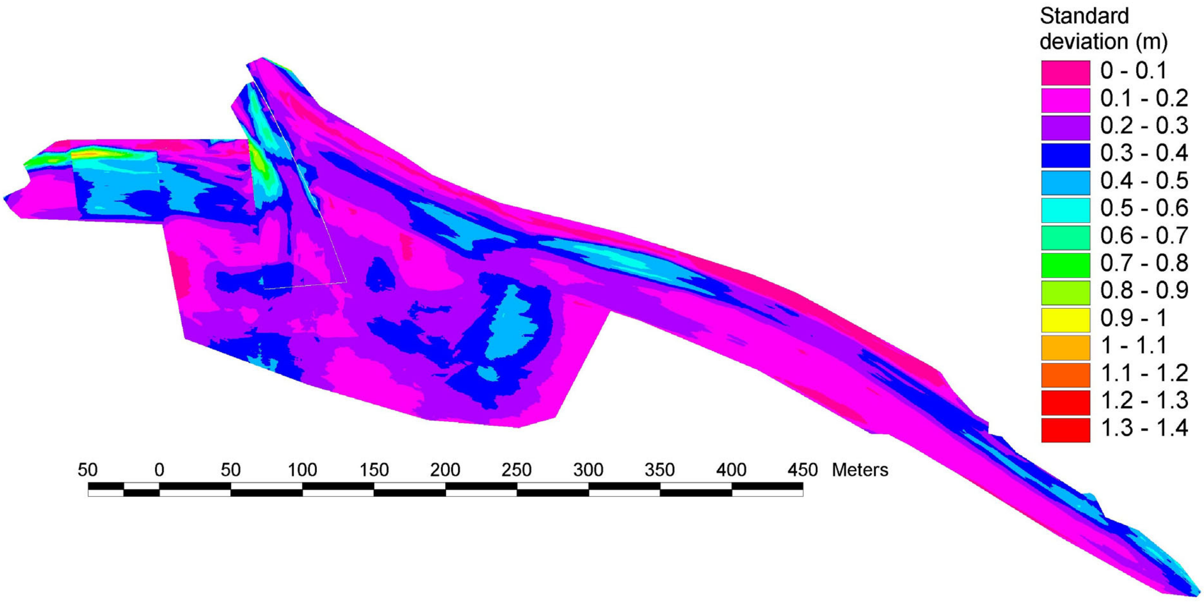


Figure 35: Standard deviation based on 14 surveys.

[1] Though section 6.6.1 has bee updated with the survey in December and January, recalculation of the parameters for beach states was not carried out and so only deals with the surveys carried out until November 2004.

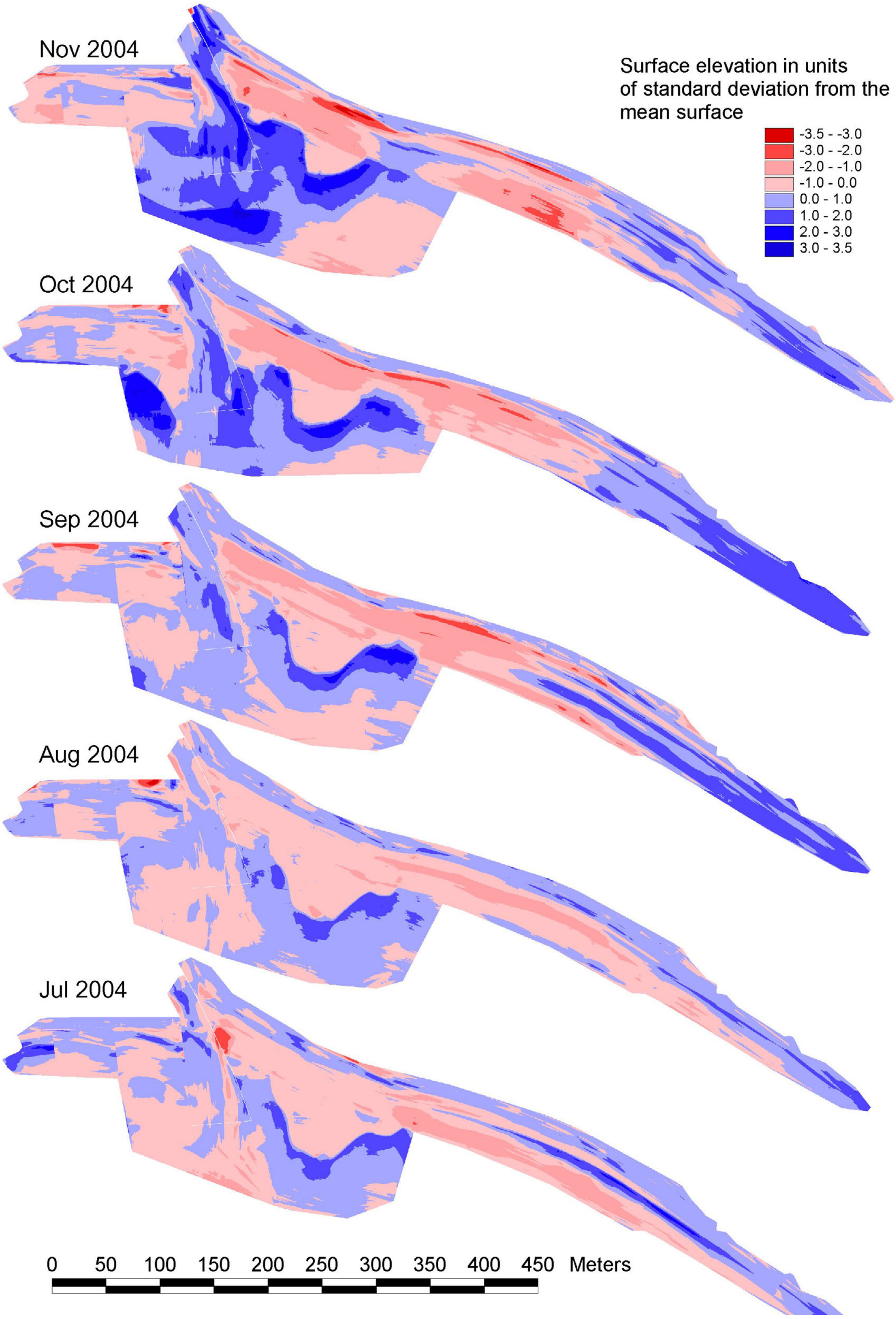


Figure 36: Deviation of surveyed beach surface from the mean surface expressed in units of standard deviation.

