Application of Current Measurement and Time Lapsed Bathymetric Multibeam Surveying to Investigation of a Banner Bank, Mispec Bay, New Brunswick, Canada

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Abstract

Time lapsed multibeam surveys show that sand dunes on top of a headland associated sand bank to be migrating in a clockwise fashion with the shallowest dunes translating at rates of up to ~50 metres from April to October in 2002. Interpretation of depth averaged current vectors show a large eddy to be initiated and subsequently advected away from the headland as the tide ebbs. Grab samples show that the sediment of the sand bank is composed of moderately well sorted, landward fining, medium sand with a very poorly sorted, strongly coarse skewed, coarse sand proximal facies indicative of winnowing by flood dominated currents. Analysis of bottom currents reveals that there is no evidence for opposing residual bottom currents either side of the sand bank.

1 Introduction

Mispec Bay sand bank is one of many Banner Banks that lie adjacent to headlands along the shores of the Bay of Fundy. The dynamic nature of this particular sand body became evident through comparing multibeam bathymetry data acquired on roughly biannual Geological Survey of Canada cruises carried out from April 2000 to November 2001. A clockwise sense of movement in the bedforms on the sand bank was observed which agreed with the sense of rotation of an eddy that was initiated adjacent to the nearby headland on the ebb tide.

Dyer and Huntley (1999) give an extensive review of theoretical and field research into the causal factors in the genesis and development factors of Banner Banks which include opposing residual bottom currents landward and seaward. Signell and Harris (1999) designed a mathematical model predicting the residual current field in the vicinity of a headland together with associated deposition of both bedload and suspended sediment. Sedimentary distribution of the Skerries Bank at Start Bay was studied by Hails (1975).

Since Banner Banks occur in pairs (one on each side of the headland), the symmetry, or lack thereof, of these pairs has been of interest to some researchers (Pingree, 1978; Signell and Harris, 2000; Bastos *et al.* 2000), however this paper will concern itself with the study of a single Banner Bank. It is evident that there exists some work done in the field of current measurement (Dyer, 1986; Geyer and Signell, 1990) and modelling of headland associated eddies but there is a dearth of bedform change observations on banner banks. Therefore there exists a niche for direct observations of bedform dynamism coupled with measurements of eddy currents to test these models.

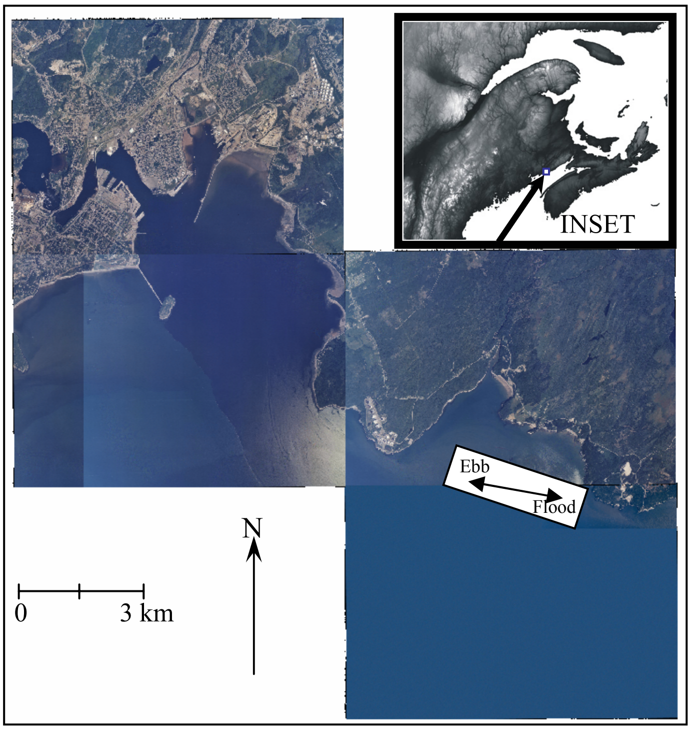

Figure 1: Location Map. Saint John, New Brunswick is shown in the upper left part of the picture and the field area is depicted by the white rectangle. Ebb and flood directions are also depicted. The headland, Cape Spencer, is on the extreme right.

2 Data Description

Multibeam echosounder (MBES), Acoustic Doppler Current Profile (ADCP) and bottom sampling data were acquired over the field area. A description follows of these data.

