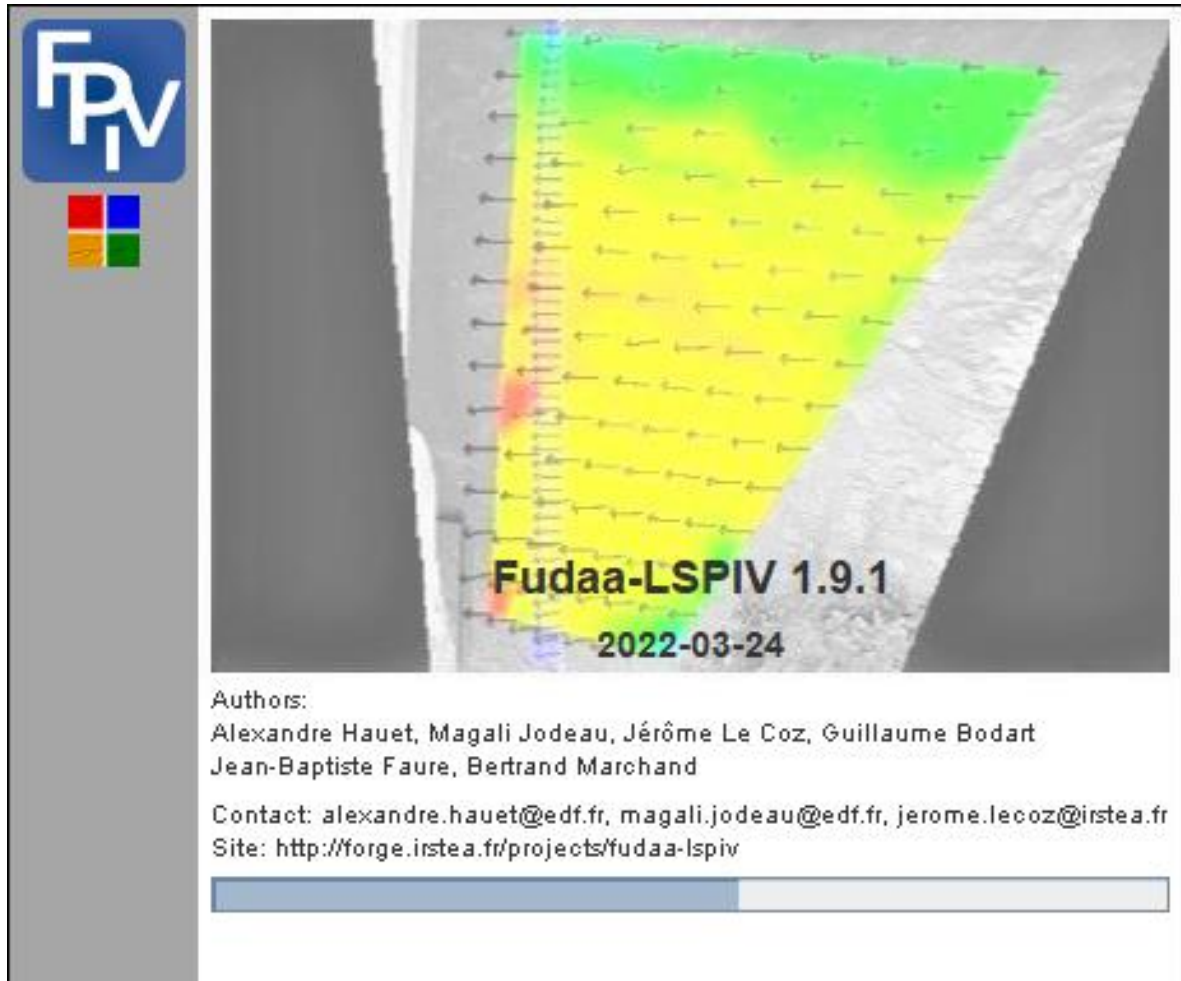


Fudaa-LSPIV Version 1.9.2

User Manual



Authors: Magali Jodeau, Alexandre Hauet, Jérôme Le Coz, Jean-Baptiste Faure, Guillaume Bodart



Table of contents

| | | |
|----|--|----|
| 1. | General | 1 |
| | Why the LSPIV?..... | 1 |
| | Principles of the LSPIV | 1 |
| | Free software Fudaa-LSPIV..... | 2 |
| 2. | Start with Fudaa-LSPIV | 3 |
| | Fudaa-LSPIV Software Installation | 3 |
| | Languages..... | 3 |
| | Architecture of the main window | 4 |
| 3. | Start a Fudaa-LSPIV study..... | 5 |
| | Prerequisites for starting a Fudaa-LSPIV study | 5 |
| | Create a new study..... | 5 |
| | Open an existing study | 5 |
| | Architecture of a Fudaa-LSPIV project | 6 |
| 4. | Management of source images | 7 |
| | Import an image sequence..... | 7 |
| | Import a video and sequence it..... | 9 |
| | Stabilize an image sequence | 12 |
| 5. | Transformation of the images..... | 17 |
| | Selection of the orthorectification mode..... | 17 |
| | Scaling..... | 17 |
| | Defining the resolution..... | 18 |
| | Change of real coordinate reference | 19 |
| | Definition of the orthoimage corners and water level..... | 20 |
| | Complete orthorectification..... | 20 |
| | Principle of orthorectification | 20 |
| | Positioning of reference points | 21 |
| | Verification of the GRP | 22 |
| | Transformation parameters | 22 |
| | Transformation of all the images | 23 |
| 6. | Calculation of the tracers velocities | 25 |
| | Principles | 25 |
| | Manual velocity computation | 25 |
| | Parameters of displacement calculation..... | 26 |
| | Calculation grid..... | 28 |
| | Calculation of the movement velocities of the tracers..... | 29 |

| | | |
|-----|---|----|
| 7. | Postprocessing of calculated velocities..... | 31 |
| | Filtering instant results..... | 31 |
| | Averaging the results..... | 32 |
| | Velocity results statistics | 33 |
| 8. | Viewing velocity results..... | 34 |
| | Description of result layers for velocity calculations | 34 |
| | Layer Res. vel..... | 34 |
| 9. | Calculation of the discharge | 37 |
| | Specify one or more bathymetry transects..... | 37 |
| | Reverse transects | 38 |
| | Transects parameters..... | 39 |
| | Discharge calculation..... | 41 |
| | Export the gauging report | 42 |
| 10. | Exporting data | 46 |
| 11. | Redo the calculations of an existing study | 47 |
| 12. | Known bug and solutions | 48 |
| | The gauging report is not created | 48 |
| 13. | Insights | 49 |
| | Principle of image stabilization | 49 |
| | Key points extraction..... | 49 |
| | Points matching | 50 |
| | Estimation of the transformation..... | 51 |
| | Image transformation..... | 51 |
| | Principle of orthorectification | 52 |
| 14. | Approfondissements | 54 |
| | Principe de l'orthorectification | 54 |
| | Le modèle sténopé et sa résolution : cas général 3D..... | 54 |
| | Le modèle sténopé et sa résolution : cas particulier 2D | 55 |
| | Création des orthoimages | 55 |
| | Principes de la mesure de la vitesse de déplacement des traceurs..... | 57 |
| | Principles of discharge calculation | 60 |
| | Principes du calcul de débit..... | 61 |
| | Définition et interpolation du profil bathymétrique | 61 |
| | Estimation de la vitesse moyenne en chaque point du transect | 62 |
| | Calcul du débit à travers chaque transect..... | 63 |
| 15. | References..... | 64 |

1. General

Why the LSPIV?

The scientist studying rivers under aspects of liquid flow or sediment flow often encounters a mismatch between available hydrometric measurements and needs. These needs have evolved, in parallel with the development of numerical modeling, towards a demand for spatialised data, with a high temporal frequency, and for various flow conditions. In particular, the measurement of velocity and streamflow during floods is often impossible with traditional gauging techniques (current meters, aDcp, tracer dilution), when high velocities and numerous floating debris endanger operators and equipment. In addition, the measurement time inherent to these techniques is often inadequate with the unsteady nature of the flood flows. The development of 2D or 3D modeling tools for the understanding of flows, in the natural environment and in the laboratory physical model, requires, for validation, other measurements in addition to water levels or flow rates. The spatialised velocity results of these models require a corresponding hydrometric measurement, that is to say a velocity field. Again, traditional velocity measurement techniques do not fully meet these needs.

Hydrometry by image sequence analysis is an interesting alternative that allows access to the measurement of instantaneous surface velocities on surfaces up to the hectare, in a non-intrusive way. The technique is called Large Scale Particle Image Velocimetry (LSPIV). For a detailed description of the method, one can refer for example to the thesis of A. Hauet (2006).

Principles of the LSPIV

The analysis of image sequences makes it possible to measure the 2D field of velocity on the surface of a flow provided that visible tracers, such as solid particles (plant debris, small floats, etc.), bubbles or turbulence patterns are advected with the flow, while remaining recognizable from one image to another. This technique is derived from the Particle Image Velocimetry (PIV) used in the laboratory, but for a study on large river-scale objects, hence the name Large-Scale PIV (LSPIV, Fujita et al., 1998). An LSPIV measure comprises (i) recording a sequence of timestamped images of the flow, (ii) a geometric correction of the images to overcome perspective distortion effects (orthorectification) and (iii) a calculation displacement of the tracers of the flow through a statistical correlation of the reasons. In practice, the seeding of the flow by adding tracers is often not necessary for flooded rivers: if the movement of the water is visible in a sequence of images, in general it will be possible to extract the velocities. This gives a "nearly instantaneous" 2D field (at the sampling frequency of the image pairs, limited by the acquisition frequency of the camera and the amplitude of the movements). Knowing the bathymetry of a cross section and assuming a model of vertical velocity distribution, one can arrive at the estimation of the flow rate from the LSPIV velocity field.