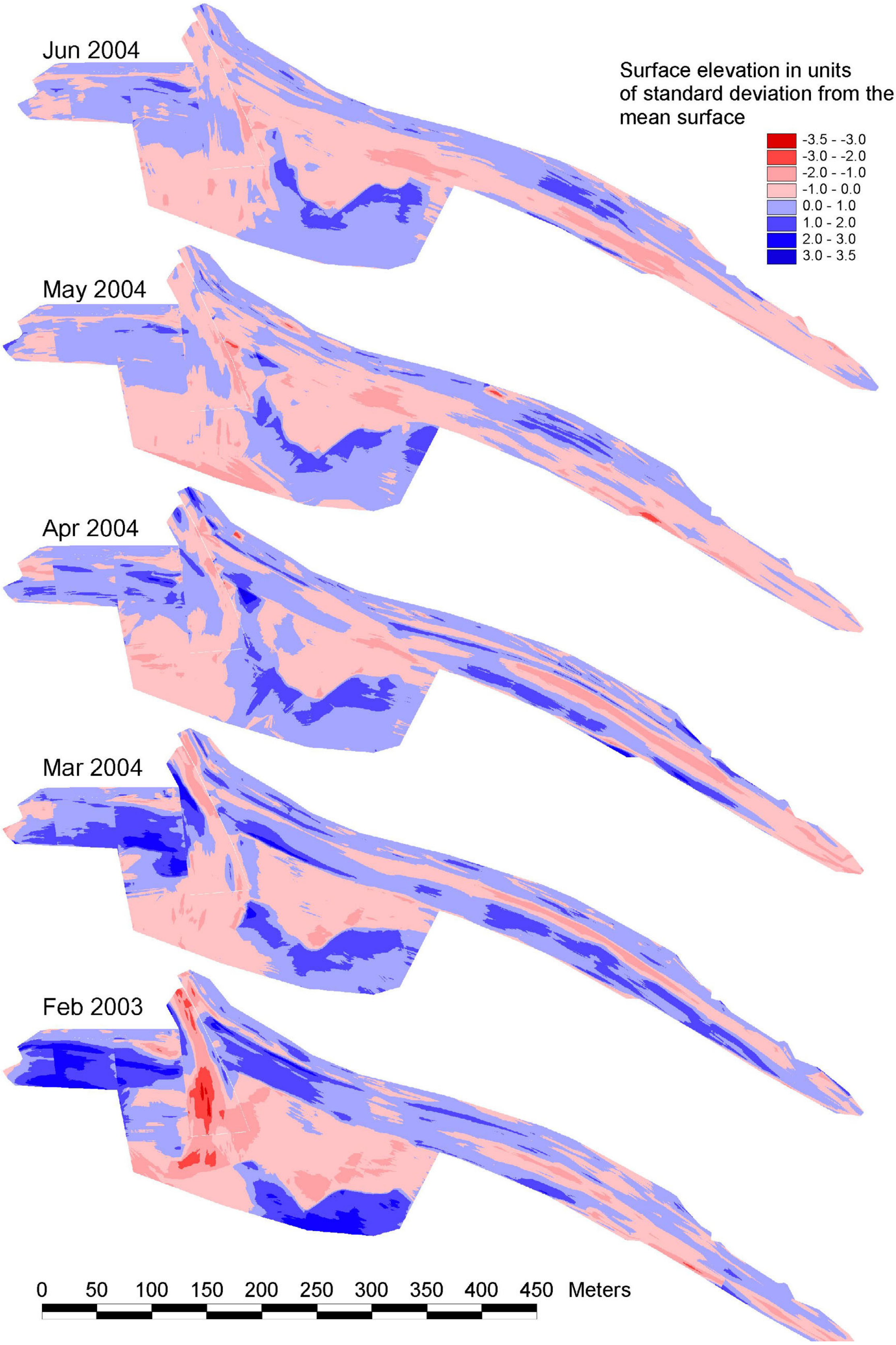


Figure 36 continued.

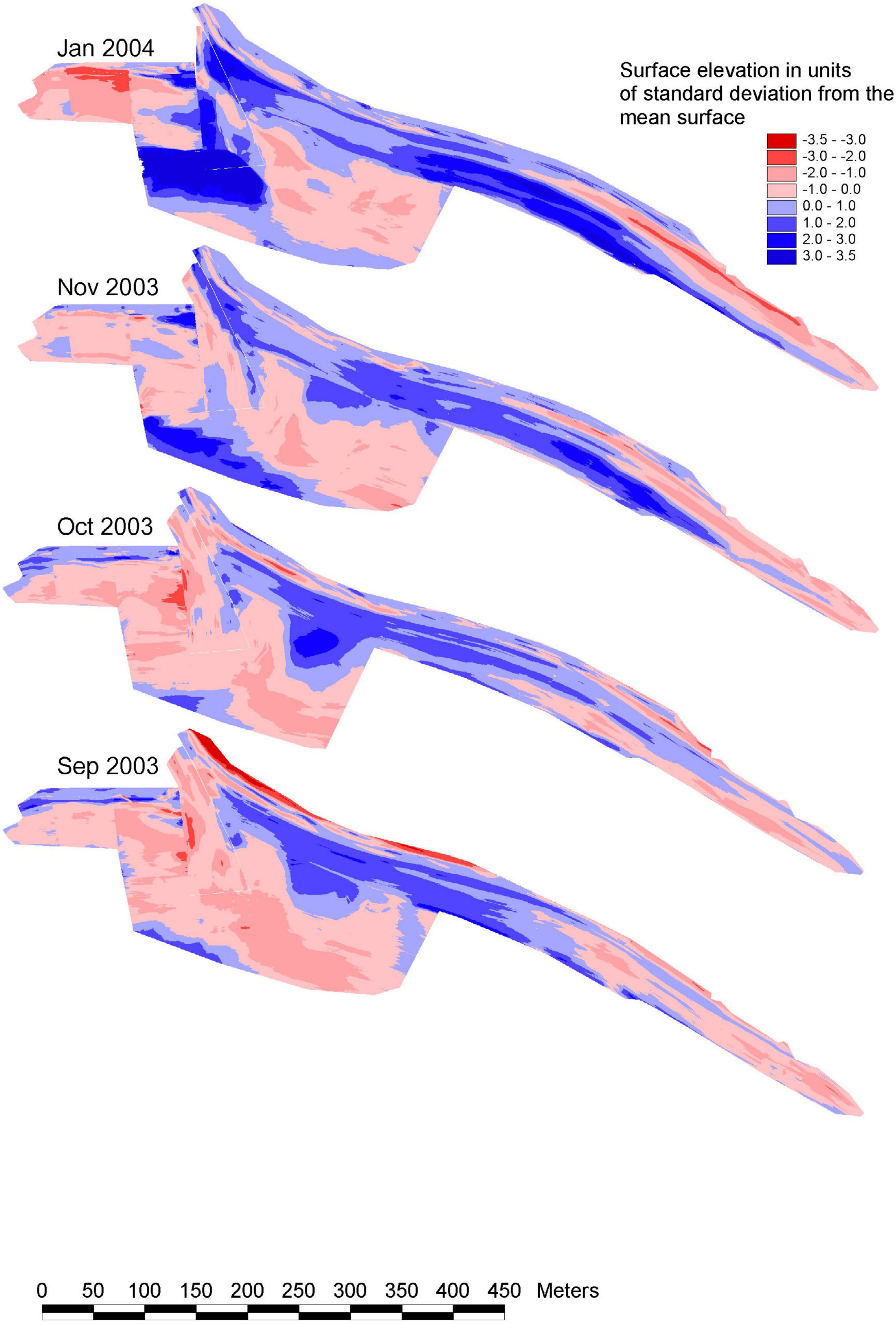


Figure 36 continued.

