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# On the Use of Surface PIV for the Characterization of Wake Area in Flows Through Emergent Vegetation

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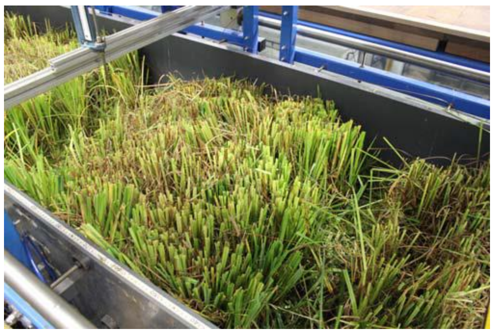
# Objectives

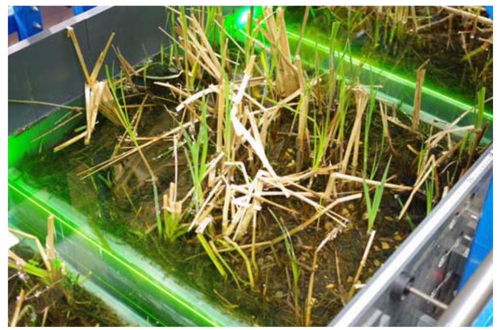
- Sensitivity analysis of the relevant parameters for application of Surface Particle Image Velocimetry (SPIV) for small-scale mapping of velocity fields and the characterization of flows through vegetation.

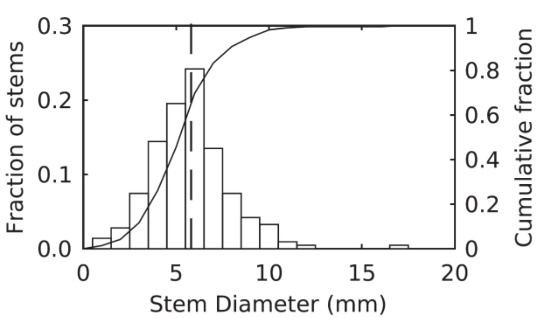
- Relate the velocity maps obtained to the problem of quantifying the proportion of a flow field occupied by stem wakes, a key descriptor for solute transport modelling.

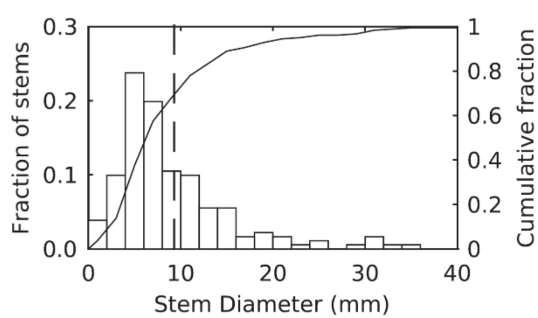
# Why artificial vegetation?

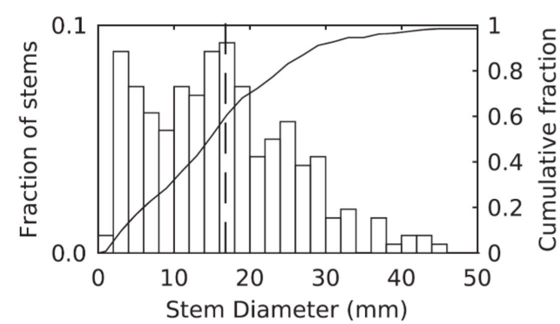
*Carex* *Winter Typha* *Summer Typha*








What about $Re_d$, $C_D$, $\overline{C_D}$, …

# Surface PIV - Definition

Velocity measurements often present a trade-off between extension and frequency.

- Acoustic Doppler Velocimetry (ADV), Laser Doppler Anemometry (LDA).

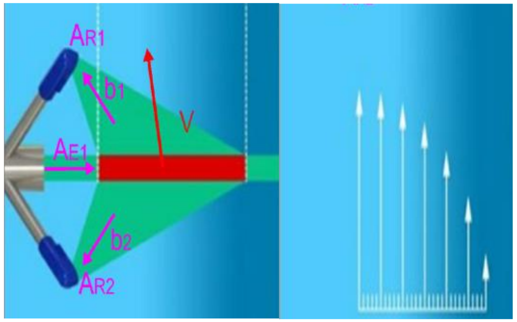
High recording frequency, single point.