The LSPIV has been used to estimate river flows of very different scales, from low to high floods (see, for example, Creutin et al., 2003, Hauet et al., 2008 or Jodeau et al., 2008) and for improvement. calibration curves in normal hydraulic regimes (Le Coz et al., 2010 or Dramais et al., 2011). The LSPIV has also been applied to flood films shared by the public on the internet (Le Boursicaud et al 2016, Le Coz et al 2016). A review of LSPIV applications for streamflow estimation has been proposed by Muste et al. (2008). LSPIV has also been used to study the dynamics of complex flows (Le Coz et al 2010b, Hauet et al., 2009) as well as debris flows (Theule et al., 2018) and physical models of mobile bottom laboratories (Piton et al., 2018). The LSPIV has also proved to be an effective tool for the study of runoff

runoff (North et al., 2009, Legout et al 2012) where intrusive instruments can not be used because of the very weak tie rods. water considered (millimeters).

Free software Fudaa-LSPIV

Fudaa-LSPIV is a software for processing flow image sequences to calculate surface velocity fields and flow rates across cross sections. The method is based on the Large-Scale Particle Image Velocimetry (LSPIV) technique, with the following main steps:

- Source images: import a sequence of images or sampled images from a video clip
- Orthorectification: Correct images from perspective distortion and assign a metric size to pixels
- PIV analysis: calculate surface velocities from statistical analysis of tracer movement
- Post-processing: apply filters to the velocity results, calculate the time average, calculate the streamlines
- Discharge: calculate discharge through a bathymetric transect using a velocity correction coefficient

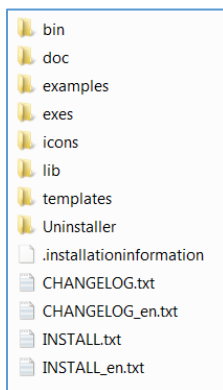
The **Fudaa-LSPIV** software is a Java interface that calls Fortran executables. The development of **Fudaa-LSPIV** has been executed by DeltaCAD since August 2010 with financing and under the direction of EDF and Irstea. This development is part of the Fudaa free software project for hydraulic applications. The supported languages are French and English and the software can be used with Windows or Linux operating systems. The conditions of diffusion are those of free GPL licenses, and the software is the intellectual property of EDF and Irstea.

2. Start with Fudaa-LSPIV

Fudaa-LSPIV Software Installation

The **Fudaa-LSPIV** software installation file is available in the following software development forge: <https://forge.irstea.fr/projects/fudaa-lspiv/>

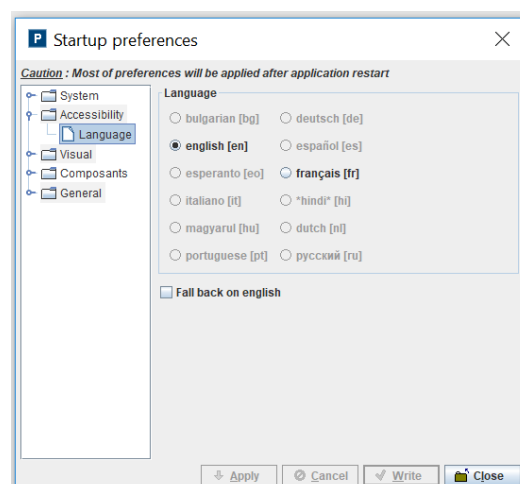
Unzip the contents of the archive.zip file beforehand. The installation file is a java .jar file named **fudaa-lspiv-xxx-setup.jar**, where xxx is the version number. The setup and executables are specific to the target OS (Windows, Linux, 32/64 bits). Start the installer (double-click) and follow the procedure. The software installs in the chosen directory, with the following architecture:



- **bin** folder: contains the executable **fudaa-lspiv.bat**, which is used to launch the application;
- **doc** folder: Contains this **User Guide**;
- **examples** folder: contains an example of a **Fudaa-LSPIV** project;
- **exes** folder: contains the Fortran executables called for the LSPIV analysis steps;
- **icons** folder: contains the icons;
- **lib** folder: contains the Java libraries required for the **Fudaa-LSPIV** application;
- **templates** folder: contains the Excel template for the **Streamgauging report** export;
- **uninstaller** folder: contains the uninstall executable.

Languages

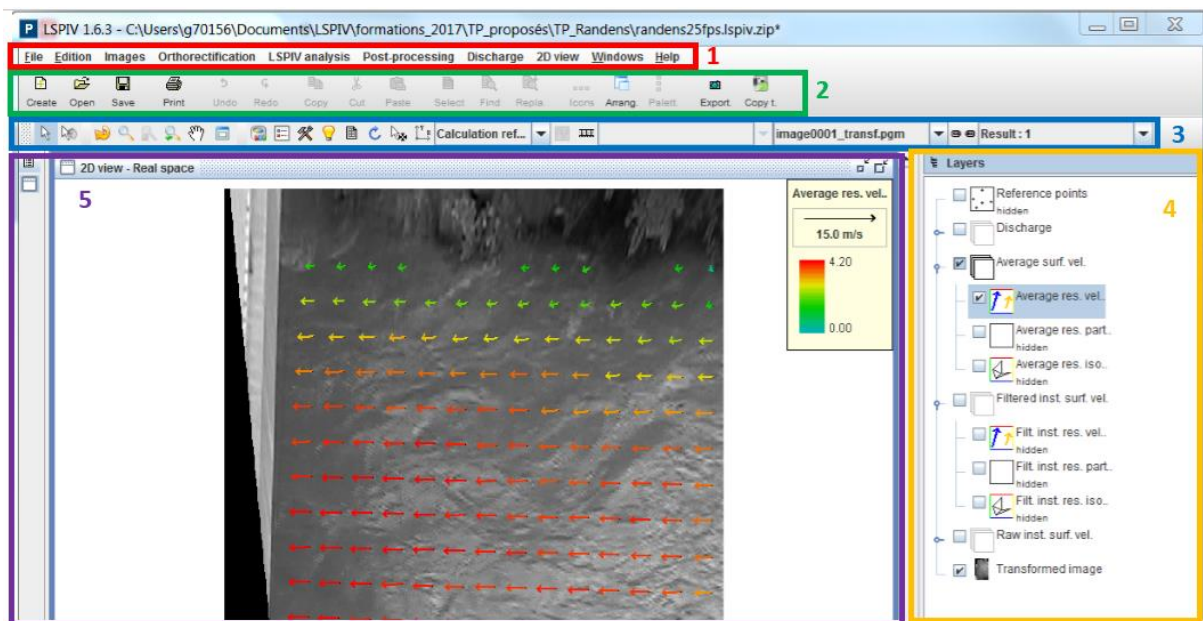
The default language of the **Fudaa-LSPIV** software is French or English depending on the choice made during the installation. It is possible to switch to English thanks to the **Edit → Preferences** menu. In the **Accessibility → Language** tab choose **english [en]**, then restart the software.



Architecture of the main window

The **Fudaa-LSPIV** software consists of 5 panels as described in the figure below:

- The **menus** (panel 1 in the figure) to access the creation or opening of files, or the launch of LSPIV treatments.
- The **quick access bar** (panel 2 in the figure) allowing shortcuts to the main functions of the menus.
- The **graphical toolbar** (panel 3 in the figure) allowing selections and modifications on the graphic display of the views.
- The **layers** (panel 4 in the figure) showing the different layers available and allowing them to be selected or deselected.
- The **graphic display of the views** (panel 5 in the figure) allowing to visualize the source or orthorectified images as well as the results of the calculations.



Important!

Fudaa-LSPIV works on a logic of layers (like a GIS software for example): to work on a data, an image or a result or to modify the display of a data, an image or a result , you must first select the layer considered.

3. Start a Fudaa-LSPIV study

Prerequisites for starting a Fudaa-LSPIV study

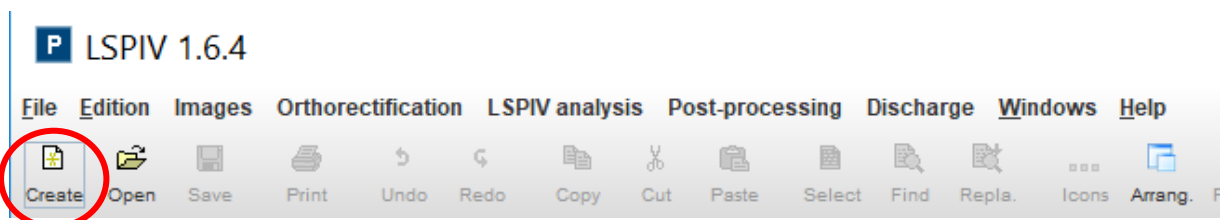
Before starting a **Fudaa-LSPIV** study, you must have the necessary input data:

- Images of a flow, in the form of a video or sequence of images (all images in the sequence must be spaced by the same time interval, and this time interval must be known precisely). The taking of images must be done without movement. If spurious movements affect the images, it will be useful to align the images using the [Stabilization](#) step.
- When acquiring the films, care must be taken with regard to the possible reflections, the good visibility of the tracers and the good distribution of the tracers in the image. When the flow does not have patterns naturally, clearly visible tracers can be added. However, it must be ensured that they move well at the velocity of flow.
- A geometric description of the image area, such as visible reference points on the images and known real coordinates, or scaling elements, to drive orthorectification.
- For discharge measurement applications, reference may be made to the imaging requirements made during the [FloodScale](#) project or by the [USGS](#).