This pattern is not repeated on the managed western beach where increasing erosion occurs from September to January. Recycling of material from the Cuckmere channel and the delta leads to much higher than average beach levels in February which in turn are eroded to the average level by May. The west beach as a whole falls below the average level again in November 2004 so that another intervention can be expected in the winter 2004/2005. However, most interesting are the surface changes in the Cuckmere Channel and Delta area. The channel and delta show lower than average levels in September 2003 with most of the material on the western part of the eastern beach. This material is moved westward until January leading to rising levels in the channel and the western delta. This delta accumulation seems to have been the main source for the recycling onto the western beach with some contributions from dredging of the channel. From February to November onshore movement (north-westward) of material can be observed on the eastern part of the delta. The accumulation has the form of a fan with a gentle south facing side and a steep north facing side that enclosed a depression that was water filled at low tide from March onwards. The movement towards the channel mouth together with erosion of the western beach and the western part of the eastern beach has led by October to a significant elevation in the channel and delta area that seems more severe that in January, again making and intervention more likely.
Shingle material is exchanged between the beaches and the 'offshore' / intertidal area. Continuing topographic surveys should include the delta at more detail and possibly to a larger extent. Because the intertidal area is changing significantly in elevation, this has implications for wave refraction and shoaling which in consequence will influence the behaviour of the beach. The changing delta elevations are therefore the most likely explanation as to why the standard deviation map shows a more complicated pattern than at Telscombe, where the intertidal shore platform remains at a constant level.

Similar to Saltdean and Telscombe, beach slope below mean high water is between 5 and 7° with a slight steepening towards the centre of the eastern beach (**Figure 37**). The steeper slopes above mean high water are best developed east of the influence of the delta with particularly steep angles where the beach toe is deepest. Due to the unmanaged nature of the eastern beach, a secondary storm berm above 4.5 m is developed in the central part of the eastern beach.

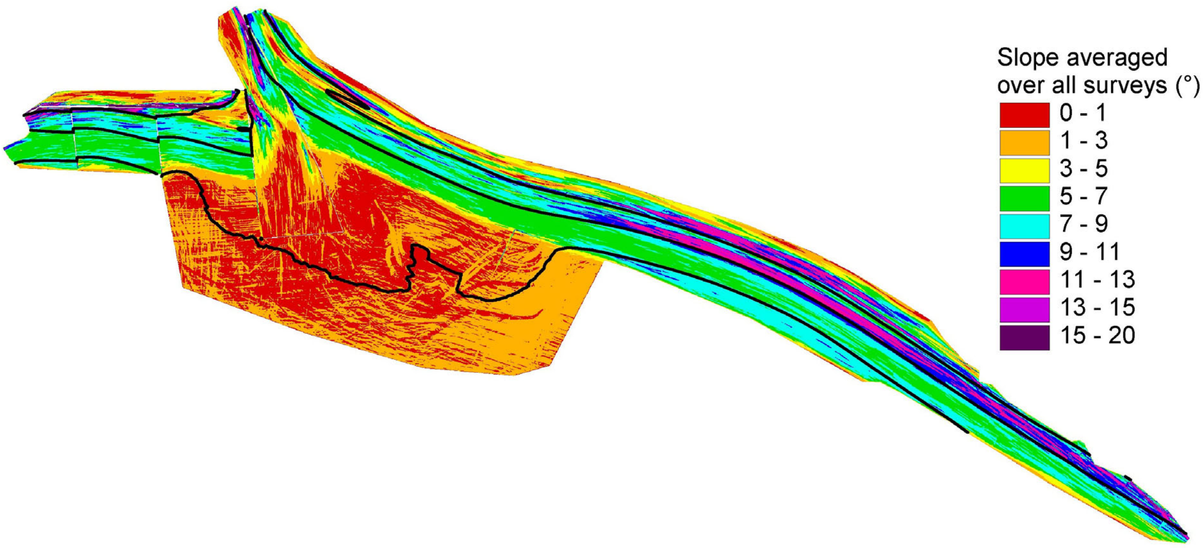


Figure 37: Average slope angle for beaches at Saltdean. Black lines for orientation correspond to 0m, 2.4 and 4.5m OD.

6.7 Newhaven

Surveys at Newhaven have been carried out as a baseline survey in August 2003 and monthly surveys have started in September 2004. The data presently available covers too short a period to provide for meaningful analysis.

6.8 Birling Gap

The cliffs and shore platform at Birling Gap are cut in Seaford Chalk. In the centre of the bay is a dry valley infilled with Coombe deposits. The beach consists predominantly of grey flints provided by cliff and shore platform erosion to the west. The beach is aligned in a WNW-ESE direction (110 degrees). A sandy foreshore is usually developed in continuation of the dry valley while most of the beach sits on the chalk shore platform. The beach has been known to disappear during storms, but is reported to quickly reappear. Strong longshore transport at the beginning of January 2005 removed large areas of beach in the western part (**Figure 38**) leading to significant accumulation in the eastern part. Comparison of present day volumes with those shown on old picture postcards, however, suggests that the volume of beach material has remained quasi-constant for more than a century.


A)

B)

Figure 38: Changes in beach levels illustrated by photos taken from the access steps.
A) Photo taken on 20-04-2004 showing the 'normal' beach levels.
B) Photo taken on 08-01-2005 exposing the underlying shore platform (photo taken by Jerome Curoy).

A baseline survey was carried out in July 2003 and monthly surveys started in August 2004. The beach is an open system in the sense that there are no groynes or natural structures to prevent the material from moving temporarily or permanently eastward or westward.

Figure 39 shows the average beach heights based on 7 surveys (August 2004 to January 2005). The widest and highest part of the beach is located in the vicinity of the access steps and the remaining area forms a narrow fringing beach at mean high water (**Figure 38**A).