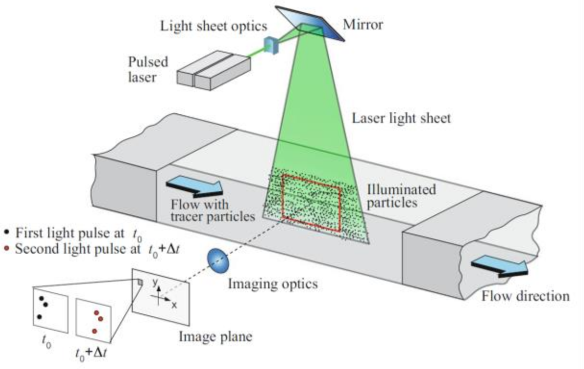
- Particle Image Velocimetry (PIV), Particle Tracking Velocimetry (PTV).

Spatial (2D-3D) measurements. Requirement of specialized illumination and image acquisition equipment.

- Surface PIV

Economic alternative to conventional PIV.



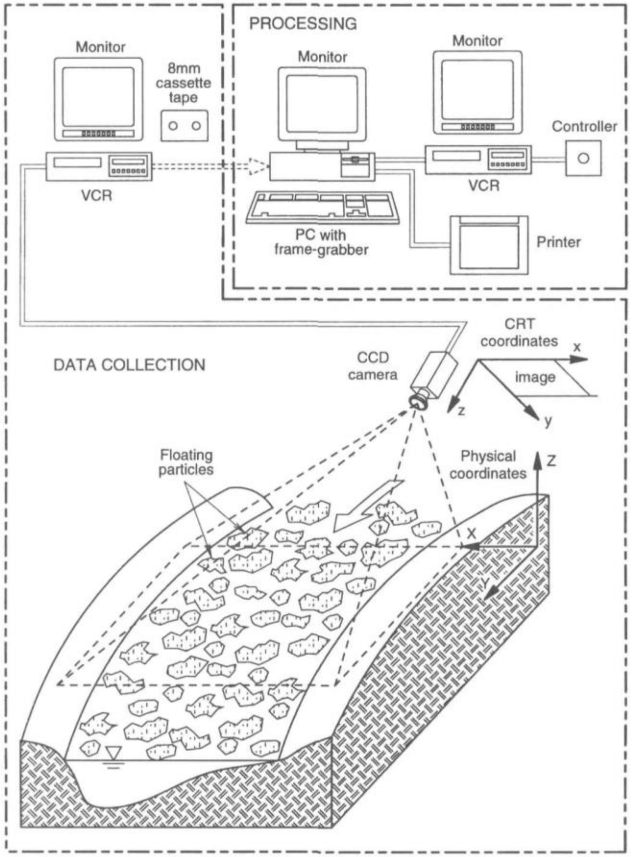
# Surface PIV - Definition

Advantages

- Useful for in situ applications, e.g. rivers, coastlines, etc.
- The mathematical framework developed for conventional PIV and PTV is applicable for SPIV

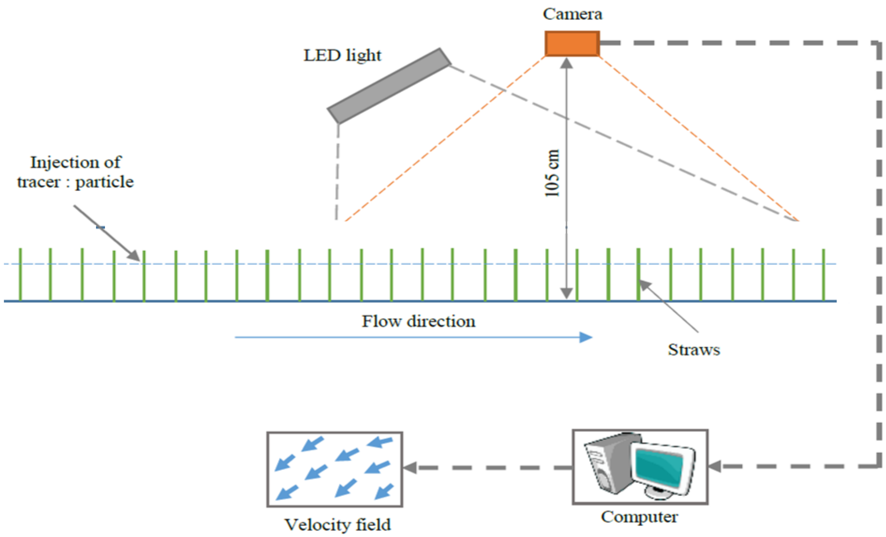
Shortcomings

- Extrapolation of surface variations to the mean flow are limited due to boundary effects.
- To date only mean flow features have been extracted.

