

Suspended sediment dynamics over a dune in the Río Paraná

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ABSTRACT: This study examines turbulence and sediment suspension over large sand dunes in the Río Paraná. An acoustic Doppler current profiler was used to measure three-dimensional velocity, and at-a-point suspended sediment concentration and particle-size were measured with a laser *in situ* scattering transmissometer. Phase coherence wavelet analysis of time series indicates that fluid ejections sourced near the bed suspend sand into the overlying flow.

1 INTRODUCTION

Turbulence is a fundamental property of river flows and is the principal driving force behind sediment transport (e.g. Best, 2005). Turbulence is related to coherent flow structures that are generated over both smooth and dune beds (e.g. Jackson, 1976). River surfaces are often disturbed by circular patches of upwelling fluid, termed ‘boils’, that are thought to be the surface manifestation of ‘kolks’, vortices which originate near the bed (e.g., Roy *et al.*, 2004). The purpose of the present study is to investigate dune-related turbulent sand suspension by examining the coherence between time series of three dimensional flow and sediment transport over a single large sand dune in the Río Paraná, Argentina.

2 METHODS

The present study was conducted on the Río Paraná, just upstream of its confluence with the Río Paraguay, NW Argentina (27°30’S, 58°50’W; Fig. 1). The discharge of the Río Paraná during the time of surveying was ~11,000 m³s⁻¹. At the study site, the Río Paraná is approximately 2.5 km wide and between 5-12 m deep.

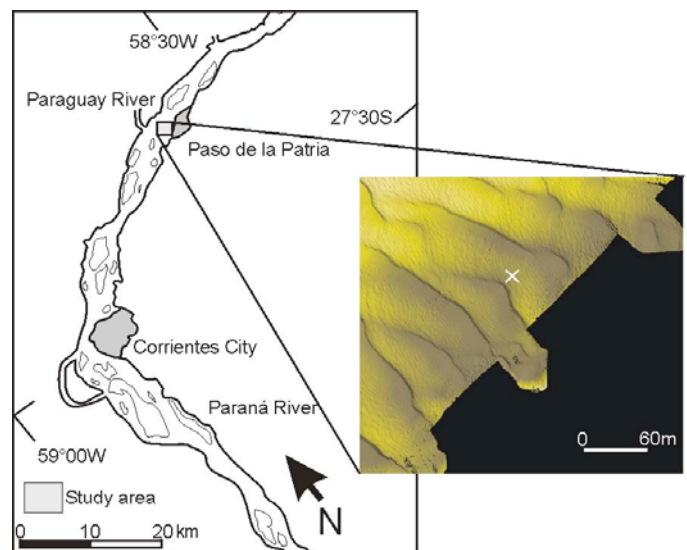


Figure 1. Map of the study area. Inset is a MBES record of the reach. Study dune shown in inset with white ‘x’.

Flow and sediment transport time series were collected from a small survey vessel on March 9th, 2004, while a bathymetric survey was conducted from a second, larger, vessel. Bathymetry was measured using a RESON™ SeaBat® 8101 multibeam echosounder (MBES), three-dimensional flow velocity was measured with a Teledyne RD Instruments® RíoGrande 600 kHz acoustic Doppler current profiler (aDcp), and suspended sediment concentration and particle size with a Sequoia® Scientific laser *in situ* scattering transmissometer (LISST). The launch

was anchored over the study dune crest and trough (Fig. 1) and the LISST was lowered a pre-determined depth and data collection was started simultaneously with the aDcp. For the deepest measurements, the LISST was lowered until it was resting on the bed, which resulted in a measurement height of approximately 10 cm.

Time series were analyzed using wavelet analysis, which allows a signal to be decomposed into both time *and* frequency (see Lane, 2007, for a recent discussion). All wavelet spectra shown in the present study are significant at 95 percent confidence limits, as tested relative to a white noise spectrum.

3 RESULTS AND DISCUSSION

Dunes in the study area range from 1 to 2.5 m in height and wavelengths between 45 to 85 m (Fig. 1). The study dune is ~45 m long with height ~2.05 m and superimposed bedforms occur on the upper stoss slope (Fig. 2). Lee side angles range from 10.3° on the highest part of the crest to the depth of the scour to 21.8° on the steepest part of the lee slope. The stoss slope is shallow, with an angle of ~3°.

