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Validation of LSPIV to Acquired 2D Surface Flow Fields in Vegetated Lowland Rivers

Validation of LSPIV to Acquired 2D Surface Flow Fields in Vegetated Lowland Rivers

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ABSTRACT: The reliability of the Large Scale Particle Image Velocimetry (LSPIV) methodology to measure 2D surface velocity fields in a vegetated low land stream is assessed. To this end, LSPIV measurements are compared with flow velocities obtained with an electronic current meter (ECM). The measurements were performed monthly, during one seasonal cycle at four different locations, allowing the evaluation of the LSPIV measurements in relation to increasing vegetation cover. Overall, the agreement observed between the mean velocities obtained with ECM and LSPIV is very good for the winter and spring season. Discrepancies arise in the summer with high biomass and high heterogeneity of the flow patterns. The seasonal average frequency of reliable LSPIV measurements is high; i.e. 97, 95 and 78 % in winter, spring and summer respectively. The results prove that LSPIV is an inexpensive methodology, which provides high resolution and reliable data to study flow field distribution in vegetated rivers.

Keywords: Image techniques, Large-scale particle image velocimetry, Validation, Field application, Vegetated river, Flow patterns

1 INTRODUCTION

In-stream vegetation occurrence controls river ecosystem functioning (Carollo, Ferro et al. 2002). Aquatic plants or macrophytes are the dominant factor determining the hydraulic capacity and ecological status of low-land rivers (Nikora, Larned et al. 2008; Sukhodolov and Sukhodolova 2010). Macrophytes development is governed by dynamic interactions with the environment, the so called- scale-dependent feedbacks. Several experimental studies have demonstrated the existence of a dynamic interaction between flow patterns and plant growth for many ecosystems. For instance, (Schoelynck, de Groote et al. 2012) showed that the dependent feedback processes between macrophytes growth and environmental conditions also occur in fresh water river ecosystems and suggest plant -flow interactions as the main feedback mechanism of macrophytes growth control.

Nowadays numerical models are a useful tool to capture and understand the dynamics of heterogeneity resulting from plant-flow interactions (Green 2005). The heterogeneity of plant flow interaction shows that 1D modelling has a fundamental restriction for accurate modelling spatial heterogeneity and 2D numerical models are necessary. However, to obtain realistic prediction the results obtained from the numerical models need to be calibrated and validated with field data from different flow and vegetation conditions. Historically, conventional techniques (e.g., ECM, ADV) have been extensively developed to obtain reliable hydraulic measurements. For instance, the electromagnetic current meter (ECM) is recommended for flow velocity measurements in vegetated low land rivers, providing reliable measurements with an accuracy up to 0.5 %, with a range of measurements between 0.0 and 2.5 m/s (De Doncker, Troch et al. 2008). However, gathering of such amount of information with classical point measurements system is prohibitive in terms of efforts and cost (Baptist, Babovic et al. 2007).

This paper proposes the application of Large Scale Particle Image Velocimetry (LSPIV) to obtain readily a high resolution data of surface flow velocity fields in a vegetated low land river. However, to the best knowledge of the authors the reliability of LSPIV to obtain surface velocity fields in vegetated river ecosystems has not been tested.

The central goal of the manuscript is therefore twofold: (i) describe the methodology of LSPIV used to obtain surface velocity field in a lowland vegetated river and (ii) assess the reliability of LSPIV by means of the comparison with an electromagnetic current meter (ECM).

2 METHODOLOGY

2.1 *Study area*

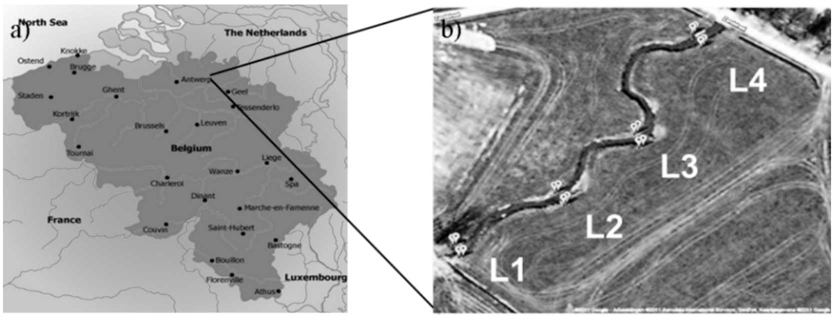

Figure 1. The location of the river reach and locations of the field campaigns (L1, L2, L3 and L4) in the Zwarte Nete River.