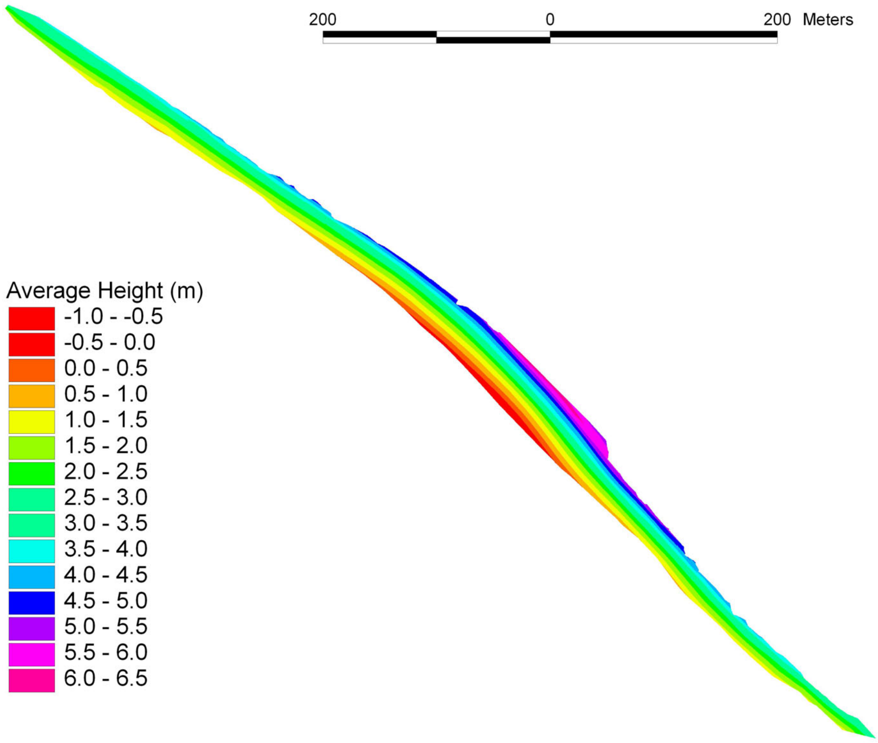


Figure 39: Average beach topography, Birling Gap (7 surveys from August 2004 to January 2005).

6.8.1 Net changes and transport rates

To compare changes over time, **Figure 40** shows the net change for each cell. To allow for a better comparison, each survey is offset by 500 m³ upwards on the y-axis. The surveys, covering July 2003 and the period from August 2004 to January 2005, show that longshore transport is by no means predominantly in one direction.

Some events clearly involve eastward transport (e.g. 8th January 2005). Comparing the surveys carried out in December 2004 and 8th January 2005 (**Figure 41**) shows that the western part was largely eroded with a maximum thickness of beach removed between 1 and 1.5 m so that the underlying shoreplatform was exposed. During this period the western part of the beach disappeared (**Figure 38**B). Over the same time peiord, the eastern part of the beach (essentially the middle beach and the beach toe) showed an accumulation between 0.5 and 1 m. These results clearly demonstrate an eastward longshore transport. The end of the western part is also characterised by an accumulation of between 0 and 1 m, sometimes reaching 2m close to the cliff toe. This accumulation could correspond to a westward longshore transport from the area in erosion, but it could be also linked to the contemporary cliff falls, which supply the beach with new material: flints but also a lot of chalk which will disappear quickly under wave attack. Over the following ten days, the mean tendencies are reversed, with erosion in the eastern part and accretion in the western part.

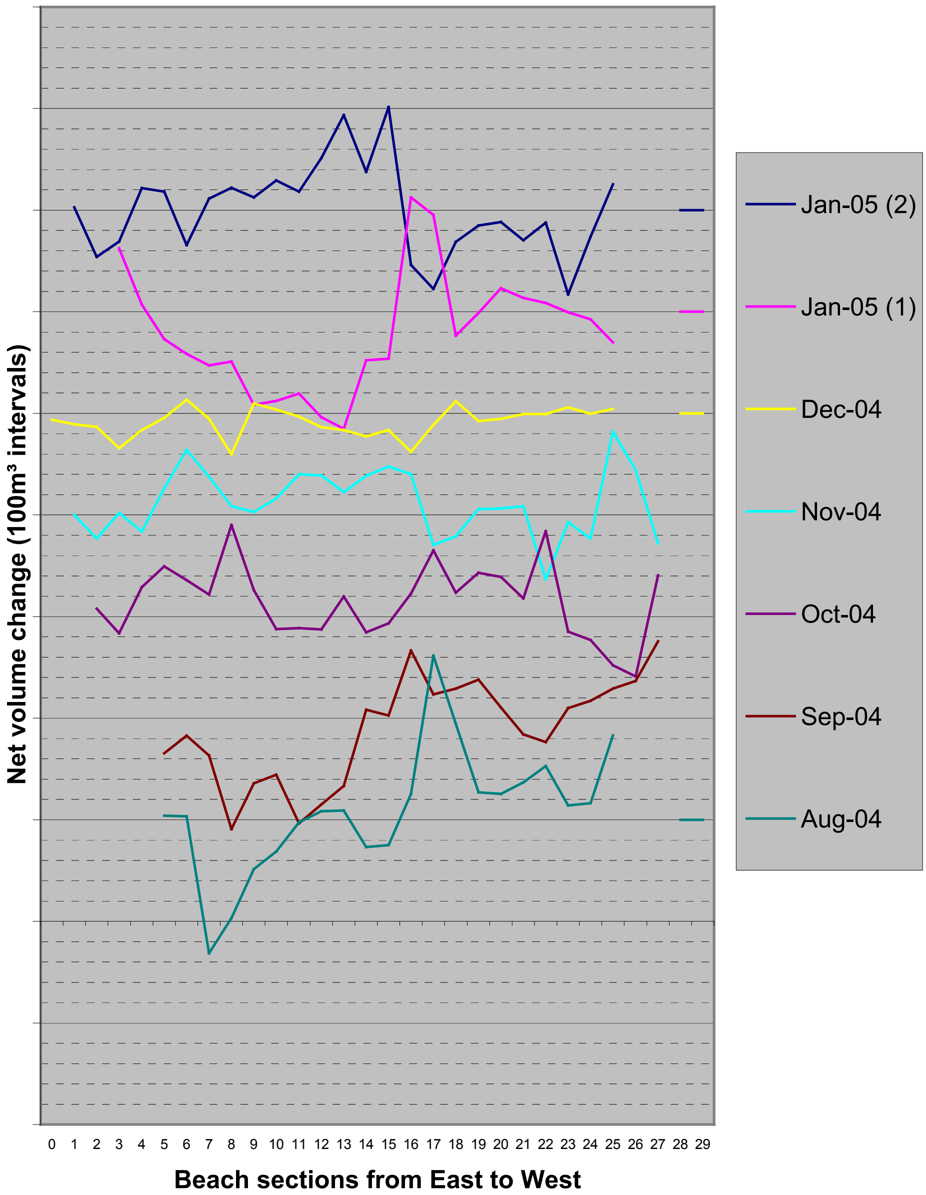


Figure 40: Net change for each cell between two surveys, Birling Gap. Legend gives the month of the later of the two surveys. Net changes are shown as positive if above the solid line and negative if below. From the distribution and magnitude of positive (accretion) and negative (erosion) changes transport direction and rate can be calculated. For the location of the cell see **Figure 42**.