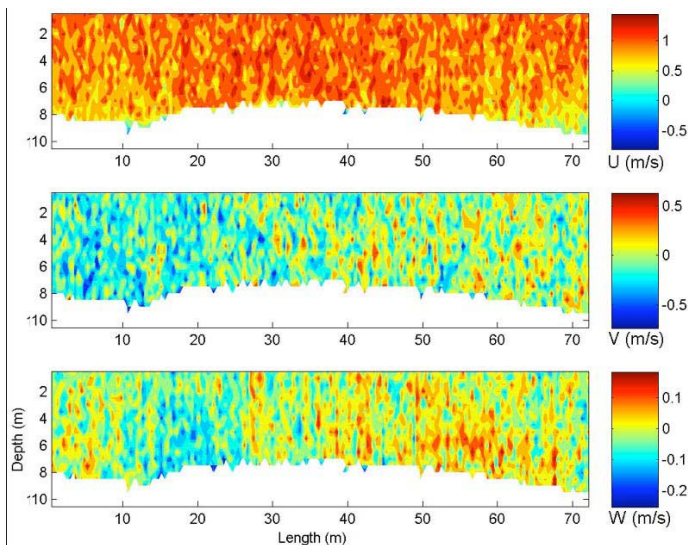


Figure 2. Contour maps of 3D flow structure over the study dune. U is streamwise velocity, V is lateral velocity and W is vertical velocity.

Flow velocities over the dune (Fig. 2) indicate flow reversal (-U values) in the dune troughs, although it is difficult to resolve flow velocity in the lee side (Parsons *et al.*, 2005). Topographic forcing (Kostaschuk *et al.*, 2004) is evident as higher, positive streamwise flow velocity (+U) and upward vertical velocity (+W) over dune crests and lower (+U), or reversed (-U), streamwise flow velocity and downward vertical velocity (-W) over the troughs.

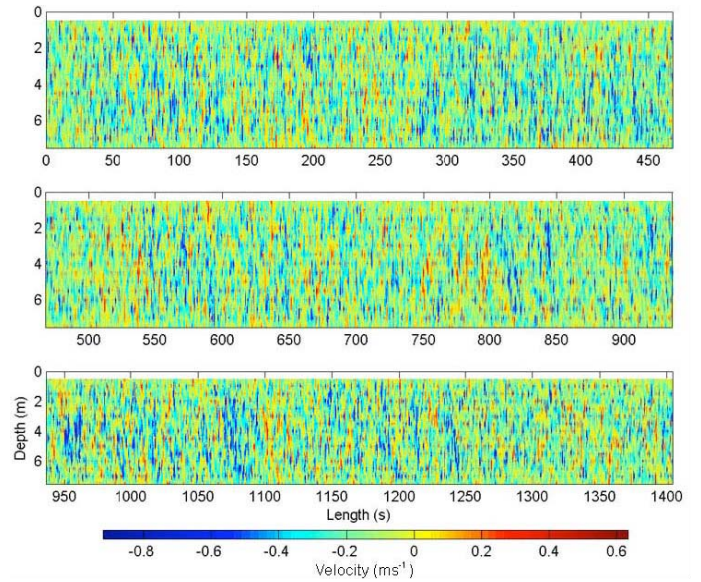


Figure 3. Time series of streamwise flow velocity (U) over the dune crest. 'Length' refers to the duration of the record.

Time series of streamwise velocity (Fig. 3) show that flow structures with relatively low horizontal velocity (e.g., ~150 to 275 s) alternate with faster moving flow (e.g., between 250 and 400 s). Vertical velocity records reveal that the slower moving flow structures are upwellings (+V) and the faster moving structures are downwellings (-V). Time series over the dune trough are similar to those over the crest and also indicate periodic flow reversals.