2.1 MBES Data

Six surveys roughly a month apart were carried out from April 2002 to October 2002. A Simrad EM-3000 MBES hull mounted on the Ocean Mapping Group vessel *Heron* was used in surveying operations. Differential GPS gave horizontal position and a Canadian Hydrographic Service operated tide gauge at nearby Saint John gave tide data necessary to correct for depth variations due to tide. Vessel attitude and heading was given by a variety of different instruments for different surveys such as POS-MV 320, Seapath 200 RTK and a Seatex MRU-6.

The smallest features resolved by the MBES were bedforms of seven metre spacing with heights of thirteen centimetres in 34 metres water depth. The EM-3000 measures depths in equiangular sectors port and starboard so the resolution is strongly nadir biased, therefore to ensure a high sounding density and resolution we kept a line spacing of typically 30 m and with an average water depth of around 30 m (with a tidal range of ~ 7 m).

The high degree of overlap meant that the seafloor was effectively surveyed twice and to take maximum advantage of this overlap the gridding process weighted each sounding according to distance from nadir (as a proxy for sounding quality) to produce an optimum representation of the seafloor. Soundings were processed to remove major motion associated artifacts and digital terrain models with a 1 metres resolution were constructed for analysis.

The six created digital terrain models were amalgamated into an AVI movie file and this was the principle tool for analysis of bathymetric change. The 1 metre grids enabled fine detail change to be resolved.

2.2 ADCP Data

Three current measurement surveys of duration one M2 tidal cycle (12.25 hour) were carried out for this study, two in October 2002 and one in September 2003. The instrument employed was a 600 kHz RD Instruments Workhorse Monitor which averaged data into vertically into 50 cm bins so a high degree of vertical velocity shear resolution was achieved. The tracks (Figure 2) were designed tp provide the best resolution of the current regime over the sand bank.

Depth averaged current data, and currents 10 m from the seabed, from the three ADCP surveys were binned into a 75 m spatial grid and 'stacked' together into common phases (roughly 30 minute increments) of the tide. This enabled the three tidal cycle measurements to be simultaneously interpreted in an AVI file (movie).

2.3 Sediment Sampling

A Shipek Grab was employed to sample the sediments of the field area in September 2003. The dry mass of the samples ranged from 0.9 kg to 1.8 kg with an average mass of 0.6 kg. The very large samples were sub-sampled representatively to make the sieve analysis easier and the other samples were washed and sieved entirely. The samples were sieved by machine and by hand through 14 standard sieves with aperture sizes ranging from 37.5 mm down to 75 micron. Statistical quantities (mean, standard deviation, skewness and kurtosis) were calculated using cumulative curves.

In the western part of the study area, the samples were muddy and so were measured by hydrometer analysis.

3 Results

3.1 Grain Size Analysis

Analysis of the sediment samples revealed that the study area is spatially highly variable indicating that contrasting sediment transport conditions exist. Four distinct sedimentary facies have been tentatively identified on a plot of grain size against sorting: (A) moderately well sorted medium sand and fine sand (8 samples); (B) very poorly sorted, strongly coarse skewed, coarse sand (3 samples); (C) very poorly sorted, fine skewed, very fine sand and silt (6 samples) and (D) very coarse sand and gravel (3 samples).

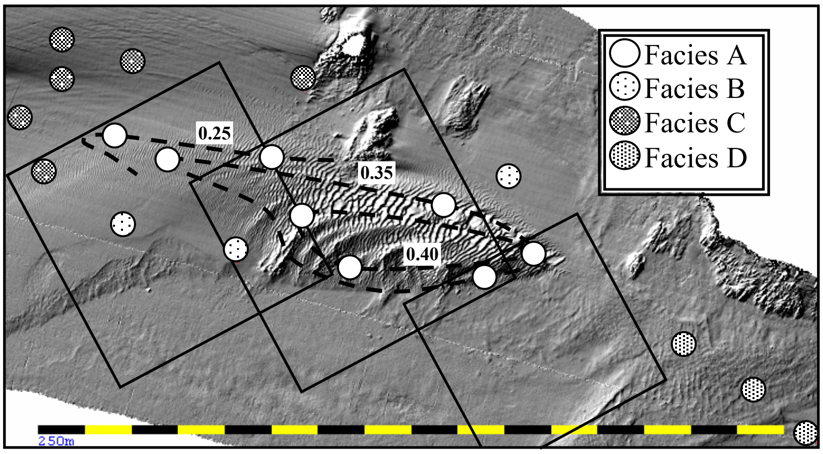

Figure 2 Facies locations and ADCP tracks taken. Grain size contour lines are also shown (units in mm)

All of the samples taken on the sand dunes fall into Facies A (Figure 2). Facies B encompasses samples taken proximal to the sand bank. The samples comprising facies C were taken off the north and north-western edge of the sand bank. Facies D is only defined by its coarse grain size and is found adjacent to Cape Spencer.