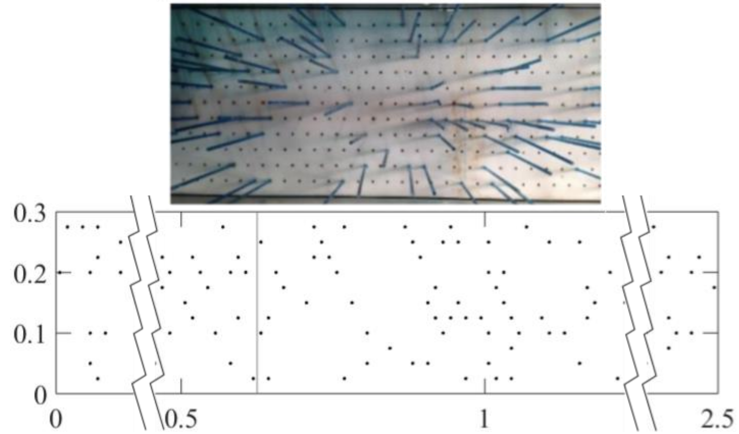


# Experimental Configuration

Scheme of experimental configuration (Elevation)




Random distribution of vegetation (plan view)




- Emergent vegetation: plastic straws $d = 4$ mm
- Vegetation Density: $n = 398$ stems/m$^2$
- Solid Volume Fraction: $\varphi = 0.005$

Image Acquisition and Illumination equipment


- Image Resolution: 3840 x 2160 pixels
- Recording Frequency: 25 fps

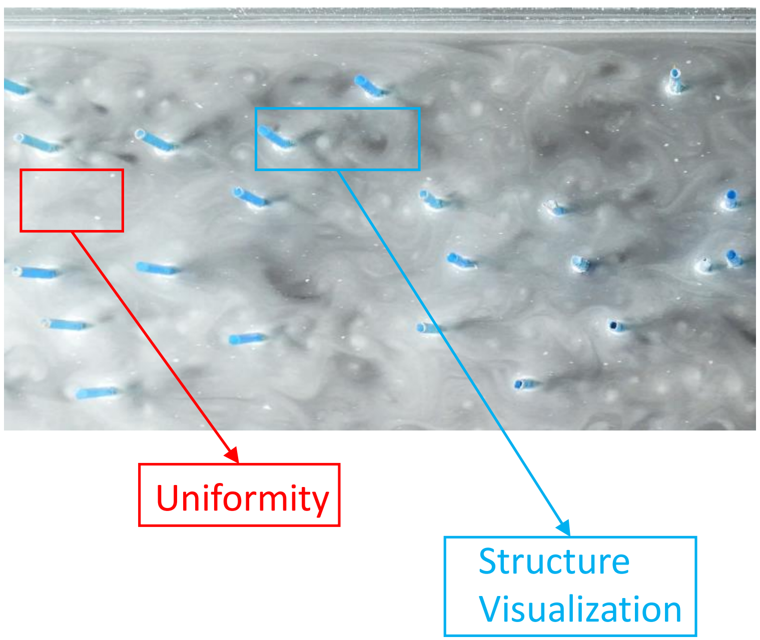
Flow conditions tested

| Test | Mean Velocity mm/s | Stem Reynolds No |
|---|---|---|
| 1 | 13 | 47 |
| 2 | 20 | 73 |
| 3 | 40 | 145 |
| 4 | 69 | 251 |