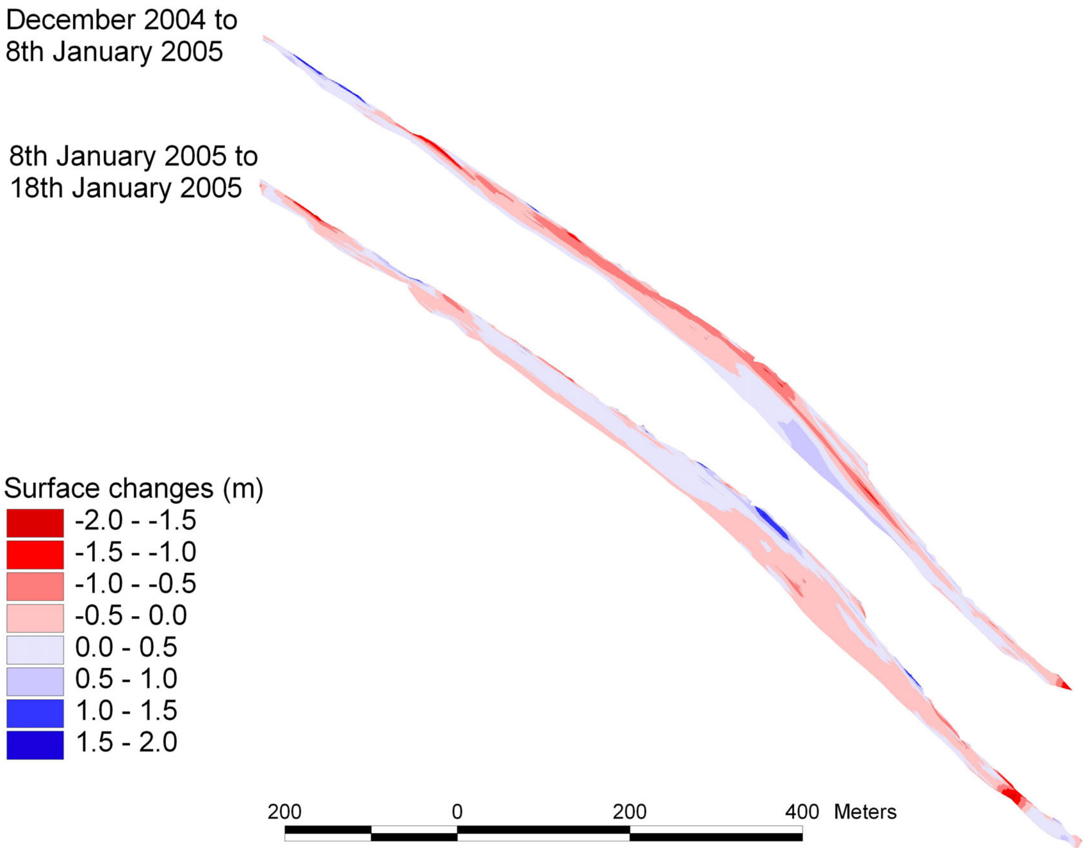


Figure 41: Comparison between surveys carried out in December 2004 and January 2005. The selection of this event is due to a significant change in beach topography related to an important longshore transport.

Net volume change mirrors observations made previously with the map calculations between December 2004 and both surveys in January 2005. The net volume changes between December 2004 and the first survey of January 2005 involves erosion from the cells 5 to 15, 18 and 19, 23 to 25 but also 2, the total amount for each group being 3700 m^3, 123 m^3, 191 m^3 and 1717 m^3 respectively. The significant erosion in cell 2 is caused by a surveying error and should not to be taken into account. So, the real volume of shingle involved in this longshore transport over the beach at this time is close to 4000 m^3. The accretion for this period is marked on the cells 16 to 17, 20 to22 and also in the western beach in the cells 1, 3 and 4, with total net volumes of 1040 m^3, 227 m^3 and 396 m^3 respectively. It is necessary to be aware that cell 3 and 4, are characterised by cliff fall deposits, which induce an increase in the beach topography by adding new flint but also chalk and creating a sort of natural barrier for the material coming from the surrounding cells. Even taking into account the cliff falls, the total net volume in accretion is close to only 1700 m^3. The difference between the two volumes clearly demonstrates that the total volume of the beach has decreased between the two surveys (almost 2300 m^3 of loss). The real question which needs to be answered now is where has this significant volume of beach material gone to?

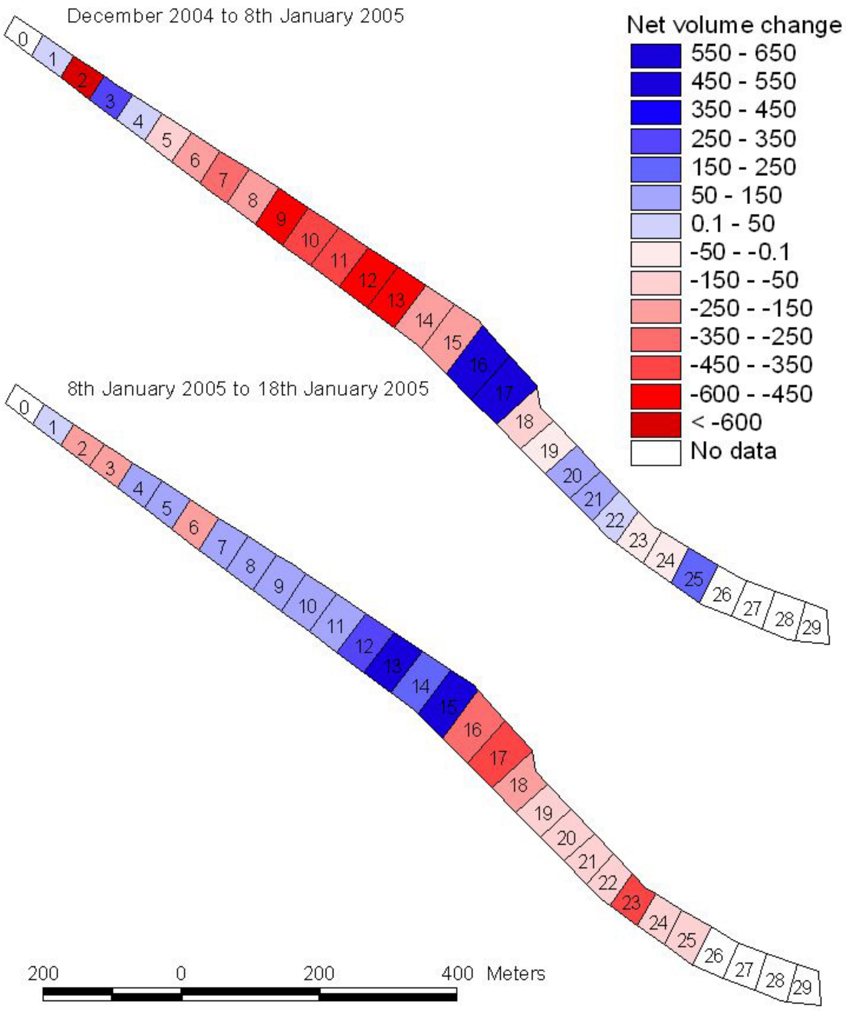


Figure 42: Maps shows the net volume change (m^3) for beach segments between surveys carried out between December 2004 and 8th January 2005 and between 8th January and 18th January 2005. Negative values show erosion and positive values accretion.

