COMBINING PHOTOMETRY AND WAVELET ANALYSIS FOR RESEARCH INTO TURBIDITY CURRENTS

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Turbidity currents initiated from natural and anthropogenic processes are known to have detrimental effects on surrounding marine flora and fauna. In the following study, sediment-laden currents are released in a lock-exchange flume at varying densities and over different substrates. A rectangular obstacle is placed across the width of the flume. A novel photometric method, involving capturing high spatio-temporal resolution images of the current, is used to provide a qualitative wavelet analysis of current flow dynamics. The technique benefits experimental work, where intrusive measurement techniques may not be feasible. This can be useful to provide insights into the feasibility of engineered obstacles to reduce the detrimental impact of turbidity currents on marine and freshwater habitats.

1 INTRODUCTION

Turbidity currents are formed from the release of a dense sediment-laden fluid into a less dense ambient fluid body. Buoyancy forces act upon the two fluids, causing a displacement of the ambient fluid by the denser fluid, hence a propagating turbidity current. They are initiated from both natural and anthropogenic processes, such as submarine landslides, rivers in flood, dredging and bottom trawling operations. They are of major environmental interest due to their detrimental impact on benthic environments and water quality; not only does suspended sediment have a direct effect on fauna, but turbid plumes can limit sunlight penetration into water bodies and degrade surrounding ecosystems [1]. Operations such as bottom trawling are known to initiate turbidity currents by inducing sediment resuspension [2]. This is a concern for environments such as submarine canyons, which have diverse habitats due to their intricate morphology [3]. Moreover, these diverse habitats can contain species of economic importance, thus fishing zones are often located nearby [4]. Other operations, such as dredging can have a secondary effect on the surrounding environment. In some cases, dredged material may contain contaminants, which are then dispersed by turbidity currents over a larger bed area [1].

Currents initiated from slope failure are unpredictable and reach vast continental areas, therefore it is infeasible to manage their behaviour. However, there is scope to mitigate currents formed from anthropogenic sources, where initiation is much more predictable. Recent research has looked at mitigation options for the sedimentation of reservoirs by turbidity currents, in both experimental and numerical capacities [5, 6]. Such research provides a starting point for managing turbid plumes resulting from dredging and bottom trawling. Furthermore, capturing detailed flow characteristics of turbidity currents interacting with obstacles is needed to assess how effective obstacles are at dissipating internal forces within the current and their dimensional relationship with bed roughness, slope and current density. Such information will provide further insight into mitigating design options and plume management.

Photometric techniques for characteristic flow measurement of experimental gravity currents have grown in popularity in recent years. They are non-intrusive on flow, can provide simple velocity measurements of current boundaries and capture visual characteristics. They are also comparatively cheap compared to other techniques. However, photometric techniques at present are limited in their use to opaque, sediment-laden currents. They have not been explored for in-depth quantitative measurement of flow structures. Wavelet analysis of current head velocity has the ability to quantify changes in flow dynamics, hence flow evolution by distributing velocity variance over time-space dimensions [7].

The present paper introduces briefly the physical modelling and discusses in more detail subsequent analysis of frontal current boundary velocity data with a combined photometry and wavelet transformation approach. The interaction of a turbidity current with an obstacle over a smooth and rough bed substrate is compared to provide further insights into how obstacles affect the flow dynamics of turbidity currents.

2 METHODOLOGY

2.1 Experimental setup and procedure

Experiments were conducted in a 0.4 m wide, 5 m long lock-exchange flume in the Hydraulic Engineering Laboratory at the University of Auckland. The flume had a slope of 2% and had a removable D_{50} = 0.8 mm sand substrate floor for selected runs. For each experiment tap water was filled to a height of 0.3 m. Sediment slurry comprising a 1:1 ratio by mass of kaolinite and spherical glass beads was mechanically stirred in a bucket with 6 L of water and added to a lock-box at the upstream end of the flume. The lock-box gate was immediately opened, allowing initiation of a turbidity current with initial density of 1020 kg m^{-3}. An analysis area of 0.6 m width was located 3.7 m from the lock-box gate. This distance was chosen to allow the current enough time to adapt from the initial slumping phase to the viscous-dominant phase. A total of four tests were completed (N1, O1, N2 & O2). For N1, a turbidity current was released over the smooth acrylic bed and recorded as it passed through the analysis area. For O1, a 140 mm wide, 50 mm high rectangular obstacle was installed across the width of the flume in the analysis area. N2 & O2 were identical to N1 & O1, respectively, however the rough sand substrate was installed on the flume bed. Ultrasonic Doppler Velocity Profiler (UVP) probes were located within the flume, however the recorded UVP data are not discussed in this paper.