Within Facies A sample mean grain size has a range of 0.24 – 0.41 mm. The sediments are for the most part moderately well sorted with 6 of the 8 samples having graphical standard deviations of 0.36 – 0.57. A possible interpretation of the spatial grain size distribution is sketched as contour lines on Figure 2; it shows sediment fining towards the periphery of the sand bank.

The proximal Facies B has also been noted by Hails (1975) in his sedimentary study of Skerries Bank where the coarse skewness is attributed to the winnowing effect of strong residual currents.

3.2 ADCP Data

One of the most impressive observations of the depth averaged current data is that most of the eddy that dominates the hydrodynamic regime on the ebb tide is resolved (Figure 3). However there is no evidence for opposing residual bottom currents either side of this banner bank, apparently contrary to Dyer and Huntley (1999) and Dyer (1986).

<u>Description of depth averaged tidal currents</u>

Figure 3(a) is an interpretation of the depth averaged current vectors temporally averaged over 3 hours after high tide. Strong (average 50 cm/s) currents are seen to shoot around the headland with currents decelerating landward over the sand bank with a region of slack water, the incipient eddy indicated by the faint dotted line, existing in the lee of the headland. This lateral deceleration could cause the landward fining of grain size depicted in Figure 2.

Figure 3(b) shows the situation as the tide approaches its lowest point. Half of the fully developed eddy is seen with strong currents flowing west to east (note: currents in the flood direction although the tide is falling) and current magnitude decreasing seaward. The ‘eye’ of the eddy has been advected away from the headland, such advection has also been noticed by other workers measuring eddy currents (Geyer and Signell, 1990).

Figure 3(c) shows the currents as the tide rises. Strong flood currents are shown over the entire sand bank. Analysis of bottom 10 metre currents reveals that these peak flood currents are much diminished in the deeper water on the seaward side of the sand bank.

Figure 3(d) shows the currents as the tide approaches high tide. Currents slacken and noticeably decrease landward.

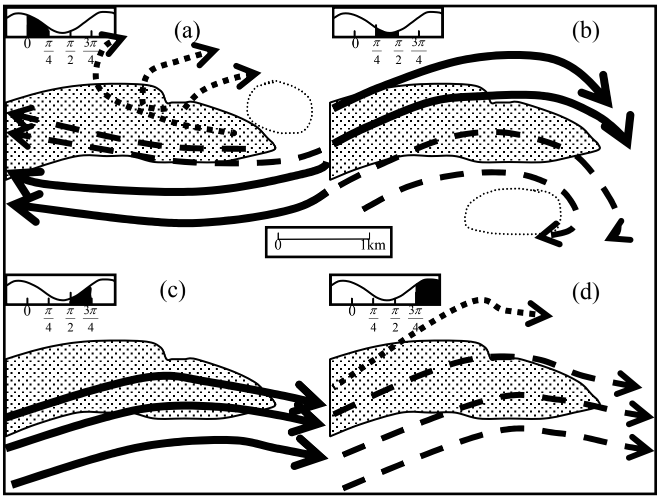

Figure 3 Interpretation of depth averaged current vectors. The ‘snapshots’ are based on current vectors averaged over 3 hours of the tidal cycle. The outline of the sand bank is depicted by the dotted area.

It is interesting to note that currents in ebb direction are simultaneously initiated at hour 8 (Figure 4) across the sand bank but thereafter their duration and magnitude varies substantially across the sand bank due to the sheltering effect of Cape Spencer.