The study area is located in the Zwarte Nete, lowland river in the Scheldt catchment in the North East part of Belgium. The selected reach is 175 m long and has an average width of 4.5 m (Figure 1). In winter, the seasonal averaged velocity calculated from ECM measurements is 0.38 m s^{-1} and the measured average discharge is 0.335 m^3 s^{-1}. During spring season a mean flow velocity of 0.31 m s^{-1} and an average discharge of 0.36 m^3 s^{-1} is measured, while, the average velocity and discharge decrease in summer reaching an average of 0.17 m s^{-1} and 0.25 m ^{3} s $^{-1}$ respectively. Water depth rarely exceeds 1 m and the maximum velocities measured are 0.45 m s^{-1}.

There are four main species of vegetation in the stream; *Callitriche platycarpa*, *Myriphyllum spicatum, Elocea Canadensis* and *Sparganium emersum*. During winter, there is no vegetation present in the stream. While in spring, the dominant species is *Sparganium emersum.* The vegetation reaches it is maximum density in summer, characterized by an irregular distribution with a wide range of heights and sizes.

2.2 *Field measurements and image processing*

Monthly field campaigns were performed at four locations (L1, L2, L3 and L4) from April to August (Figure 1b) to collect the annual variability of surface flow velocity patterns determined by vegetation occurrence. The LSPIV image time series were recorded from the edge of the stream in a fixed position for each location. The camera was installed 4 meter high at the top of a mast with the optical axis positioned perpendicular to the water surface. During the image recording, seeding particles were manually spread upstream over the water surface. The underling concept of LSPIV is to take a series of photos in quick succession in such a manner that the flow velocity can be inferred from the displacement of the tracers spread on the water surface. The open source software PIVlab v1.32 (W. Thielicke and Stamhuis 2010) was used to process the image time series. The mean 2D flow field was calculated by averaging instantaneous vector fields over the complete time series of images (Figure 2). A summary of the main information and parameters applied during the LSPIV methodology is given in Table 1.

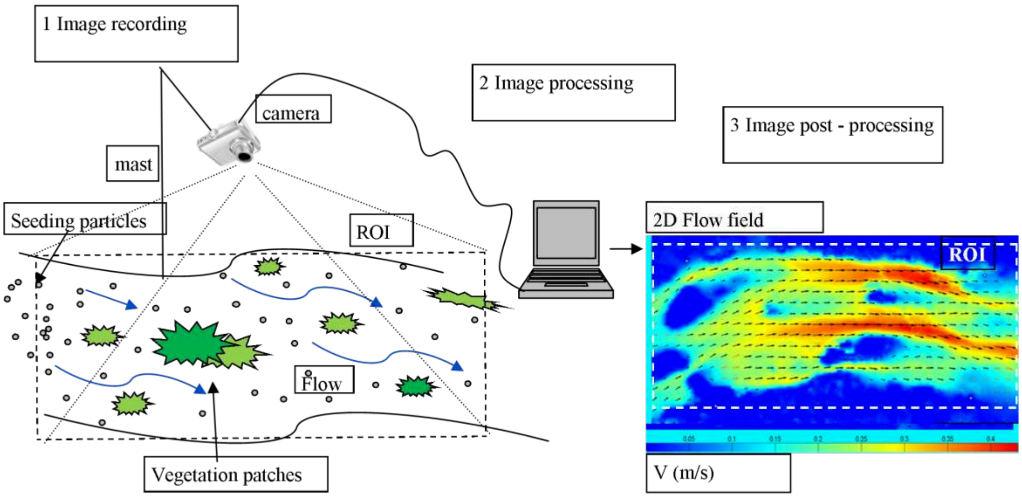

Figure 2. Schematized illustration of the LSPIV methodology and main steps followed to obtain the velocity vectors in the region of interest (ROI).