2.2 Image capture and processing

For all experiments, a Lumenera LT425 CMOS camera coupled with a Nikkor 50 mm f/1.8 lens was installed adjacent to the analysis area. Raw images of the current passing through the analysis area were captured at a resolution of 2048 x 1502 pixels and at a frequency of f = 120 Hz. All images were first batch-corrected for lens distortion, using an automated action in Photoshop CS6. MATLAB was then used to crop and generate a binary image, based off the thresholding technique. The largest binary boundary (turbidity current boundary) within each image was automatically located and delineated to provide a spatial vector (Figure 1). The coordinates of the leading current boundary (frontal nose) were located using an algorithm, allowing the nose to be spatially tracked over time. The pixel-pixel coordinates were converted to metric distance through calibration of the images against a reference ruler attached to the flume wall. The coordinates were then used in conjunction with the capturing frequency to produce horizontal velocity-time data for each test.

Figure 1. Vector delineation of an image from experiment N2 using the thresholding technique. The identified frontal boundary of the current is shown by the red ‘x’.

Large velocity spikes were evident in the datasets due to errors in delineation of the current boundary in regions where the current was obstructed by UVP probes. Therefore a series of filtering methods were applied to the data. Any data outside 1 standard deviation of a n±50 point moving mean were replaced with the average of the two preceding and proceeding velocities. Each end of the dataset was concatenated with the average of the first and final 100 velocity readings in a 100 point matrix, respectively. All velocities were then padded with a moving average of 20 points and the concatenated matrices were removed (Figure 2).

2.3 Wavelet analysis

A wavelet transform method developed by Torrence and Compo [8] was performed on velocity data for each of the three experiments, allowing peaks in power/variance distribution to be identified in relation to time. Conventional Fourier transforms do not take into account time-variance relationship, which is of interest in the case of current interaction with obstacles. Hence, a one-dimensional wavelet transform was applied to the velocity data series using a Morlet wavelet basis function. The Morlet wavelet was chosen as it has been used previously for transforming velocity data from sediment-laden turbidity currents [7]. Power distribution was compared against a red-noise spectrum, and the chi-squared significance test at the 95% level was applied to identify peaks in variance.

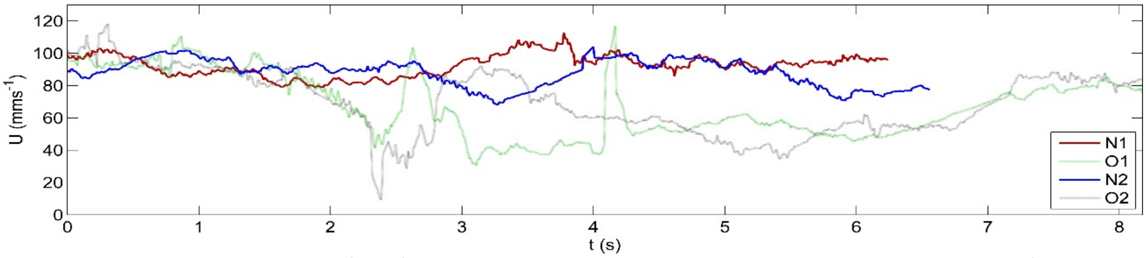

Figure 2. Temporal velocity plot of the four experiments. There is a noticeable decrease in velocity for experiments O1 & O2 at t = 2. Experiments N1 & N2 have reasonably consistent velocities.