Considering the net volume involved during the period of reconstruction of the eastern part of the beach, there is clearly a movement of material from the eastern part to the western part of the beach. Indeed, accretion characterised the cells: 1, 4 and 5, 7 to 17, and 25, which were previously almost entirely characterised by erosion. The change of net volume for the cells 1 (+15 m^3), 4 and 5 (+200 m^3) could be liked to the removal from cells 2 and 3 (-380 m^3) or to reverse movement from cell 6 (-170 m^3). Cells 7 to 15 and 25 involve accretion with net volumes respectively close to 1900 m^3 and 128 m^3.

Erosion in the eastern part corresponding to cells 16 to 24 is quantified at 1700 m^3. The balance sheet of the net volume is close to 0 m^3. So for this period, the beach volume stayed relatively stable, indicating that the beach material lost at the beginning of January 2005 has not yet returned (**Figure 43**).

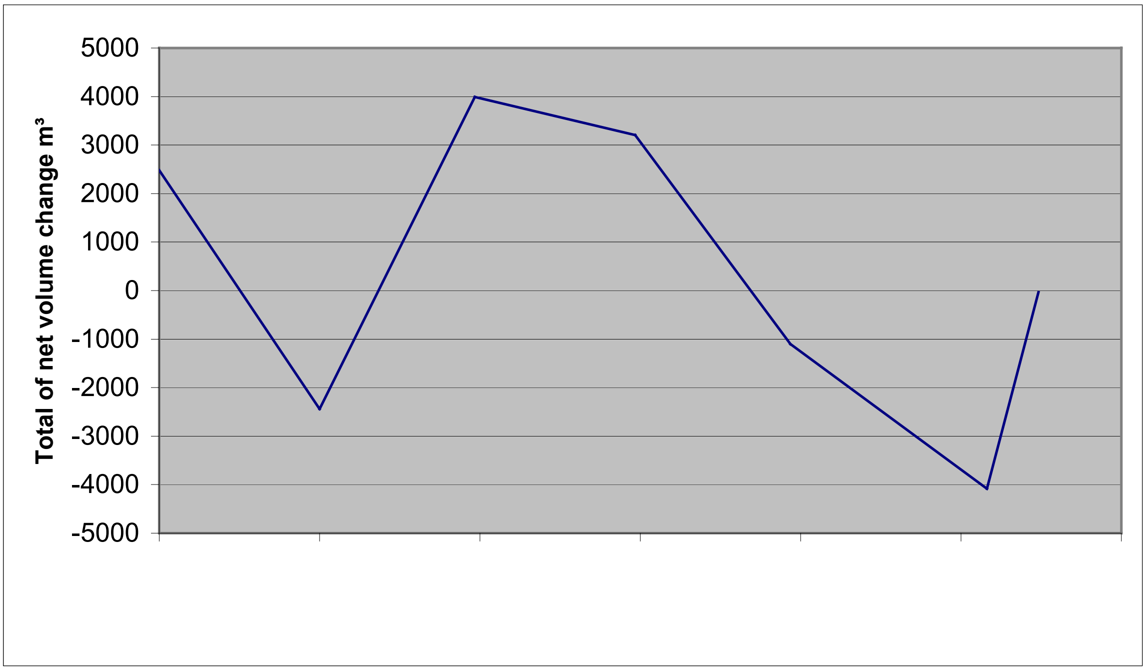


Figure 43: Total net volume change in function of time from August 2004 to January 2005.

To help assess the forcing factors that led to the changes observed in the monthly surveys, **Figure 44** shows wave heights and wave approach. Wave conditions are from The Channel Coastal Observatory's buoy in Pevensey. Previous observations based on sediment tracers (Curoy & *al*., 2005) showed that westward drift corresponds with wave approach close to 90 degrees (depending to the location on the beach, results obtained on the western side of the beach) and eastward drift usually corresponds to a wave approach close to 220 degrees. The drift distance is likely to be linked to the wave height. These results linked to the wave conditions in December 2004 and January 2005 directly explain the sediment beach behaviour. The wave direction during this period is normally oriented 220 degrees inducing an eastward transport. However, it was noted that the sea was more choppy than usual during the weekend between the 7th and the 9th January 2005. During this period, wave height reached 5.5 m, whilst the usual maximum wave height is around 3.5 m. This explains why the longshore transport was so significant in volume and distance at this period (Curoy & *al*., 2005). The ten days following this event were characterised by a wave direction reaching sometimes 130 to 150 degrees (probably coupled with effects of wave refraction) which explains the reverse movement of shingle and the readjustment of the beach over the entire embayment.

To conclude it should be noted that, even with this reverse longshore transport, shingle that was 'lost' since the first surveys appears not to have returned. This maximal loss has not been recorded during the following surveys, which leaves us with the question: will the shingle volume totally recover or is the material indefinitely lost to the beach system?

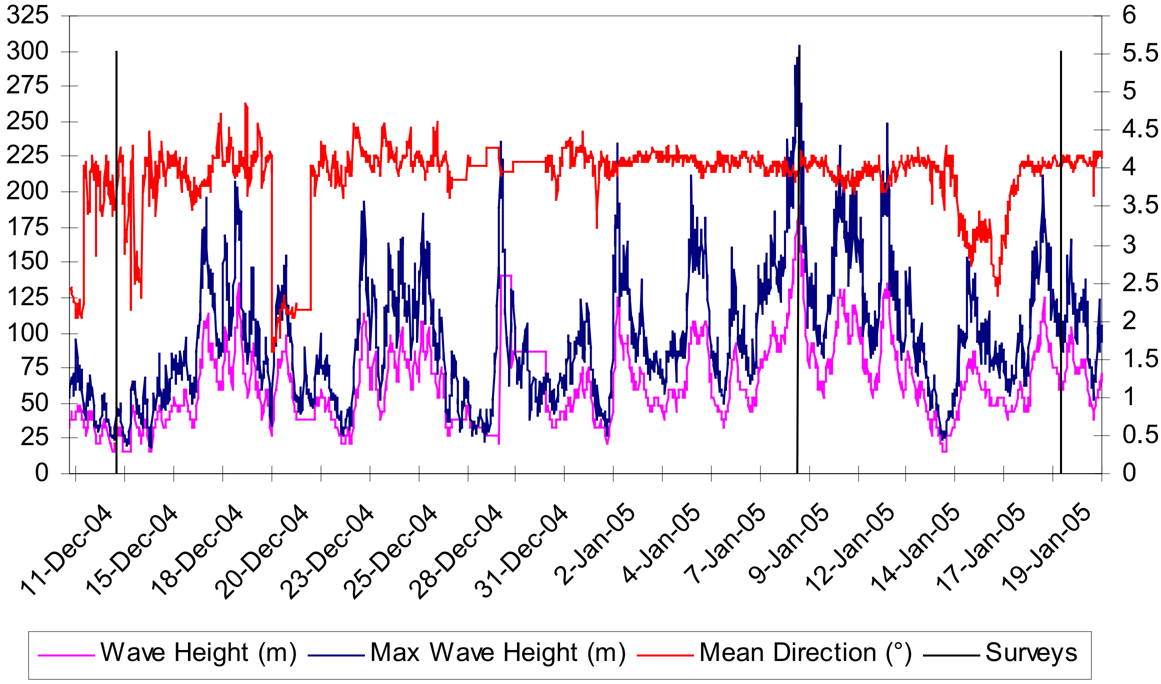


Figure 44: Wave data for the December to January period from The Channel Coastal Observatory's buoy in Pevensey.