Create a new study



To create a new study, click on the **Create** icon in the quick access bar.

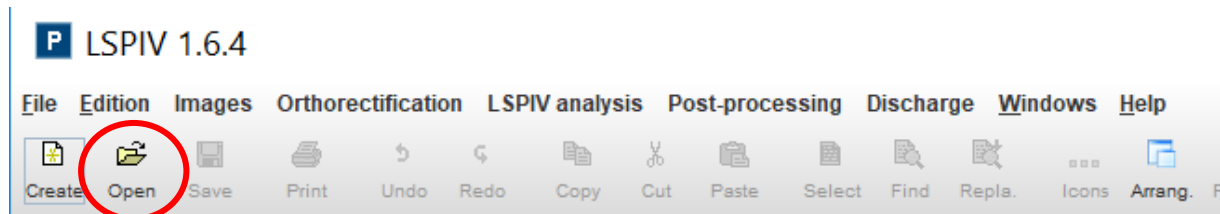


Otherwise, follow the **File** → **Create** menu. The corresponding keyboard shortcut is Ctrl + N

Open an existing study



To open an existing study, click the **Open** icon in the quick access bar.

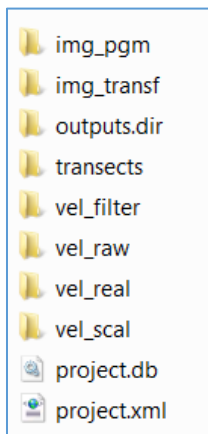


Otherwise, follow the **File** → **Open** menu. The corresponding keyboard shortcut is Ctrl + O. The **File** → **Reopen** menu allows you to search for one of the last saved studies.

Architecture of a Fudaa-LSPIV project

Fudaa-LSPIV projects are saved by the **File** → **Save** menu as an extension file **.ls piv.zip**. The architecture of a **Fudaa-LSPIV** project is composed of:

- **img_pgm** folder: contains source images in .pgm format used for processing;
- **img_transf** folder: contains a cache folder of orthorectified images in .gif format, less large in size (optimization of the display); orthorectified images in .pgm format are not saved (.pgm files are empty).
- **outputs.dir** folder: contains the calculation files and LSPIV parameters;
- transects file: contains the projected and interpolated bathymetric transects data;
- **vel_filter** folder: contains the results files of the filtered instantaneous LSPIV velocities, in image coordinates;
- **vel_raw** folder: contains raw instantaneous LSPIV velocity results files, in image coordinates;
- **vel_real** folder: contains the results files of the filtered instantaneous LSPIV velocities, in real coordinates;
- **vel_scal** folder: contains the scalar result files (velocity norm, correlation) computed from filtered instantaneous LSPIV velocities, in real coordinates.



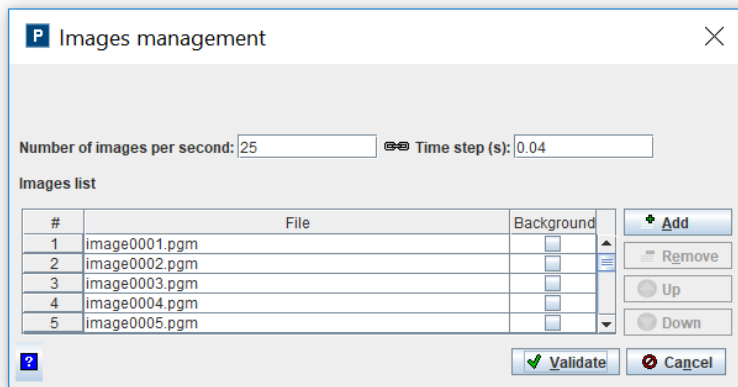
4. Management of source images

The calculations performed in **Fudaa-LSPIV** are performed on consecutive image sequences with a known and fixed time interval. The user can:

- Import an image sequence
- Import a video and sequence it in **Fudaa-LSPIV**

Import an image sequence

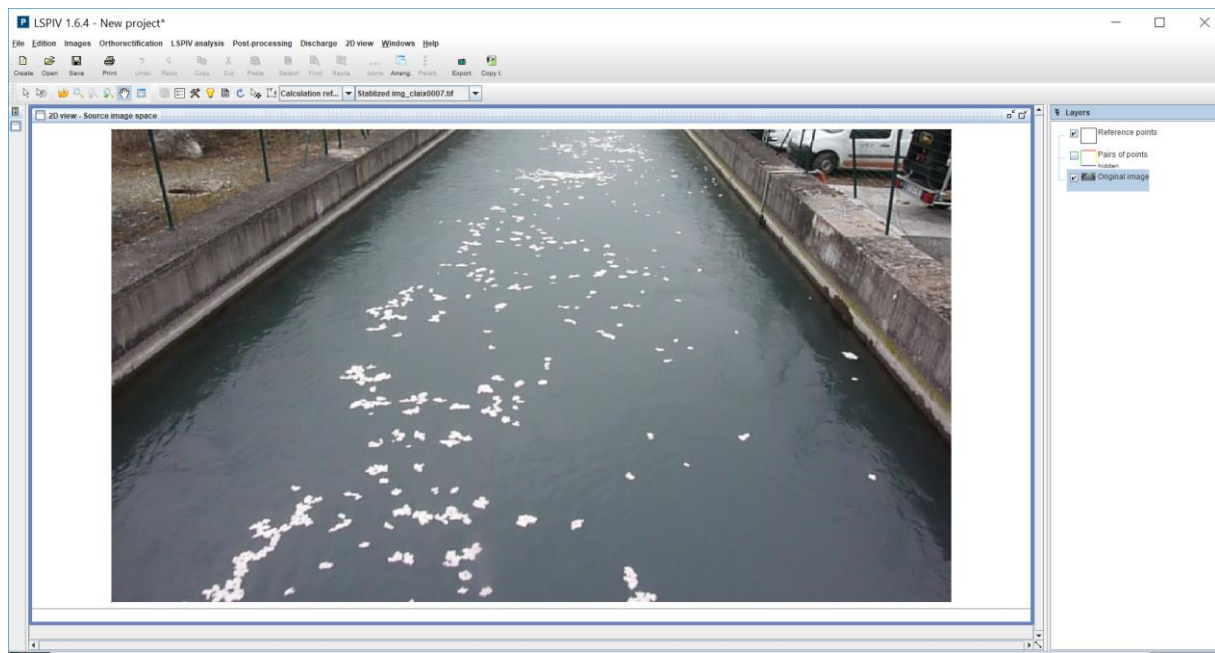
The **Images** → **Source Image Management** menu opens the image management window. The **Add** button launches an explorer to select the sequence of images to be analyzed. All standard image formats are managed (png, tif, pgm, jpg, tiff, jpeg, gif, bmp ...). The selected images appear in the image management window.



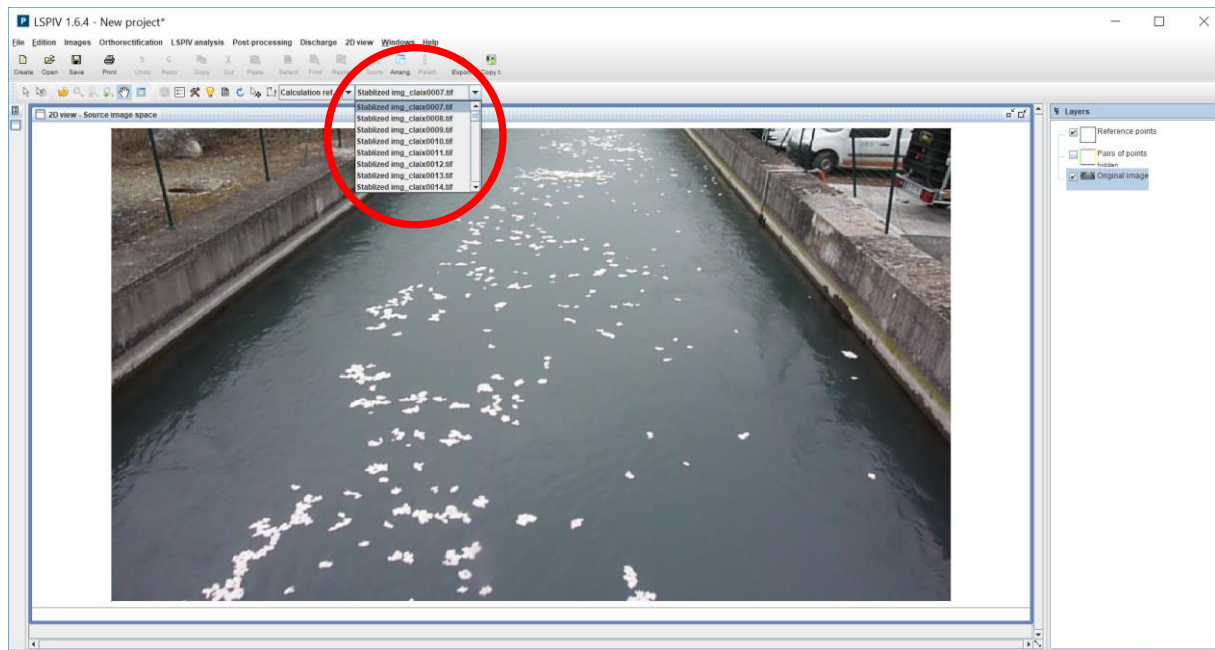
The **Add** button allows you to add new images of the same sequence. The **Remove** button allows you to remove one or more selected images. The **Up** and **Down** buttons change the order of the images in the sequence.

