The morphology and flow fields of three-dimensional dunes, Rio Paraná, Argentina: results from simultaneous multibeam echo sounding and acoustic Doppler profiling

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Abstract
Many studies of river dune dynamics have concentrated on two-dimensional (2D) bed features and their associated flow structures. This morphological simplification imposes inherent limitations on our interpretation and understanding of dune form and flow dynamics. For example, studies over 2D forms neglect the significant effect that lateral flows and secondary circulation may have on the flow structure and thus dune morphology.

This paper details a field study of a swath of dunes in the Rio Paraná, Argentina. A large (0.25 km wide, 1.8 km long) area of dunes was surveyed using a Multibeam Echo Sounder (MBES), providing high-resolution 3D detail of the river bed. Simultaneous to the MBES survey, 3D flow information was obtained with an Acoustic Doppler Current Profiler (ADCP). The results demonstrate a complicated pattern of dunes and flow structures within the swath.

This paper presents details of the methodology and results using this integrated approach that has enabled investigation of the interactions between the 3D morphology and 3D flow structure of large alluvial sand dunes. The paper highlights the effects of lateral flows in the lee side of dunes and considers the effects and implications these may have on our understanding of dune dynamics.

1. Introduction
The morphology, flow and process mechanics of river channel dunes has attracted much interest over many years and recent years in particular (e.g. Nelson, 1993; Bennett and Best, 1995; Kostaschuk, 2000; Best and Kostaschuk, 2002; Maddux et al., 2003). However, many of these studies have concentrated on two-dimensional (2D) bed features and their associated flow structures and bed stress distributions. This morphological simplification imposes inherent limitations on our interpretation and understanding of dune form and flow dynamics, as natural dunes are invariably three-dimensional (3D) with an associated fully 3D flow structure. For example, studies over 2D forms neglect the significant effect that lateral flow and secondary circulation may have on the flow structure, shear stress and thus dune morphology. Only recently have the 3D effects of dune form on flow structures being investigated in the laboratory (Maddux et al. 2003). Maddux et al. (2003) found enhanced topographic forcing producing higher secondary currents over the dune forms.

This paper details a field study of a swath of dunes in the Rio Paraná, Argentina. A large (0.25 km wide, 1.8 km long) area of dunes was surveyed using a Multibeam Echo Sounder (MBES), providing high-resolution 3D detail of the river bed. Simultaneous to the MBES survey, 3D flow information was obtained with an Acoustic Doppler Current Profiler (ADCP). This paper will present details of the methodology and results using this integrated approach that has enabled investigation of the interactions between the 3D morphology and 3D flow structure of large alluvial sand dunes.

2. Study Site

The study area is a swath of dunes in the Rio Parana, close to the confluence of the Paraná and Rio Paraguay, 16 km north of the city of Corrientes (Fig. 1), Argentina. The Paraná River basin is a 2,600,000 km^2 fluvial system, most of which is in Southern Brazil and Argentina. The mean annual discharge of the Rio Parana is about 17,000 $m^3 s^{-1}$. The field site the Parana is approximately 2 km wide and around 9-14 meters deep (Fig. 2). At the time of surveying the discharge of the full channel section was close to 15,000 $m^3 s^{-1}$.

Fig. 1 – Location of the Rio Paraná. The field site is near 'Corrientes'.

3. Methods

The fieldwork was completed in May 2003 and involved use of a Reson® Inc. SeaBat 8101 Multi-Beam Echo Sounder (MBES) to obtain the 3D river bed morphology. The SeaBat 8101 is a 240 KHz system, which measures the relative water depth across a wide swath perpendicular to the vessel's track. A transmit projector array section of the sonar head transmits pulses of acoustic energy into the water column. Reflection from the water column and the bed are 'heard' with a semicircular receive array. The bottom is then detected using a combination of both amplitude and phase detection methods. The 8101 has an across track subtended angle of 250° permitting it to measure a swath width of 7.4 times the water depth. It provides information on the river bed morphology (cm resolution mm precision) over scales from ripples on dunes to whole river reaches.

Simultaneous to the MBES survey, an RDI Instruments 600 KHz Acoustic Doppler Current Profiler (ADCP) was used to quantify the 3D flow structure over the swath of dunes. These instruments were tied

together in time and space using a Differential Global Positioning System (DGPS), outputting in a Pulse Per Second mode to remove latency from the arrangement set-up. Interactions between the two acoustic instruments were also tested for running individually for short test runs and comparing the results obtained.
Measurements were made along a total of 6 streamwise parallel transects, each approximately 50 meters apart. Two cross sections were also measured at the upstream and downstream limits of the surveyed area, which were approximately 2 km apart.

Fig. 2 – Upwelling and surface boils observed above the swath of dunes during surveying.

4. Results

Figure 3 shows the bathymetry of the full swath of dunes surveyed. Although the swath is apprximetley aligned NorthNorthEast, the dunes have a complex 3D pattern. On average the dunes were found to be around 1.5 to 2 m high and to have wavelengths of apprximetkley 60-80.

The measured flow structure over the dunes is shown for one of the centeal transects in figure 4. The near bed deccelertion and separation in the dune lee can be identified. Moreover, the strong morphological and topographic forcing of the near bed flow produces strong lateral velocities that are significantly enhanced in the lee of the dunes. Vertical velocities are enhanced on the stoss sides of the dunes, with boils at the surface often evident (figure 2). These results confirm some of the findings of Maddux et al. (2003) in the field and have implications for our understanding of 3D dune form-flow interaction.