Table 1. Summary of the LSPIV information and parameters.

Parameter	Value
Number of images in each time series	60 images
Time step between images	0.14 s
Image resolution	1 pixel = 0.002 m
Interrogation area (adaptive multipass)	Pass 1: 64 x 64 pixel2 Pass 2: 128 x 128 pixel2
Seeding density	≈ 20 particles / 64 x 64 pixel2

During the field campaigns, stream velocity measurements with an electromagnetic current meter (Valeport 2007, Model 801) previously calibrated in laboratory conditions were performed in parallel with the LSPIV image recording. To obtain the ECM measurements, one fixed cross section was selected in each location. Averages of 10 horizontal measurements were obtained along the width of each cross section with a horizontal spacing of 30 cm. The ECM measurements depth was 5 cm beneath the water surface in order to compare with free surface velocities obtained with LSPIV. The ECM was kept stationary for at least 30 s with a frequency of 1 Hz obtaining as a result the time averaged ECM velocity in each measurement point of the cross section (see Figure 4).

3 RESULTS AND DISCUSSION

The results presented were obtained following the LSPIV methodology and by applying the field campaigns described in section 2.2. Among all data gathered, one field campaign with the vegetation characteristic in each season is selected; winter (non-vegetated), spring (submerged vegetation) and summer (floating and submerged vegetation).

3.1 *LSPIV flow fields*

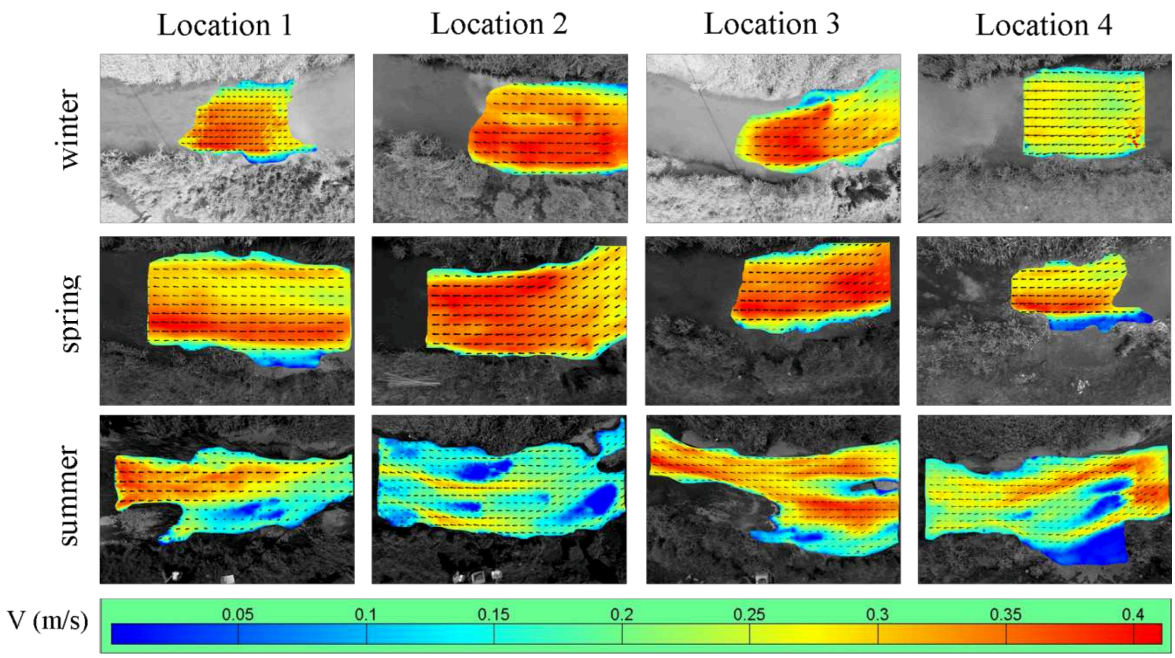

Figure 3. Plan views and the time average velocity field corresponding with the four locations (L1, L2, L3 and L4) in winter, spring and summer season. Velocities in the main channel vary from 0 m s-1 in blue colour to 0.45 m s-1 in red colour.