The user here specifies either the **time interval** between two images or the **number of frames per second**.

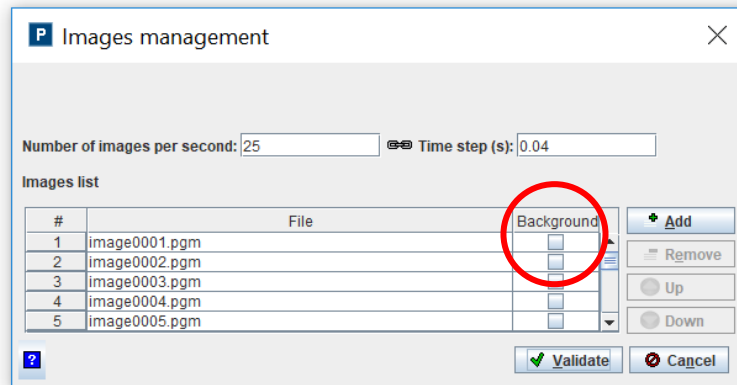
Once the selection is validated, the images are displayed in the **Source Image Space**.



The source images can be viewed with the scroll list:

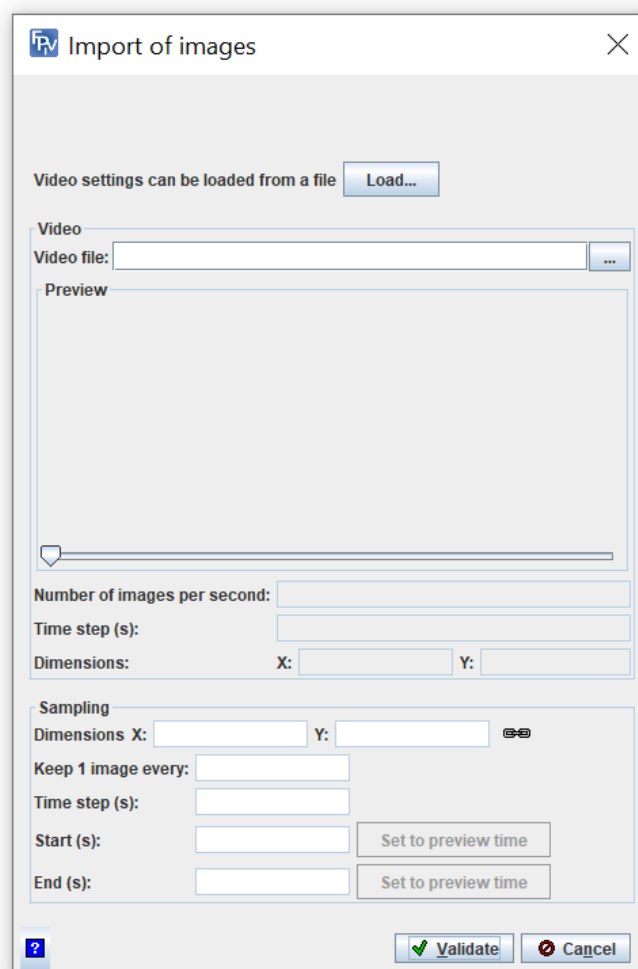



Among the images thus imported, some may be used only for the orthorectification step (check the background box) or only for the velocity calculation.



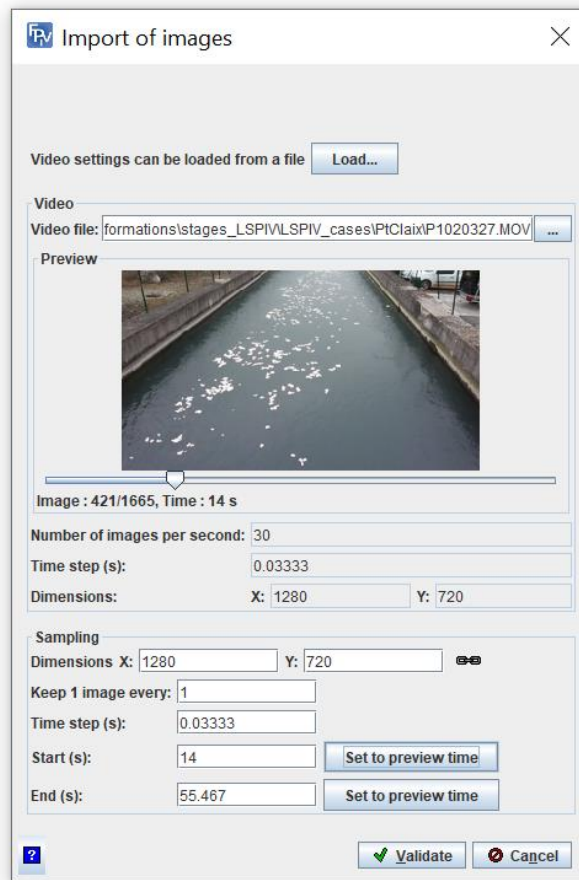
Import a video and sequence it

The **Images** → **Import images from video** menu opens the window for importing videos:



The  button launches an explorer to select the video to be sequenced. All the standard video formats are managed (avi, mov, mpeg ...). A preview of the video is displayed, which allows to optimize the image sampling parameters. The current image in the preview can be selected using the cursor. The rank of the current image out of the total number of images in the video is displayed along with

basic information on the video: duration, framerate (fps), the corresponding time interval in seconds, the image size (in pixels).



In the **Sampling** area, enter the sequencing parameters of the video:

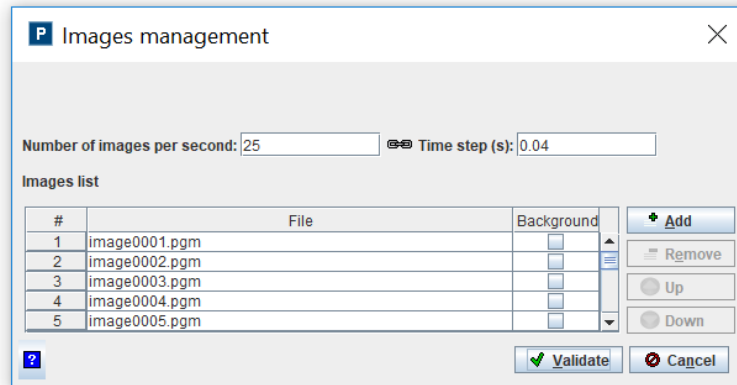
- The **size (dimensions X and Y)** of the sampled images, in pixels
- The **image sampling rate**: keep 1 image every N images
- Or the **time interval** between two images. This number must be greater than the initial time interval.
- If the entire video is not to be analyzed, enter the **start and end times** of the sequence of interest, in seconds. The start and end times can be made equal to the time of the current image in the preview by pushing the **Set to preview time** button.





The image sampling information is stored in the project file and reported in the gauging reports. The configuration file is named user_extract.dat and located in the outputs.dir sub-folder of the .lspiv.zip archive. It contains the start and end times (in seconds), the sampling parameter N (keep 1 image every N images), the size of the extracted images (in pixels), and the path to the video file. Video settings can be loaded from a user_extract.dat file using the **Load...** button.


The  button pops up a tooltip providing recommendations on the image sampling parameters.

By pushing **Validate**, we start the sequencing. Sampling progress is displayed and the image sampling operation can be stopped if necessary. The first and last images in the sequence are deleted

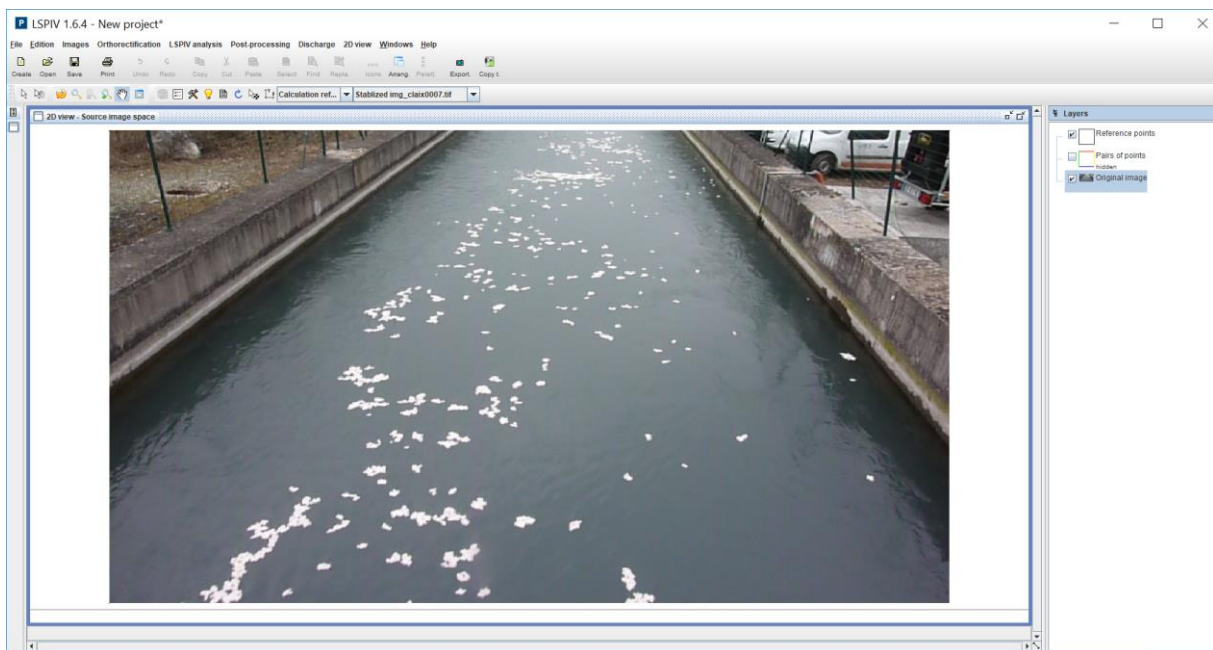
automatically to avoid time interval errors. The .png image sequence can be displayed in the image management window.