6.8.2 Beach states

The standard deviation map (

Figure 45) shows that there are not clear areas of high values, except on the eastern part of beach which may be linked to longshore transport and the natural eastward movement of the beach. However, the largest values are found on the eastern part shaped as small pockets linked to the beach morphology. This end of the beach is characterised by well-confined shingles deposits (as a sort of small-scale embayment) linked to cavities in the cliff, which appear to act as natural traps. Most the time the chalk platform between these shingle deposits is covered by a variable thickness of shingle which sometimes disappears revealing the chalk platform.

The largest values are also found on the top of the beach, probably linked to the berm movement along the period of survey; the berm movement being induced by the combined effect of tide and wave height.

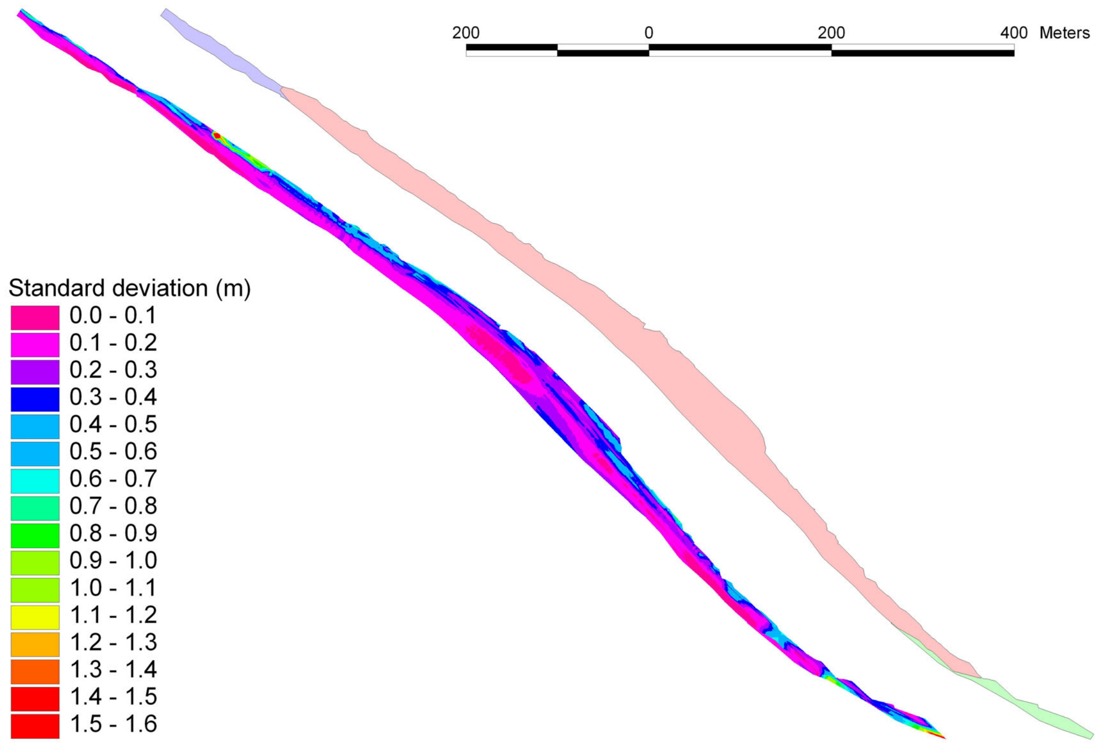


Figure 45: Standard deviation based on 8 surveys in the central area (pink), 6 for the western part (lilac) and 3 for the eastern part (green). Note that the extreme value (red point) at the north should be linked to the error margin; data collected at the eastern part of the beach seem also to be affected.

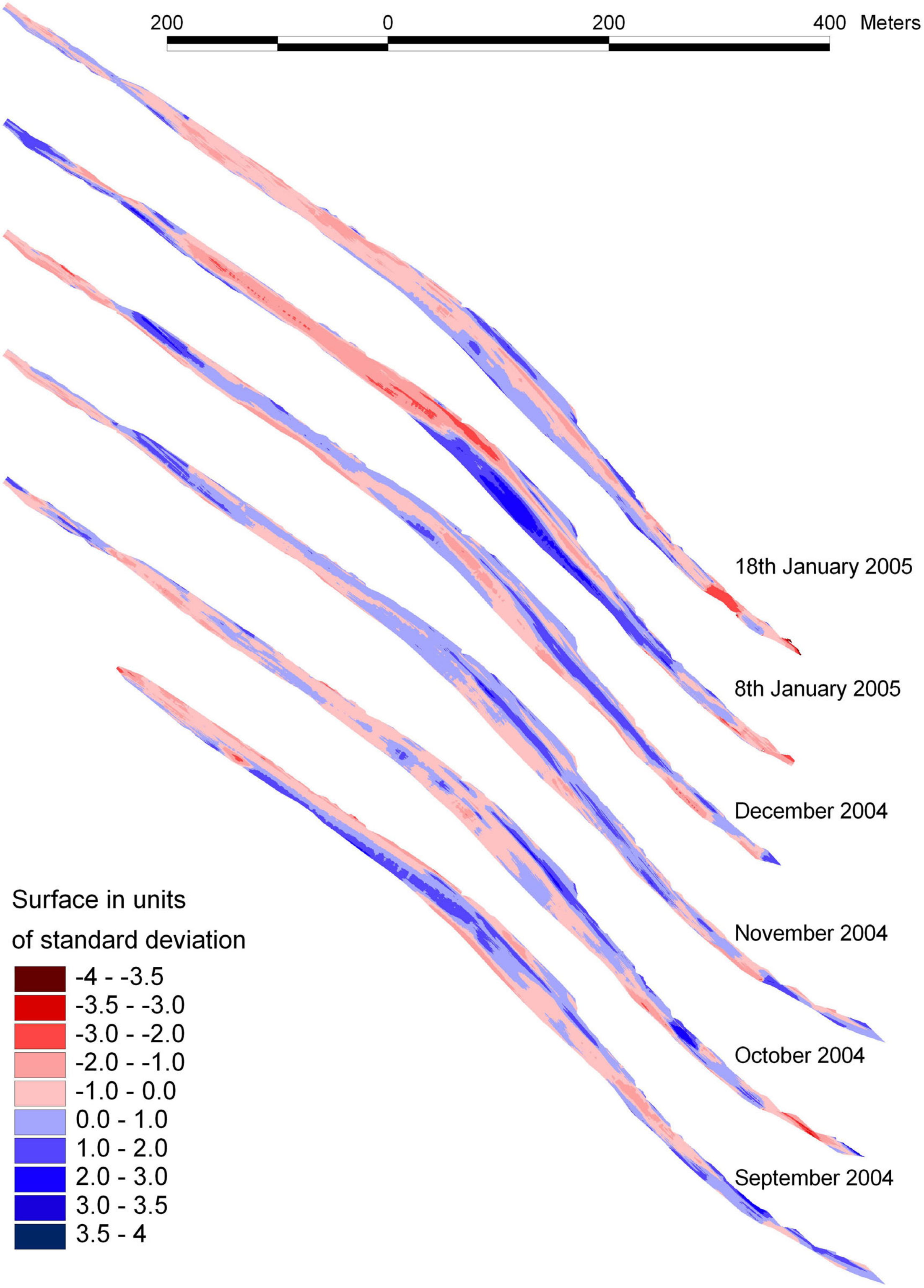


Figure 46: Deviation of surveyed beach surface from the mean surface expressed in units of standard deviation.