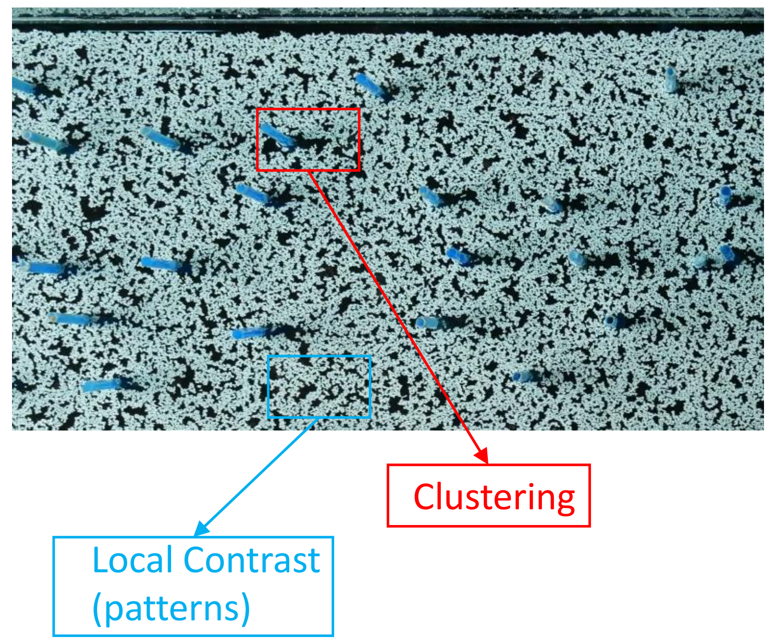
# Sensitivity Analysis – seeding particles

Higher Particle Image densities are desired for Surface PIV. However, differences in particle size can have effects on the final quality of velocity information.