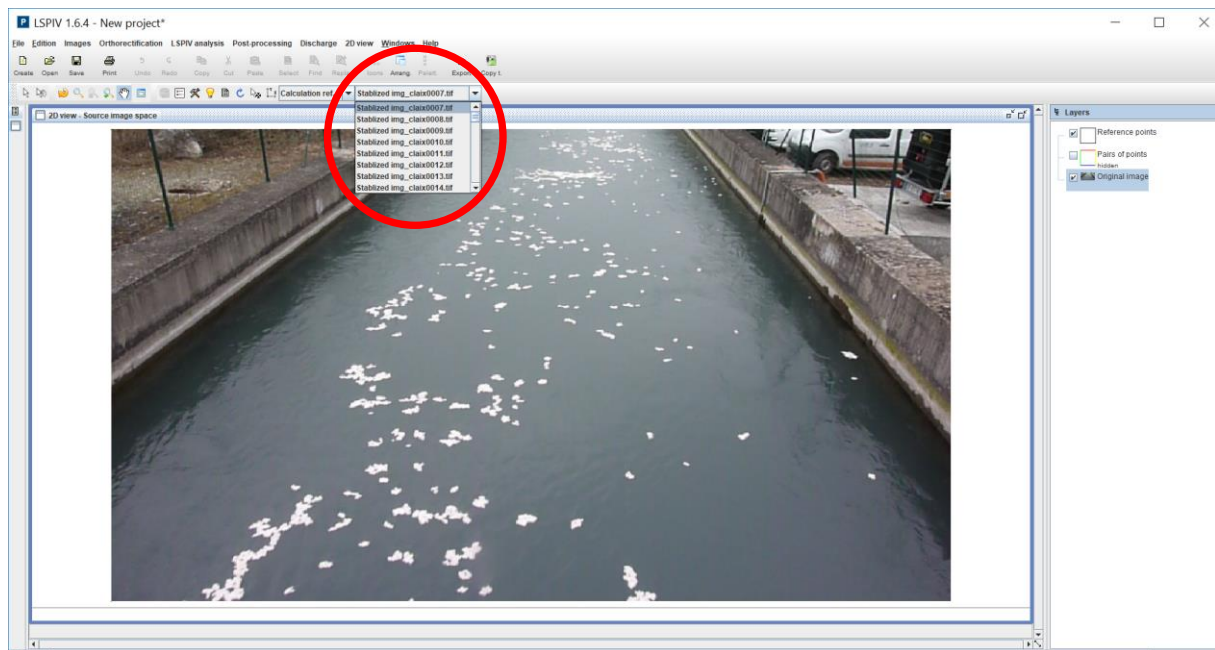
The **Add**  button allows you to add new images of the same sequence. The **Remove**  button allows you to remove one or more selected images. The **Up**  and **Down**  buttons change the order of the images in the sequence.

The  button pops up a tooltip providing recommendations on the image sampling parameters.

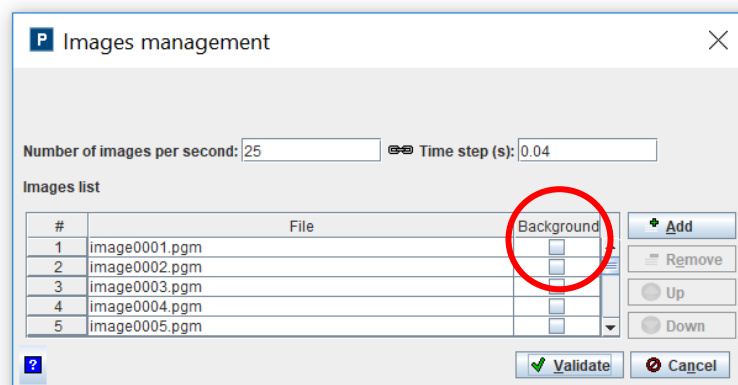
Once the selection is validated, the images are displayed in the **Source Image Space**.



The source images can be viewed with the scroll list:

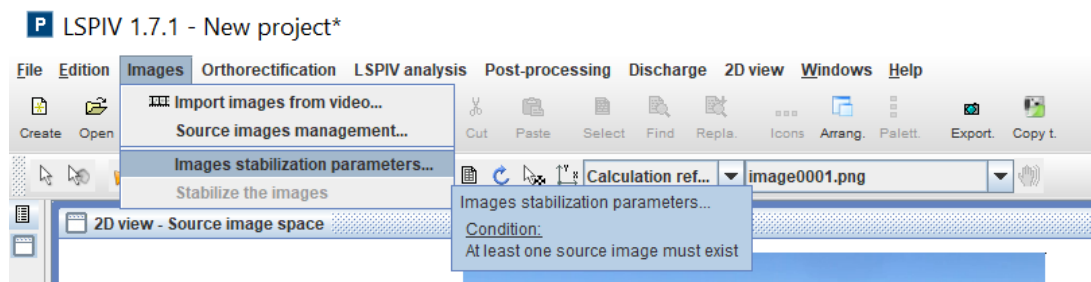


Among the images thus imported, some may be used only for the orthorectification step (check the background box) or only for the velocity calculation.

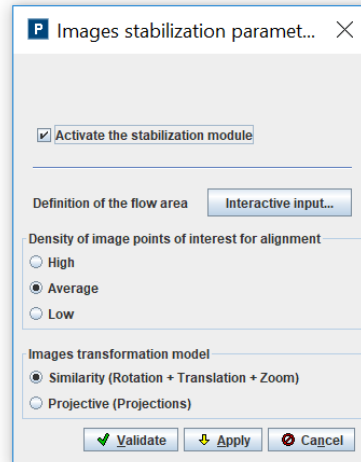
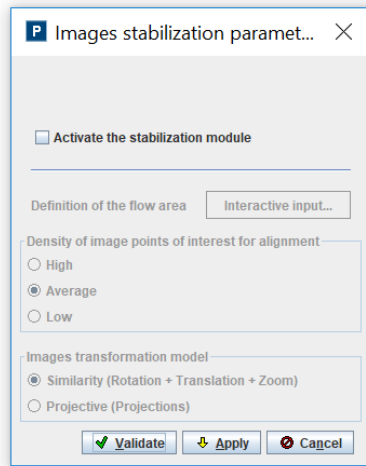


Stabilize an image sequence

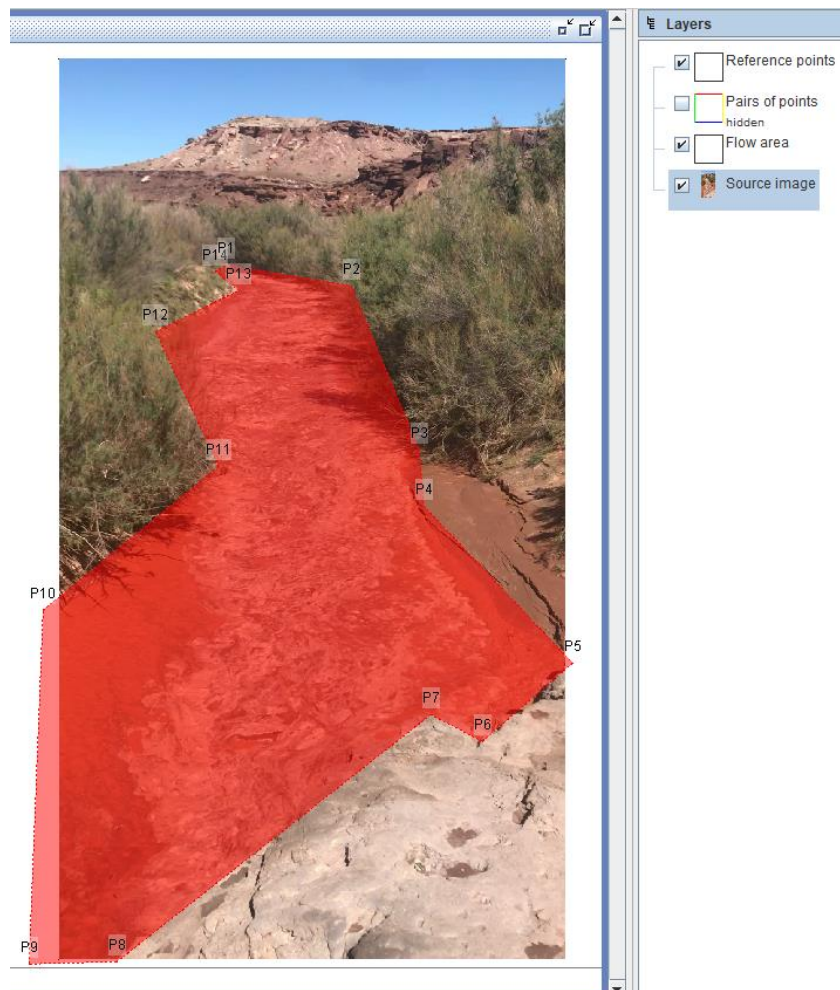
The **Images** → **Images Stabilization Parameters** menu gives access to a source image stabilization module, which eliminates the effects of possible camera movement. For more technical details on the algorithm and its parameters, see Section 12. *Insights*.