Figure 3 summarizes the surface velocity patterns obtained with LSPIV over the areas covered with seeding particles. The free-surface velocity fields show an increasing flow heterogeneity correlated with vegetation occurrence. In winter we observe a homogeneous velocity field with maximum horizontal velocity gradients situated close to the river banks.

During the spring the low shooting density of *Sparganium emersum* allows the flow to penetrate trough the patch, reducing the impact in the mean velocities (Sand-jensen 1998). The vegetation density increase reaching the maximum values during the summer when the flow patterns become highly irregular. Maximum velocities are measured in the free path of the stream, while the lower velocities correspond with the location of vegetation patches and stagnant regions close to the river margins. Furthermore, complex flow patterns with reversing flow and reduced velocities are observed in the wake areas behind patches. It is noted that measurements in summer clearly cover more area with one measurement. This is because additional experience of the particle seeding resulted in a better initial particle coverage, which points out the importance of adequate seeding.

3.2 *LSPVI –ECM comparison*

The evaluation of the LSPIV mean velocity field is made through a direct comparison with the ECM measurements obtained over the cross section. Since the LSPIV spatial resolution is higher than the ECM, each of the ECM measurements was compared to the nearest LSPIV measurement over the cross section. Larger velocity deviations observed in spring and summer reveals a higher unsteadiness of the flow. The turbulence generated by the undulant movements of the plants increase the fluctuations on the velocity range leading to an increment of the measurement deviation (Sand-Jensen and Pedersen 1999) (see Figure 4).

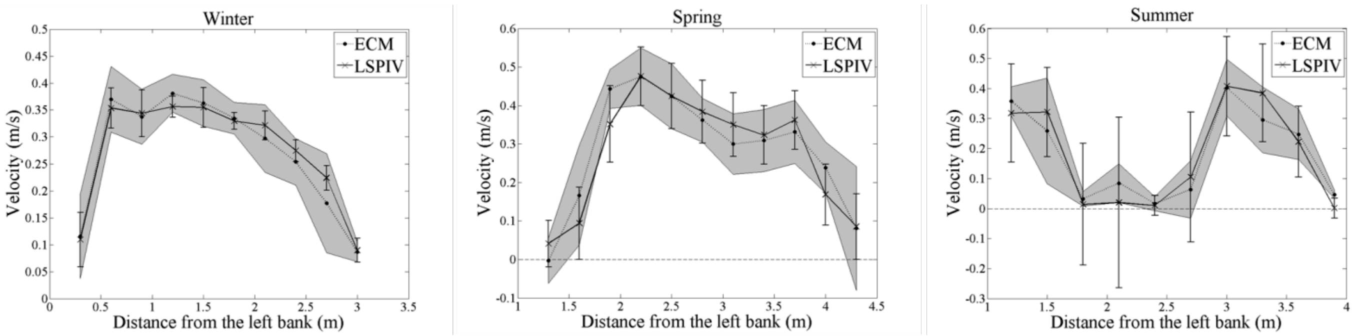

Figure 4. Comparison of the ECM and LSPIV averaged velocity over the cross sections for three locations in winter, spring and summer. The shadowed area and error bar corresponds with 95% confidence interval (CI) for the ECM and LSPIV measurements.

The discrepancy remains low in winter and spring, but an increment is observed in summer season (see Figure 5, upper panel). To gain more insight on the LSPIV reliability in each season, we perform a null hypothesis (significance level $\alpha = 0.05$) to know if a statistical significance between each ECM - LSPIV measurements exist. Figure 5 (lower panel) shows the percentage of reliable LSPIV measurements for each season. The frequency of reliable measurements obtained for winter and spring is 97 % and 95 %. During the summer season the percentage of reliable measurements decreases up to 78 %. The level of agreement between the ECM-LSPIV measurements is high, however, several discrepancies between ECM and LSPIV measurements do exist.