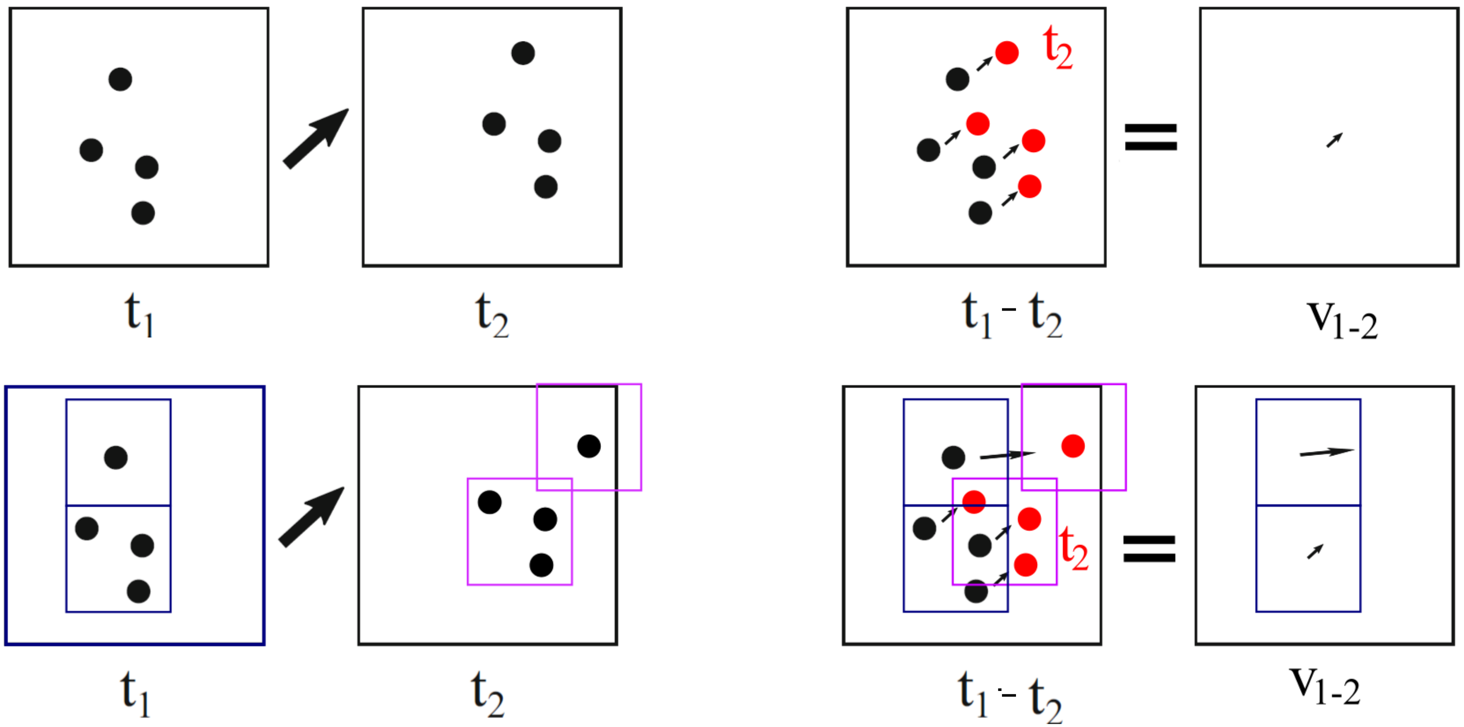
Small Particle Size




Large Particle Size



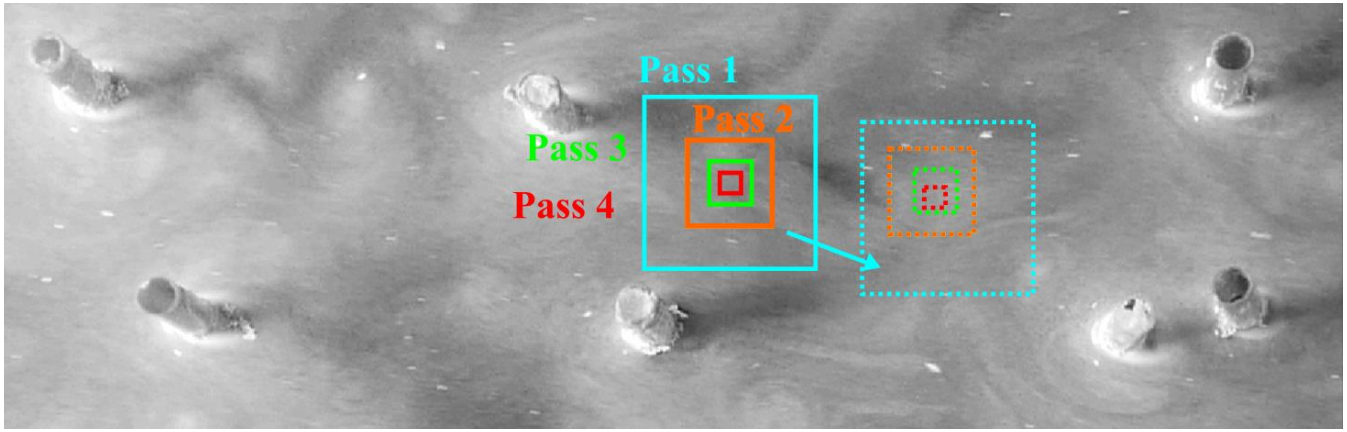
# Sensitivity Analysis – Interrogation Window




To capture a wider spectrum of velocities, correlations are computed sequentially with interrogation windows of different sizes. Each correlation with a single window size is called a pass.

# Sensitivity Analysis – Interrogation Window

Using various passes reduces noise and allows for the calculation of small scale velocities, by decreasing sequentially the size of the following interrogation window.