In this panel, the **Activate the stabilization module** checkbox activates or deactivates the stabilization of source images.



It is then necessary to delimit the footprint of the flow area by clicking on the **Interactive input** button and by entering the positions of the vertices of a polygon on a source image. This flow area corresponds to moving patterns that should not be used as points of interest by the stabilization algorithm. The flow_area.dat file containing the flow area is generated and saved in the outputs.dir sub-folder of the .lspiv.zip archive. A **Flow area** layer is added in the 2D view **Source image space**.



By default, the density of the points of interest is **Average** and the transformation model is **Similarity**. Two models are proposed: **Similarity** and **Perspective**. Selection depends on the shakiness intensity of the camera and on the “quality” of the river banks.

- Weak shakiness (<10 pixels) : **Similarity** model preferred
- Strong shakiness (>10 pixels) : **Perspective** model preferred

By “quality” of the river banks we mainly denote their texture and contrast. A highly textured and contrasted environment with a lot of edges/corners will be considered as a good one, as per our definition of “quality”. A smooth concrete slab without bumps will have a bad “quality” whereas banks composed of vegetation + stones + trees + shadows will have a very good “quality”.

- Poor “quality”: Select **High** density of points
- Good “quality”: Select **Low** density of points

The banks/flow ratio is an important parameter to consider. The example shown above is an ideal case study: the river flow occupies a third of the image. The area covered by the river banks is then large enough. Moreover the environment is highly textured and shows lots of edges. In such a case a **Low** density could be used.

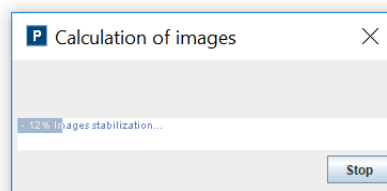
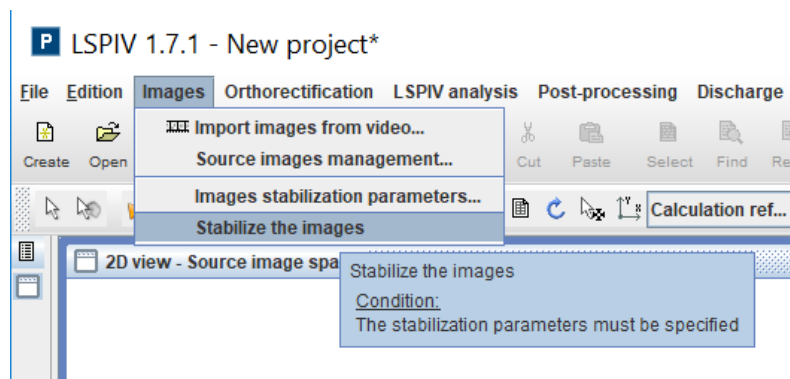



To ensure a good stabilization river banks should cover at least a quarter of the image on each side of the flow (so 50% flow and 50% banks overall).

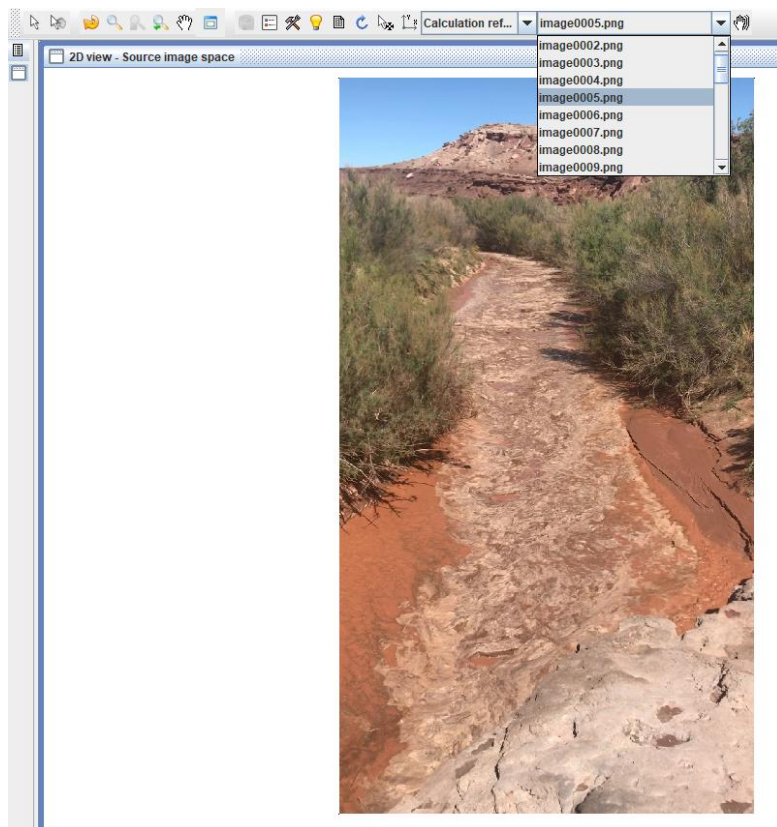
It isn't recommended to use a **Low** density of points with the **Perspective** transformation model. Errors may occur since it is more sensitive to lack of points.

You must then **Validate** or **Cancel** the settings thus defined. The **Apply** button is useless here. The stabilisation parameters are reported in the gauging reports.

The **Images** → **Stabilize the images** command starts the calculation of the stabilized images, which will then be used for orthorectification (see next section). The stabilisation calculation can be interrupted.

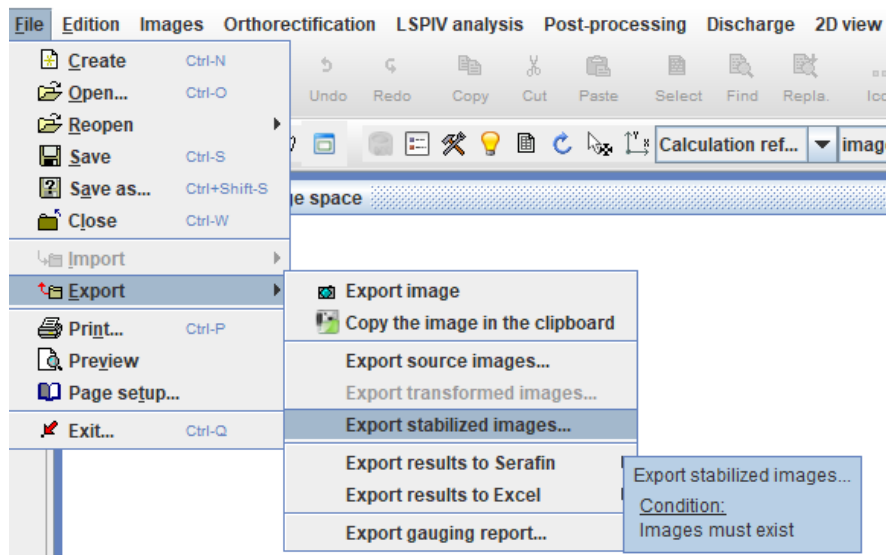


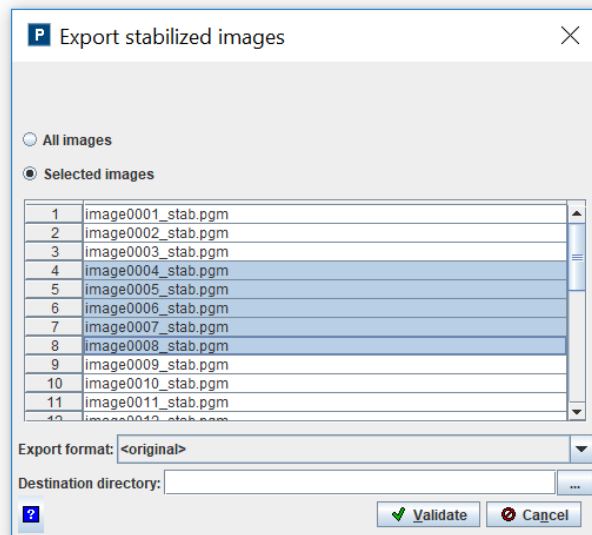
The stabilized images can be viewed one by one in 2D View **Source Image Space** by first clicking on the "Shaky Hand" icon .



The **File** → **Export** → **Export Stabilized Images** command allows you to export the stabilized images.