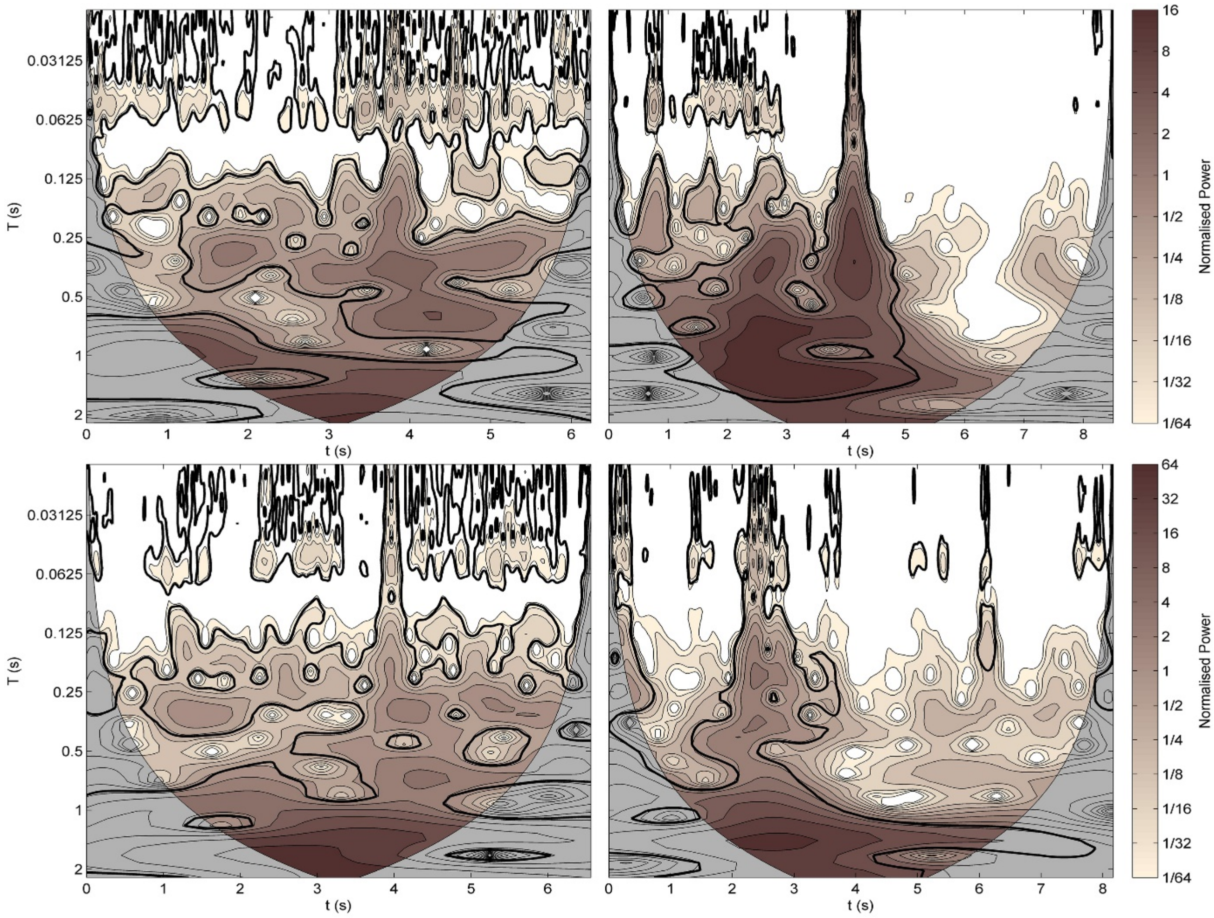

Figure 3. Wavelet transforms of turbidity current nose velocities from four different experimental arrangements. From top left: Experiments N1, O1, N2 & O2. Bold contours outline the 95% confidence level for a red-noise background spectrum. Gray area represents the Cone of Influence (COI), where edge effects become significant.

3 RESULTS & DISCUSSION

Filtered velocity data for all experiments are shown in Figure 2. N1 & N2 both show relatively consistent velocities. N1 has a slightly higher net velocity, evident by the current traversing the analysis area t~0.33s faster than N2. This is due to increased drag forces from greater friction of the rough bed in N2. O1 & O2 both showed a sharp reduction in velocity at t=2s, when the current collided with the obstacle, and gradual increases in velocity from there on as the current recomposed. O1 shows a sharp velocity spike at t=4s that was not filtered correctly, showing further optimisation of the filtering process is needed. Figure 3 shows wavelet transformations of all four experiments. Immediately, it can be seen that there are both significant differences and similarities between the plots. All plots appear to show a void of variance in the period band of 1/16 – 1/8s. This may be due to interference from AC frequency (T=0.02) of the lighting rig. Experiments N1 & N2 both show similar wavelet transformations, with no immediate differences in variance distribution. Both experiments show a large collection of power spectra in the high frequency T<1/16s band. Noticeably, O1 & O2 both have regions of high frequency variances (T=1/32 - 1/16) before the current reaches the obstacle (t~2-3s), however, after a region of increased variance over a wide frequency band during obstacle collision, both experiments show minimal variance of frequencies higher than T=1/8. This suggests that the gradual acceleration of the current front after interaction with the obstacle (as seen in Figure 2) may cause an elongation of eddies at the frontal boundary, resulting in reduction of high frequency oscillations. Presence of the obstacle causes a large decrease in current velocity, hence a reduction in inertial forces within the current head. The large oscillations in variance caused when the current interacts with the obstacle suggest that there is a sudden increase in the spatial reach of current eddies, which is confirmed through visual analysis of the current. This is likely to result in greater mixing and entrainment of ambient fluid, which assists in reducing the buoyancy forces within the current. This implies that rectangular obstacles may be effective in reducing the horizontal reach of turbidity currents initiating from anthropogenic sources, however more research is needed into how current density, substrate roughness and obstacle shape might affect the velocity oscillations.

4 CONCLUSION

Wavelet analysis has successfully been applied to velocity data of turbidity currents captured with photometric techniques. Increasing bed roughness is shown to not have any significant effect of the velocity variance distribution of both obstructed and non-obstructed turbidity current fronts. The presence of an obstacle caused a large increase in variance upon obstacle impact, and appears to remove all high frequency oscillations. The study showed that a rectangular obstacle is effective in reducing inertial forces within the current head, and that installation of obstacles may be a feasible option to mitigate the environmental impacts on turbidity currents initiating from anthropogenic sources, which will be relevant for ecohydraulic applications in future. Further research is needed to determine what effect current density has on velocity variance of obstacle interaction and how velocity variance is related to obstacle dimensions.

5 ACKNOWLEDGMENTS

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http://atoc.colorado.edu/research/wavelets/

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