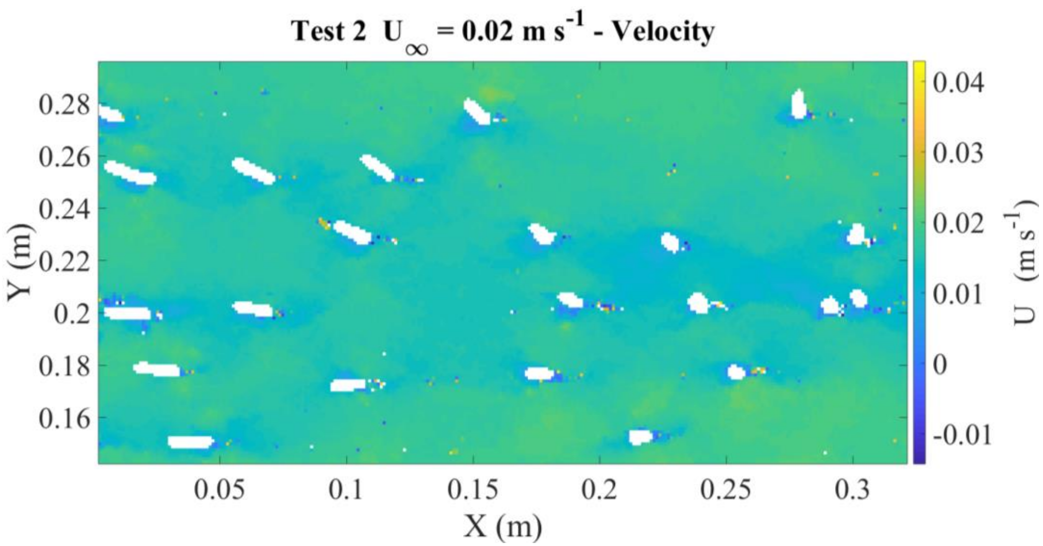


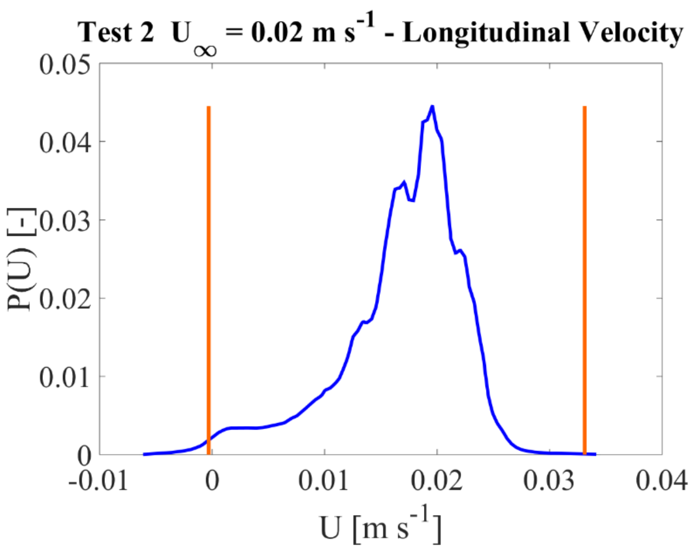

Resolution Analysis: Fine Resolution for the smallest possible velocity fluctuations, Intermediate Resolution for a conventional PIV window size, and a Coarse Resolution, which is equivalent to the ones used for SPIV.

| Resolution | Pass 1 [px*px] | Pass 2 [px*px] | Pass 3 [px*px] | Pass 4 [px*px] | Large Part. Size | Small Part. Size |
|---|---|---|---|---|---|---|
| Coarse | [256 * 256] | [128 * 128] | [64 * 46] | [32 * 32] | | X |
| Intermediate | [128 * 128] | [64 * 64] | [32 * 32] | [16 * 16] | X | X |
| Fine | [64 * 64] | [32 * 32] | [16 * 16] | [8 * 8] | X | X |

# Sensitivity Analysis - Results

- A performance analysis was done to quantify the proportion of valid velocity values for each configuration. A valid value was determined based on the following criteria.




- Valid Numeric value: when the analysis software does not find a correlation high enough to consider a displacement, it yields a Not-a-Number error (NaN). A VNV is the opposite

- Values within 3 standard deviations from the global mean.

# Sensitivity Analysis - Results

Percentage of valid data

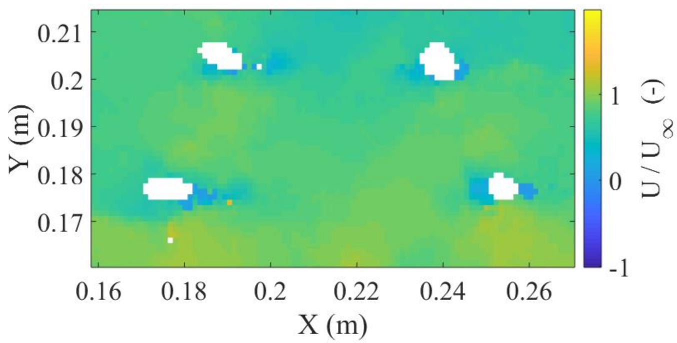
| Test | Small Particles | | | | | Large Particles | |
|---|---|---|---|---|---|---|---|
| | 4 Passes | | | 3 Passes | | 4 Passes | |
| | CR | IR | FR | CR | IR | IR | FR |
| Mean | 98.5% | **98.6%** | 89.7% | 98.7% | 97.3% | **98.7%** | 97.8% |