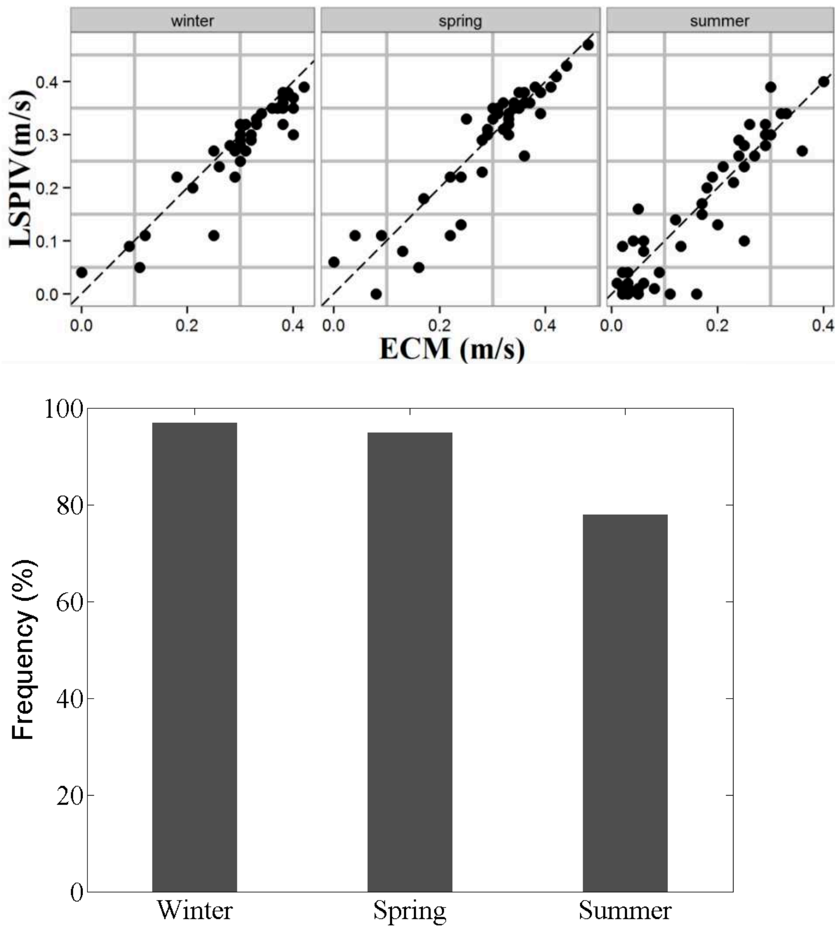

Figure 5. Comparison of all the ECM –LSPIV velocity measurements performed and frequency histogram of total number of reliable LSPIV measurements for each season; winter, spring and summer.

A rigorous LSPIV uncertainty analysis of the surface velocity field by a direct comparison with a current device is a complicated task. When LSPIV is assessed through a direct comparison with ECM measurements a certain level of discrepancy should be expected as consequence of the inherent properties of the techniques:

- The LSPIV time series were recorded over 3 s while the ECM measurement time was 30 s.
- The geometric dimensions of the measurement area or sampling volume of the techniques should be taking into account to calculate and compare the mean velocities. In case of LSPIV, each mean

velocity vector is obtained in each interrogation area of 12 x 12 cm, whilst, the ECM calculates the mean velocity corresponding with the cylinder of 2 cm diameter and 1cm height.

- Measurement depth; LSPIV provide measurements of the free surface water and ECM rom some centimetres (5-10 cm) beneath the water surface.

In general, the capacity of LSPIV shows several advantages compared with ECM. For instance, LSPIV measures the full magnitude of the velocities regardless the flow direction, which is an advantage to provide high spatial resolution data of the complex flow patterns. However, during the summer season it is not possible to obtain LSPIV reliable data in the areas where the density of floating vegetation is too high to allow the seeding particles follow the water motion.

4 CONCLUSION

The results presented here show that LSPIV can be used as a time-cost effective technique that provides results with very high spatial resolution at ecosystem scale. As such, the LSPIV technique can contribute with a great amount of detailed data to gain new insight in developing flow velocity in vegetated rivers. Based on the achieved insight, further research is needed to provide a deeper analysis into LSPIV uncertainty in vegetated rivers to perform reliable measurements.

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