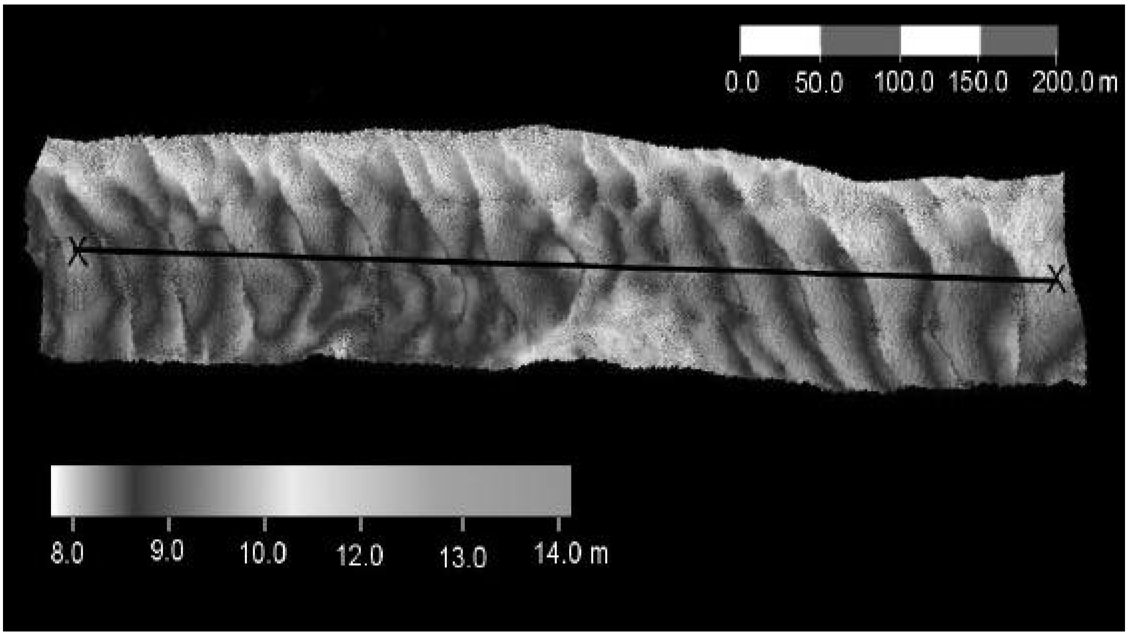

Fig. 3 – Contour map of the swath of dunes obtained with MBES sonar.

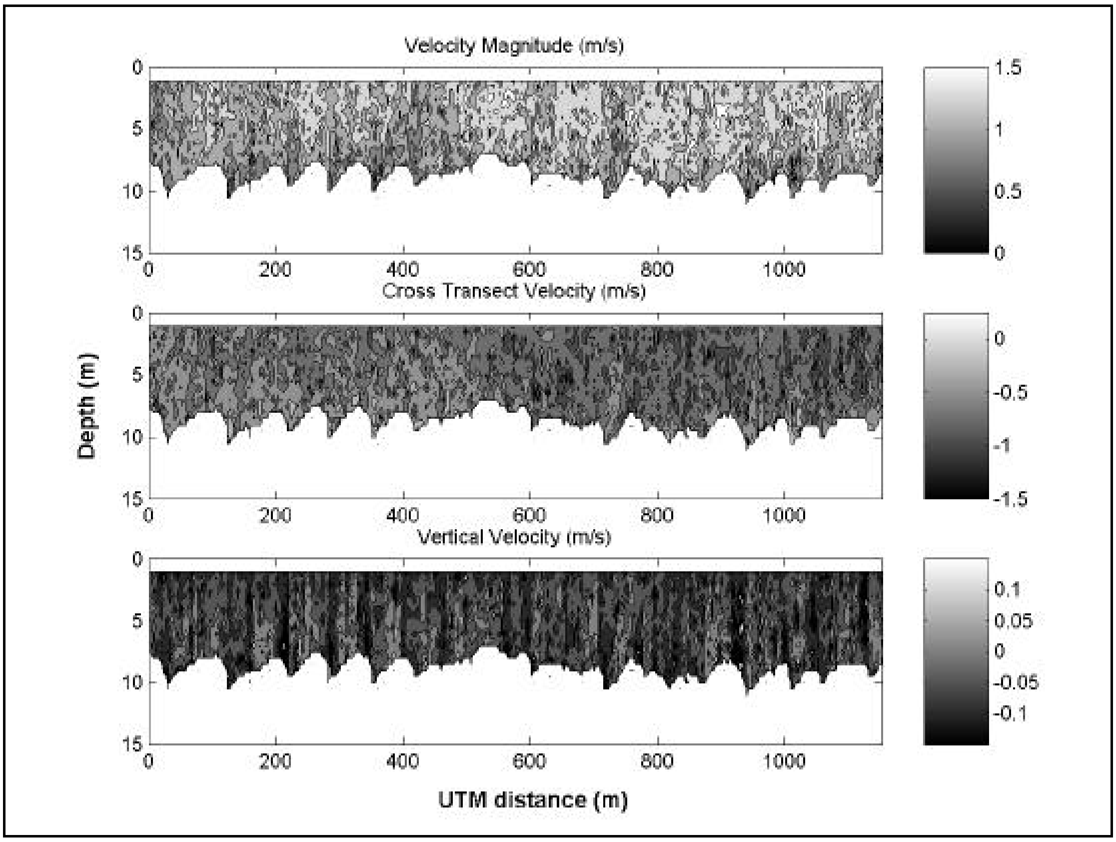

Fig. 4 – Contour maps of the measured velocity magnitude (top), cross-transect lateral velocity (middle), and vertical velocity (bottom) over the transect of dunes shown in figure 3.

Conclusions

Acknowledgments

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