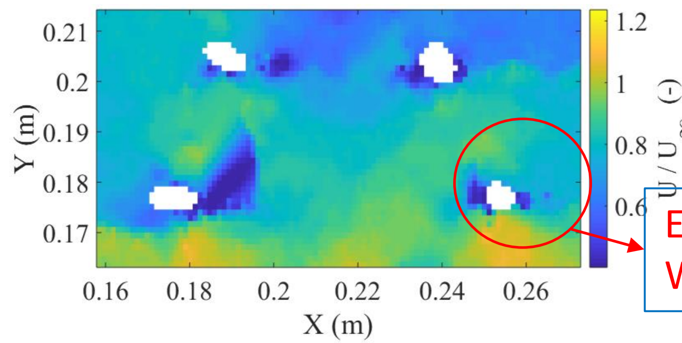
- The sensitivity analysis showed that an Intermediate Resolution produced better velocity plots
- There is a lower limit to the scale of information attainable. Smaller window sizes (below the IR) are prone to compute poorer correlations.
- More passes do not necessarily mean more reliability of information.
- However, a proportion does not tell the whole picture…

# Sensitivity Analysis - Results

Small Particles (SP) vs Large particles (LP)

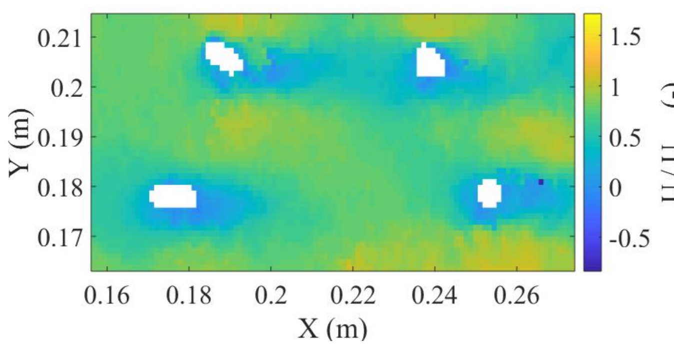
LP: More outliers were found for the tests with larger seeding particles. Which means that are prone to errors after post-processing

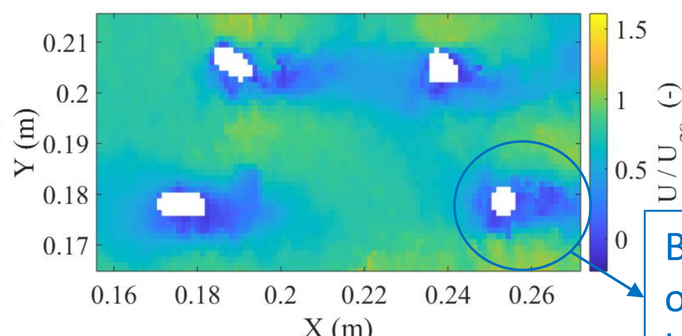



Effect of clustering. Wakes not identified

SP: Plots obtained from the tests with smaller particles produce plots with better quality and less outliers.




Better characterization of velocity variations behind stems

# Application of Results – Identification of Wake Area

Wakes behind stems are characterized by

- Increase of vorticity $w_z$
- Reduction of $U$ within the wake

$w_z$ represents time averaged vorticity, which is computed from the time averaged longitudinal and transverse maps

$$W_z = \frac{\partial U}{\partial y} - \frac{\partial V}{\partial x}$$

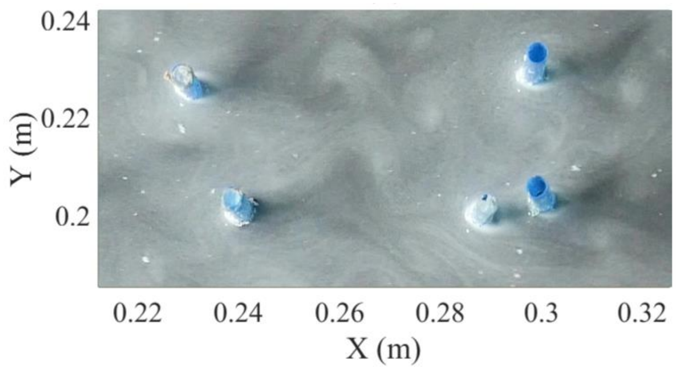
An *ad hoc* criterion for the identification of points within a wake is presented.