Seaward current regime

Offshore, the ebb currents are shorter and stronger than the flood currents with the duration and peak magnitude steadily decreasing as we go across the sand bank (Figure 4(a,b)). The ‘outside’ sand bank current pattern (Figure 4(b)) is quite different to the pattern in the flood trapped eddy observed by Dyer (1986) in the same relative position, i.e. outside Skerries Bank at Start Point. There the flood and ebb currents were of roughly equal duration with the current moving away from the headland (in that case flood current) being much (~75%) greater than the current in the opposite direction; the authors therefore proposed a dominance of currents away from the headland (flood dominated). In Mispec Bay, in the same relative position, the current moving away from the headland (in this case ebb current) is also greater than the current moving in the opposite direction, although to a lesser degree (~10%) but in contrast to the situation on Skerries Bank, the currents moving away from the headland have a much shorter duration to the opposing currents (4 hours versus 7 ½ hours). So in

Mispec Bay the residual current at this location is still towards the headland in contrast to Start Point where the residual current is away from the headland.

Landward current regime

The ‘inside’ sand bank current pattern is also different to Dyer (1986) *although* it still gives the same sense of tide dominance, i.e. toward the headland. In Dyer (1986), the currents moving toward the headland (in that case flood currents) were of shorter but higher magnitude than the currents moving away from the headland but the author maintained that the current regime in this ‘inside bank’ region was still ebb dominated because of the *longer duration* of the ebb currents. In Mispec Bay (Figure 4(d)), the current field ‘inside’ the sand bank is also dominated by currents moving towards the headland (in this case flood currents) although in this case the situation is more straightforward since the ebb currents are greatly diminished with respect to the flood currents in both duration and strength.

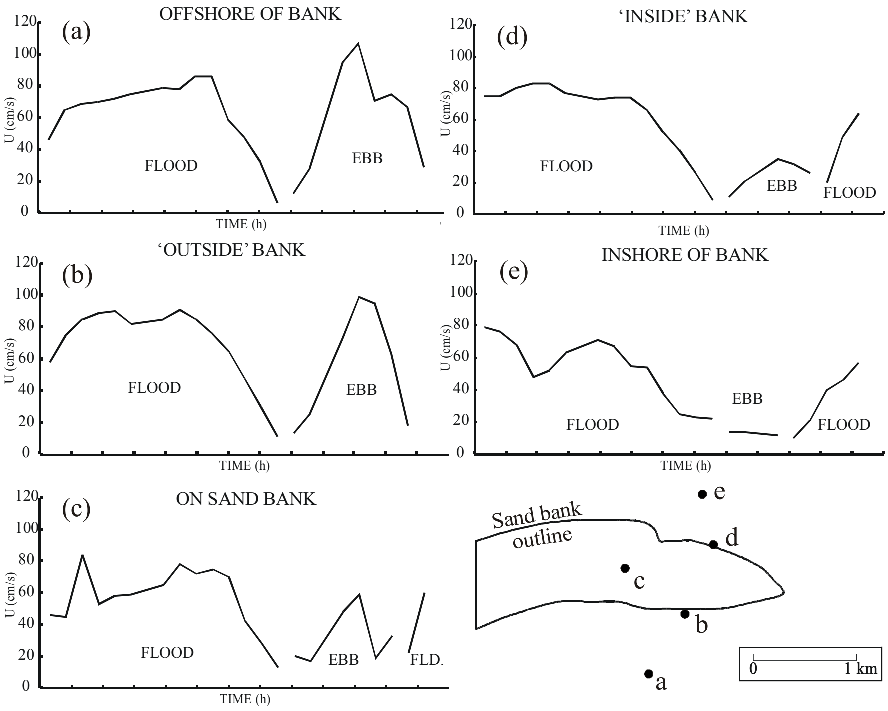

Figure 4 Plot showing increasing flood domination of depth averaged currents from offshore of sand bank (plot a) to inshore of sand bank (plot e)

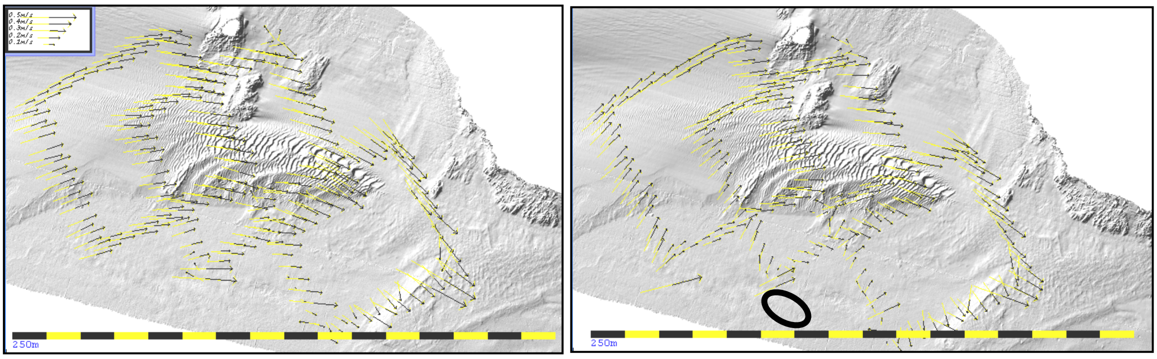

Figure 5 Residual currents across the sand bank. LEFT: Depth averaged; RIGHT: Bottom 10 m averaged currents