P LSPIV 1.7.1 - New project*





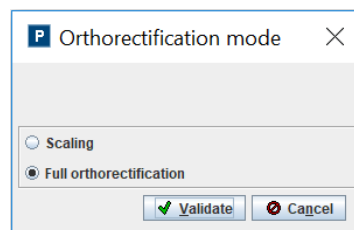
5. Transformation of the images

Selection of the orthorectification mode

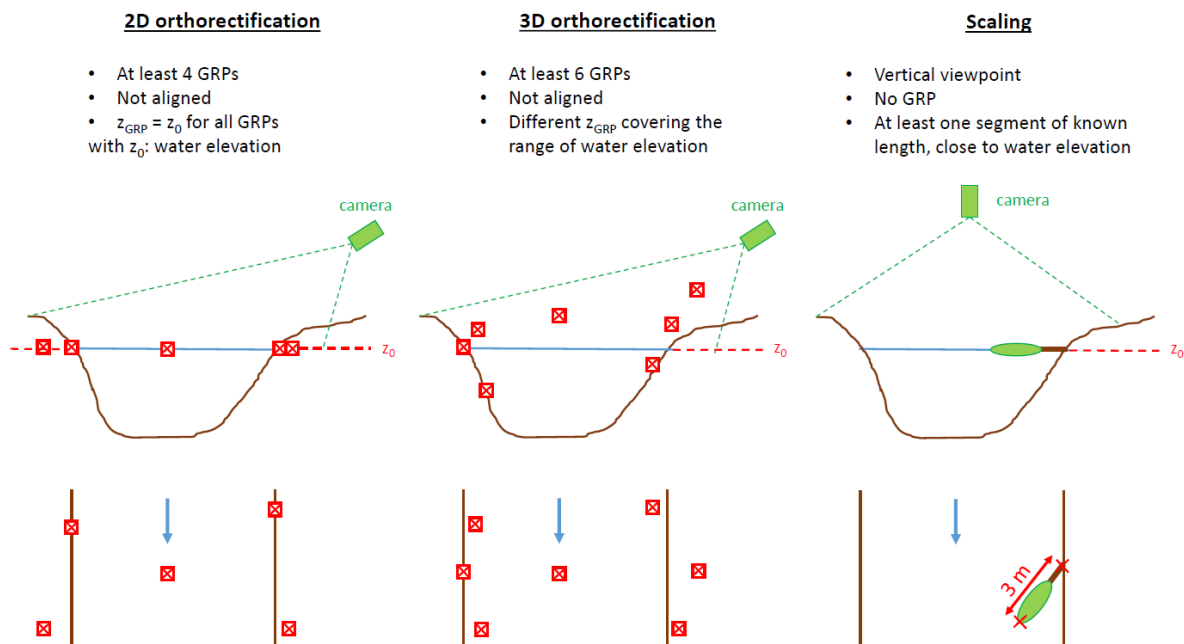
Fudaa-LSPIV offers two modes of orthorectification:

- **Scaling**: when images are not distorted by perspective effects (vertical viewpoint with no lens distortion), a simple scaling in metres per pixel can be sufficient;
- **Complete Orthorectification**: when images are distorted by perspective effects, a complete orthorectification based on reference points must be done.

These modes can be accessed via the **Orthorectification → Orthorectification Mode** menu.



These two modes of image transformation allow for a 2D or 3D orthorectification, or a simple scaling of the pixels of the image. These three types of transformation and their requirements are summarised in the following diagram and described in the following sections.



Scaling

When the point of view of the camera is vertical (seen from the sky), we can often neglect the perspective effects, at least in the centre of the image. Orthorectification of the images is not necessary. Scaling simply consists of specifying the physical size of a pixel. The **Orthorectification → Scaling → Parameters** menu brings up the window for setting the scaling parameters:

Parameters

Resolution Transformation Others

☒ Direct input of resolution (m/pix): 0.0

☐ Input by pairs of points / Distance

| I1 | J1 | I2 | J2 | Distance (m) | Resolution |
|----|----|----|----|--------------|------------|
|----|----|----|----|--------------|------------|

Enter a pair Delete

Average computed resolution (m/pix):

Validate Apply Cancel

Defining the resolution

In the **Resolution** tab, three methods are proposed to specify the resolution of the images (the physical size of the pixels in metres):

- Direct input of the resolution if it is known: enter the resolution in m/pix in the dedicated box.

Parameters

Resolution Transformation Others

☒ Direct input of resolution (m/pix): 0.007

☐ Input by pairs of points / Distance

| I1 | J1 | I2 | J2 | Distance (m) | Resolution |
|----|----|----|----|--------------|------------|
|----|----|----|----|--------------|------------|

Enter a pair Delete

Average computed resolution (m/pix):

Validate Apply Cancel

- Entering pairs of points defining segments of known size: click on the positions of the ends of the first segment in the image; the image coordinates (I1, J1) and (I2, J2) of the two points then appear in the array; indicate opposite the length of the segment (distance between the two points) in metres; the corresponding resolution is calculated. You can re-iterate the operation for as many segments of known size. The average of the resolutions thus calculated is displayed and will be the one used for the image transformation.

Parameters

Resolution Transformation Others

☒ Direct input of resolution (m/pix): 0.007

☐ Input by pairs of points / Distance

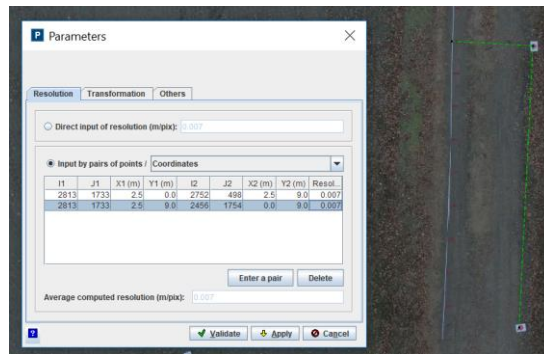
| I1 | J1 | I2 | J2 | Distance (m) | Resolution |
|------|------|------|------|--------------|------------|
| 2813 | 1733 | 2752 | 486 | 9.8 | 0.007 |
| 2813 | 1733 | 2456 | 1754 | 2.8 | 0.007 |

Enter a pair Delete

Average computed resolution (m/pix): 0.007

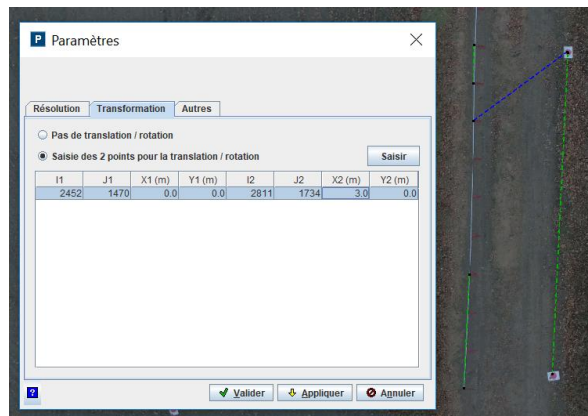
Validate Apply Cancel

- Alternatively, the real-world coordinates of the ends of the segments can be filled in, instead of the lengths of the segments. Select **Coordinates** instead of **Distance** from the drop-down menu.

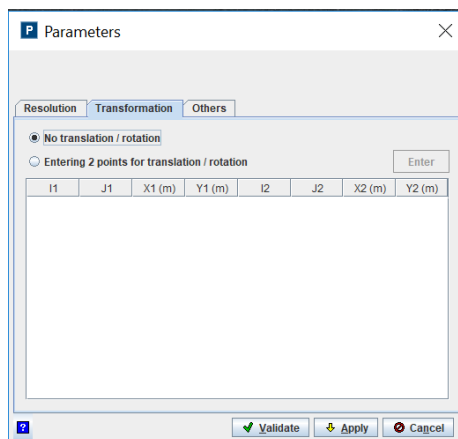


Change of real coordinate reference

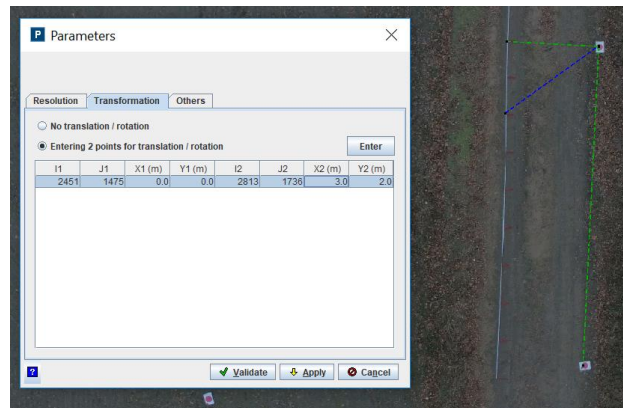
The **Transformation** tab is used to define the translation/rotation parameters that can be applied to the actual orthoimage reference. This is particularly useful if the velocity field is to be compared to other data, or if a bathymetric transect measured in this particular reference is then used for the calculation of the discharge.



By default, the option "no translation/rotation" is selected and no reference change will be applied. The lower left corner of the image is the origin of coordinates (0,0) and the X and Y axes are the horizontal and vertical axes of the original image.



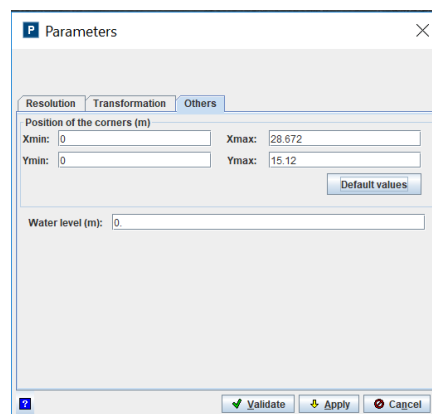
Otherwise, it is possible to define the change of reference to be applied by entering the real coordinates (X1,Y1) and (X2,Y2) of two points previously positioned (by clicking) in the image: their image coordinates (I1,J1) and (I2,J2) are displayed in the table.



Definition of the orthoimage corners and water level

The **Others** tab allows you to define the coordinates of the corners of the orthoimage: it is simply a sub-selection (crop) of the original image. The proposed **Default values** are the positions of the left-bottom and top-right corners of the total image, calculated by multiplying the image dimensions (in pixels) by the previously calculated resolution (in m/pix). This amounts to keeping all the original images for the transformation.