$$\frac{|w_{z,wake}|}{\max|w_z|} \geq \varepsilon = 0.1 \quad \text{and} \quad \frac{U_{wake}}{U_\infty} \leq \alpha = 0.5$$

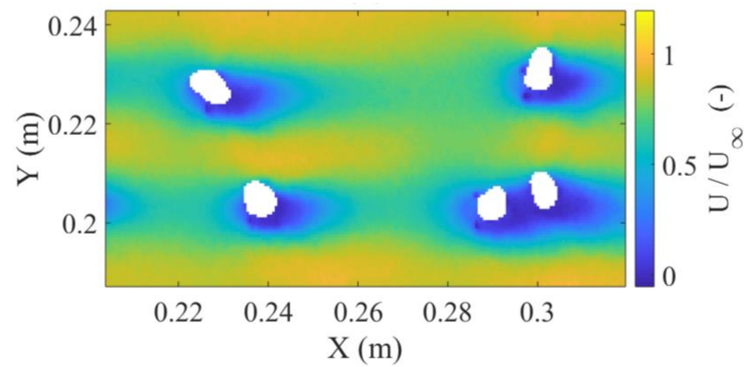
The values $\varepsilon$ and $\alpha$ are constants to be determined experimentally.

# Application of Results – Identification of Wake Area

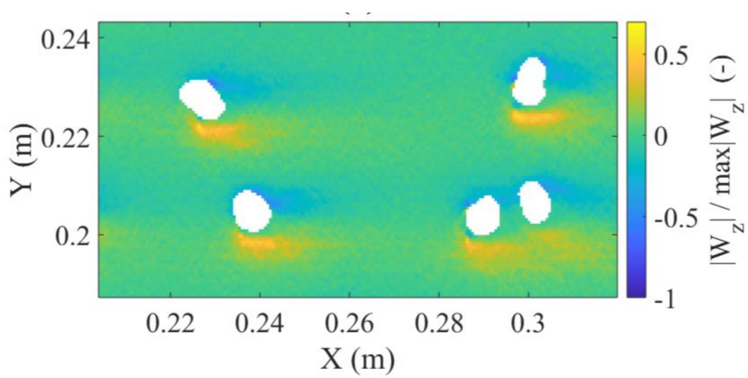
Experimental section Test 3



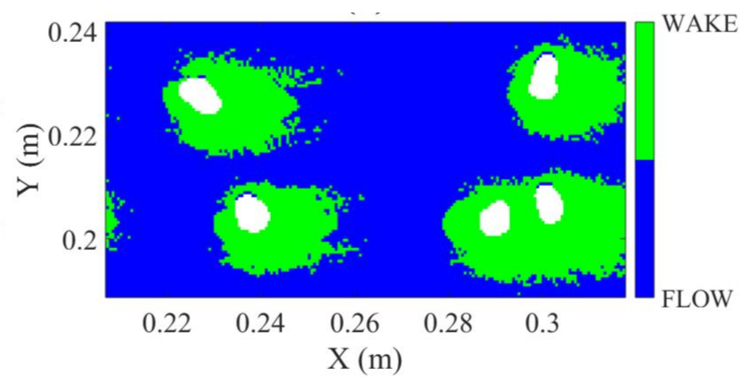

Time averaged velocity $U$




Time averaged vorticity $W_z$




Wake map



# Conclusions

- Surface PIV was tested and its use demonstrated to extract small-scale features from velocity maps
- For a successful application of Surface PIV, it was found that a combination of small seeding particles and high particle image densities provide reliable velocity maps.
- The experimental settings presented should seek to improve local pattern differentiation.
- The technique presented in this research was applied to identify the proportion of a flow field occupied by wakes, a key parameter in the study of ecohydraulics and solute transport within vegetation.