The residual currents were more rigorously quantified by averaging the depth averaged and bottom current vectors over the entire tidal cycle (Figure 5).

The residual bottom 10 metre currents have a spatially confined minimum, represented by the oval in Figure 5(right) and increases alongshore and landward to a maximum of ~30 cm/s. The latter figure leads the authors to believe that the advecting eddy has a bigger spatial impact (since we only appear to have resolved 'half' the circular residual current field) on the residual current field than previously thought.

3.3 Multibeam Data

Analysis of a specific digital terrain model (DTM's) yields information about the spacing and height of the dunes atop the sand bank whilst analysis of the time lapsed DTM's gives information about migration rate and direction.

The sand dunes fall into two broad categories: symmetrical and asymmetrical forms. The asymmetrical dunes lie in the shoreward part of the sand bank and their dimensions increase from a spacing and height of 16 m and 50 cm to 130 m and 500cm from west to east with the largest, steepest dunes being in the shallowest (~20 m) part of the sand bank, close to the headland. The symmetrical dunes have a uniform spacing of 20 m and height of ~80 cm. They exist from 25 m depth to the edge of the sand bank at 33 m. Their dimension is spatially uniform unlike the shallower asymmetric dunes.

Analysis of the DTM time series at the scale of the entire study region reveals an overall motion trend similar to the six-monthly GSC time series although the clockwise sense of motion is not as pronounced. It appears that the symmetric smaller sand dunes are stationary over the 6 months. Especially noticeable is the high rate of migration in the shallowest (< 20 m), flat patches in the north-eastern part of the sand bank. It's possible that these flat areas are depocentres related to the radially decelerating currents at the eye of the eddy that are continually flattened by the rising and falling wavebase and the sediment being forced to take the form of swiftly migrating smaller dunes instead of the large amplitude dunes found adjacent. It is evident that the lunate megaripples just off the tip of the sand bank are the swiftest moving features with some having migrated 50 m towards the headland during the observation period (average 0.2 m/day).

4 Discussion

Analysis of the ADCP, grain size and bathymetric datasets has lead to the discovery of interesting correspondences. The median grain size of 370 micron along the top of the banner bank together with consideration of peak currents over this area indicates that the underlying sediment seems to be in equilibrium with the tidal currents. Assuming a Rouse parameter of 2.5 (after Soulsby (1981), Van Rijn (1993)), logarithmic vertical current structure and measuring bedform roughness from the DTM we find that the minimum depth averaged current necessary to commence "incipient suspension" at location Figure 4(d) (full suspension being initiated at Rouse parameter of 1) for this median grain size is 60 cm/s. We see that this threshold is exceeded by peak flood currents of 80 cm/s so it appears that the grain size distribution is in equilibrium with the flood currents and that the weaker ebb currents at this location have little effect on the grain size distribution. Landward lateral deceleration of currents before and after high tide (Figure 3(a,d)) may cause the observed landward fining of grain size.

Inshore of the Banner Bank, the sheltering of the headland causes the current regime to be, from a sediment transport point of view, unidirectional (Figure 4(e)) so there is little deceleration of current causing this area to be subject to winnowing of the finer fraction causing the observed very coarse skewed grain size distribution in this area.

The advection of the eddy from the headland seawards causes local deceleration of bottom currents in the centre of the eddy and deposition of sediment between depths of 20 and 40 m. Subsequent mobilisation and migration of bedforms correspond with residual depth averaged currents towards the headland across the field area. The residual currents reach a maximum on the shallowest part and along the northern edge of the banner bank and correspond with the high rate of bedform migration in this region.

We do not see evidence for opposing residual currents either side of the sand bank. The only way we would see such a current configuration would be if the eddy were stationary or did not have such large excursion on the ebb. Possibly if a fourth tidal cycle survey was carried further seaward of the bank, we would see a circular residual current field.

5 Acknowledgements

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