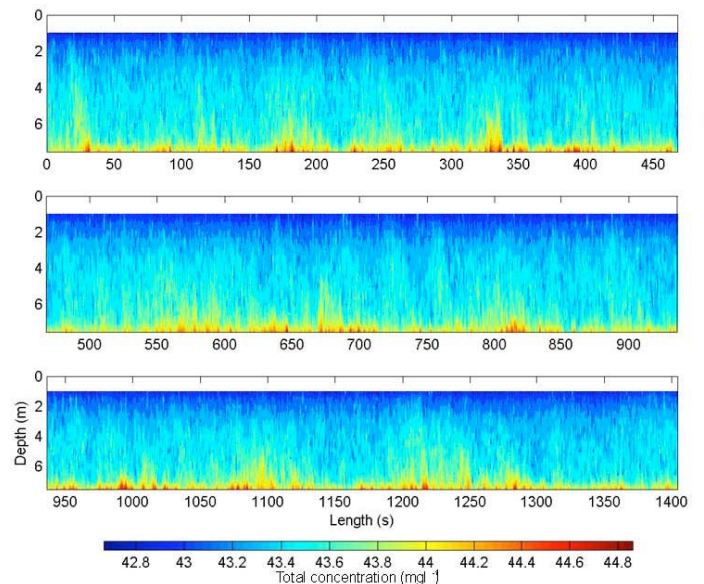


Figure 4. Time series of calibrated suspended sediment concentration (SSC) over the dune crest. 'Length' refers to the duration of the record.

Time series of suspended sediment concentration (SSC), calibrated from the aDcp backscatter and LISST data, over the dune crest (Fig. 4) reveal several pulses of sediment erupting from the bed (e.g., ~150 to 275 s, 500 to 600 s). Compared to the suspended sediment time series over the crest, pulses of suspended sediment over the dune trough are more episodic but penetrate higher into the water column.

Figure 5 illustrates the phase coherence wavelet spectrum between streamwise velocity and SSC over the dune crest. Figure 5 shows streamwise velocity to be strongly out-of-phase with the suspended sediment concentration above the dune crest. Medium-frequency structures (periods between ~50 and 100 s), as well as low-frequency structures (periods between ~150 and 350 s) are common throughout the first 1000 seconds of the time series (e.g. between 100 and 250 s, and from 750 to 950 s, at periods ranging from 50 to 90 s). The remainder of the time series is characterized by strongly out-of-phase regions at periods ranging from 70 to ~280 seconds. Phase coherence analysis between vertical velocity and SSC shows a predominance of in-phase relations. Similar results were also found over the dune trough. This suggests that fluid ejections, structures characterized by relatively low streamwise velocity and an upward vertical velocity, are suspending the sediment. These results are consistent with those of several other studies (e.g., Schmeckle *et al.*, 1999).

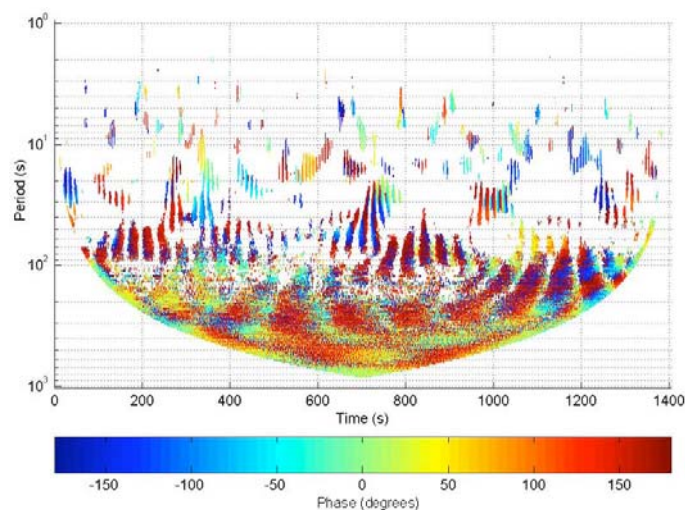


Figure 5. Phase coherence wavelet spectrum of streamwise velocity and calibrated suspended sediment concentration 3 m above the dune crest.

4 CONCLUSION

The main finding of this study of suspended sediment dynamics over a dune in the Río Paraná is that phase coherence wavelet analysis shows an inverse correlation between streamwise velocity and suspended sediment concentration (SSC) and a positive correlation between vertical velocity and SSC. This indicates that fluid ejections sourced near the bed are suspending sand into the overlying flow.

5 ACKNOWLEDGEMENTS

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