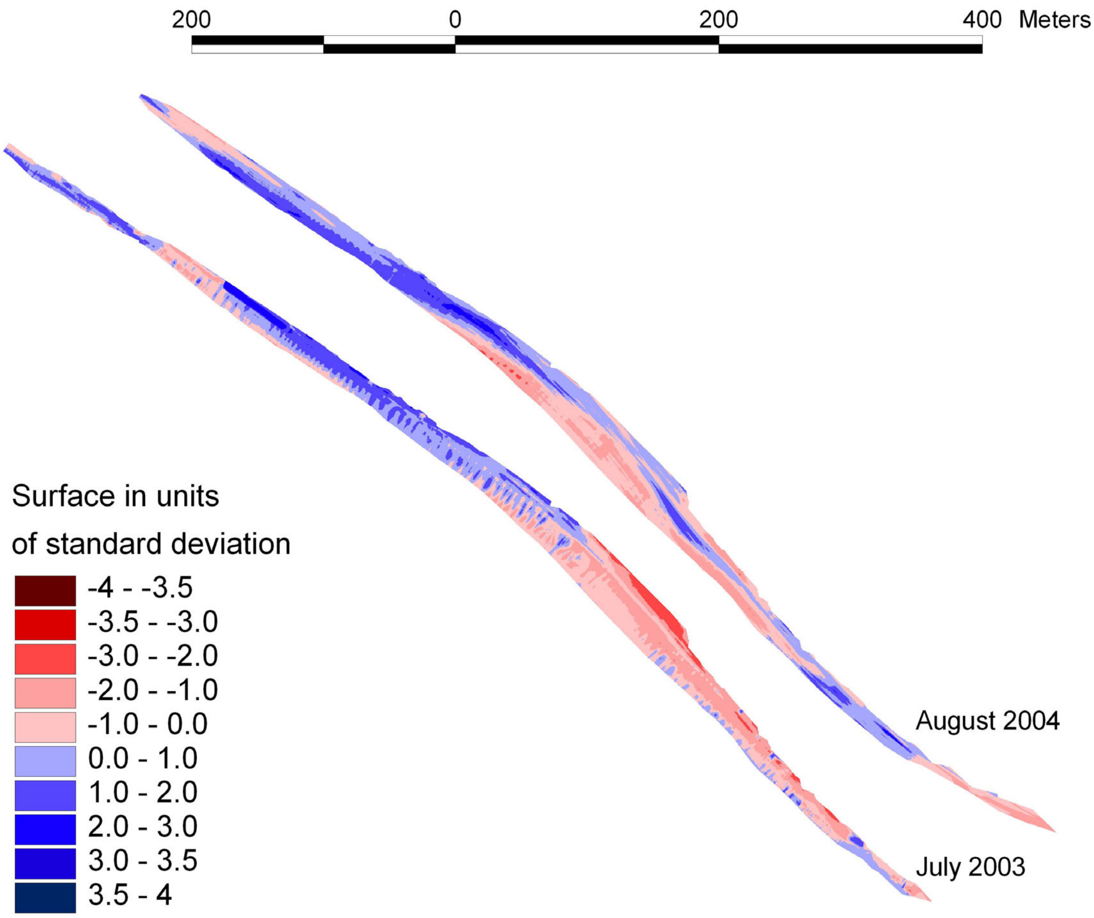


Figure 46 continued: Deviation of surveyed beach surface from the mean surface expressed in units of standard deviation.

The surface deviation map of July 2003 shows some different features to the other maps (**Figure 46**). This is mainly due to the method of survey being a mixture of cross-shore and longshore transects. However, even if there are these little artefacts in dark blue, probably also linked to beach cusps, the mean information keeps it validity.

A brief overview of each map identifies three key periods. One shows lower levels of topography than usual in the eastern part of the beach and higher levels of topography in the western part (July 2003, August 2004 and September 2004), a second describes the reversal tendency (both surveys of January 2005), and the third is a sort of transitional statement with lower and higher topographies well distributed in pockets (October 2004 and November 2004) or longshore transects (December 2004).

It can also be seen that surveys which belong to the same group also show similarities in location and amplitude of the high values of standard deviation, which indicates that the behaviour of the shingle beache could be predicted even for extreme events such as January 2005 from a detailed base data surveys on a long term.

7 Discussion

Three different methods are used to (1) measure changing beach volumes on a range of time scales, (2) calculate longshore transport rates and (3) relate beach behaviour to wave conditions. Results over the long term indicate moderate net eastward transport as indicated by the accumulation of shingle against Newhaven harbour arm and other examples not detailed in this report (e.g. accumulation against the Rother mouth, Folkestone Harbour). Modern monthly transport rates are ~10-20% of the long-term annual rate suggested by the Newhaven data, which provides a good match. However, the monthly surveys have shown that the annual net transport may be quite small compared to amounts of monthly transport, which occurs both east- and westwards.

It would appear as if the general longshore transport direction for the south coast of southeast England is a product of a sometimes slight predominance of eastward transport over westward transport coupled with changes in the coastline configuration that work like a one-way valve only allowing eastward transport (e.g. Newhaven, Seaford Head, Beachy Head). The modest transport rates found between Brighton and Beachy Head increase dramatically at Eastbourne. This increase could be due to a more oblique angle of wave approach favouring longshore transport but also to the large amount of sediment available for transport following recharge.

8 Outlook for Phase 2 of BAR

The largely qualitative analysis of wave / tide conditions and longshore transport needs to be developed into a quantitative relationship and model during Phase 2, possibly taking local wave refraction models into account. The work on medium term changes will bridge the data on long- and short-term development.

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Chapter 6.8 by Jerome Curoy
Photos by U Dornbusch unless otherwise stated

9 References

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This report is partly based on the following reviews, protocols and reports:

2003-08-27-Report_Topographic surveys 02-Telscombe West Beach.doc

2003-08-29-Report_DEM extraction from air photographs.doc

2004-07-28-Report_Storm ridge and back beach heights in Sussex and Kent.doc