It is also possible to enter in this **Others** tab the water level (in m) that will not be used for the transformation of the images or for the calculation of velocities but will be used for the calculation of discharge.



The **Apply** button runs the transformation of the first image using the specified parameters, in order to get an idea of the result. The **Validate** button saves the scaling parameters, displays the first transformed image and allows you to proceed to the next step (Transform all images).

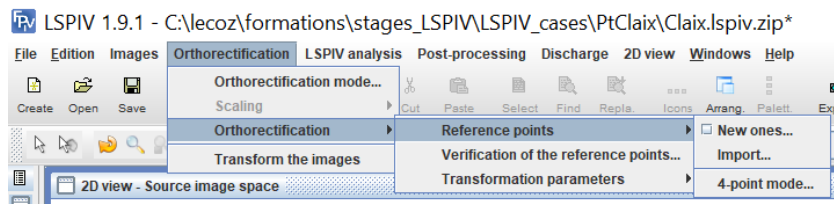
Complete orthorectification

Principle of orthorectification

Orthorectification consists of creating a corrected image of the perspective and scaling effects of the real world for a given plane. Full details on the [Principles of Orthorectification page](#).

Positioning of reference points

Three methods are possible for positioning reference points:



- The **Orthorectification → Orthorectification → Reference points → New ones** menu brings you to the GUI for positioning reference points. Enter the terrain coordinates (**real X**, **real Y** and **real Z**) of the first point, then click on the pixel of the image locating the GRP, the image coordinates **I** and **J** are then filled. It is possible to zoom to better see a point. Repeat the operation for all reference points (at least 4 for 2D orthorectification, at least 6 for 3D orthorectification, see the **orthorectification principles** for more details). The **Input finished** button closes the operation and creates a file in the project architecture **outputs.dir\GRP.dat**.

| | I | J | Real X (...) | Real Y (...) | Real Z (...) |
|---|--------|--------|--------------|--------------|--------------|
| 1 | 351.03 | 484.19 | 0.0 | 0.0 | 0.0 |
| 2 | 768.54 | 267.7 | 12.0 | 14.0 | -2.0 |

- The **Orthorectification → Orthorectification → Reference points → Import** menu allows you to load a **GRP.dat** file. This file must be a text file, with the following format:
 - The first line contains only the text "GRP"
 - The second line is an integer specifying the number of reference points used
 - The third line contains the titles of the data: X Y Z i j; let X, Y, Z be the field coordinates of the points and i, j the image coordinates of the points.
 - The following lines are the data.

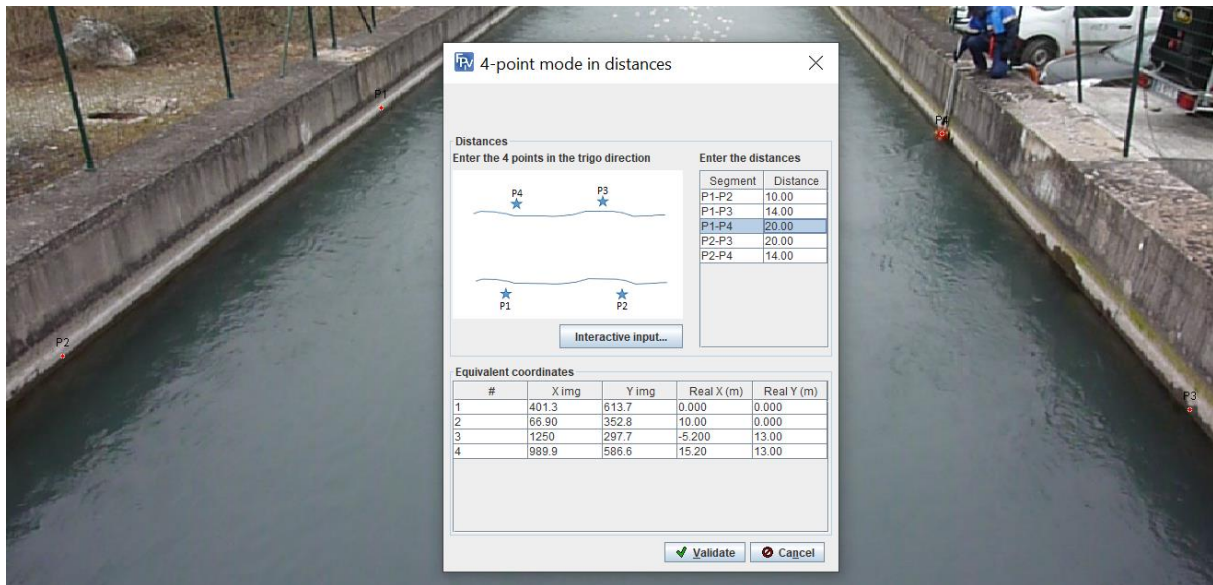
```

GRP.dat - Bloc-notes
Fichier Edition Format Affichage ?
GRP
4
X Y Z i j
11.49 30.38 0.76 189 16
10.91 30.33 1.0 172 8
13.16 29.96 0.77 255 20
14.09 30.33 0.67 287 19
  
```

It is important to note that the reference points must be entered in metric units (this defines the units for further processing).

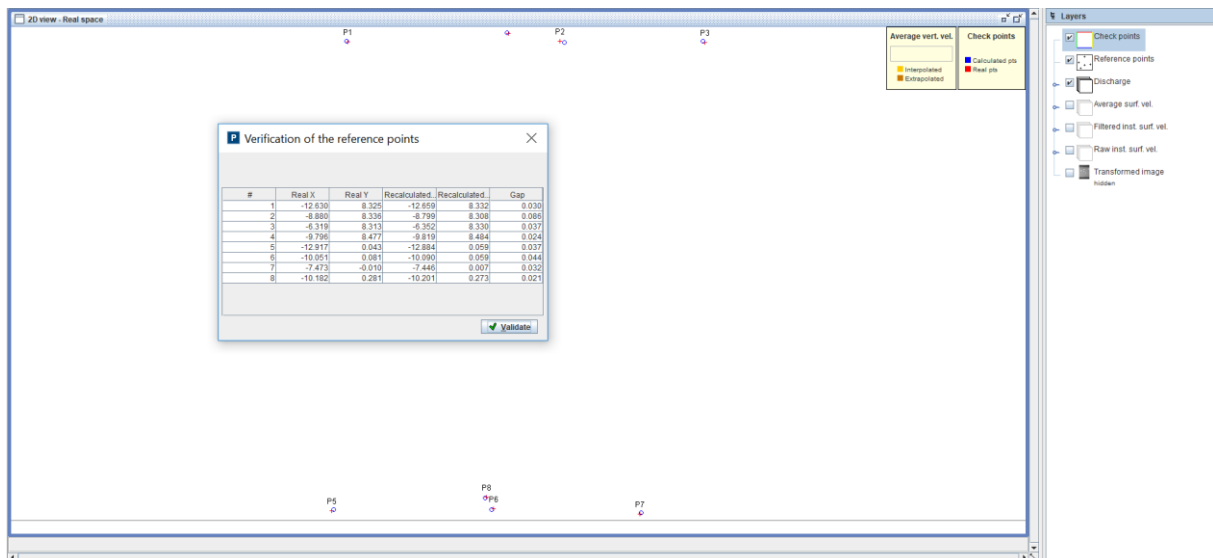
- The **Orthorectification → Orthorectification → Reference points → 4-point mode...** menu offers a simplified specification of 2D orthorectification by pointing 4 reference points in the

image in the anticlockwise direction (click on the **Interactive Input...** button) then entering 5 distances (in metres) between these points. The corresponding real coordinates (X and Y) are automatically computed in an arbitrary reference system. The water level will be assumed to be equal to zero.



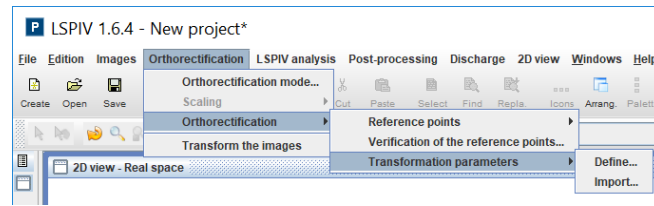
Verification of the GRP

The **Orthorectification** → **Orthorectification** → **Verification of the reference points** menu makes it possible to ensure the quality of the correspondence of the GRP field and image coordinates. The orthorectification matrix (see **Principles of orthorectification**) is calculated, and the land position (X, Y and Z) of the landmarks is calculated from their image coordinates (I and J). The true terrain coordinates and the calculated terrain coordinates are then compared. The distance between these true and calculated coordinates, called **Gaps**, is presented in a table and graphically.

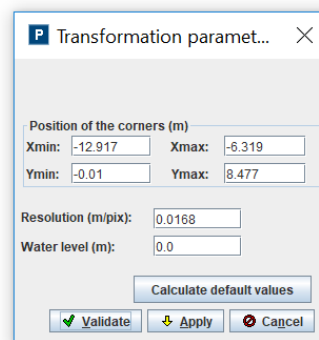


Transformation parameters

There are two methods for entering transformation parameters:



- The **Orthorectification** → **Orthorectification** → **Transformation Parameters** → **Define** menu opens the **Transformation Parameters** management window. The study area is defined by a rectangle whose position of the corners in the real coordinate system (**Xmin**, **Xmax**, **Ymin**, **Ymax**) is indicated. This framework makes it possible to reduce the orthorectification to the area of interest and thus limit the calculation times. The **resolution**, in meters per pixel, corresponds to the size of a pixel in the orthorectified image. The resolution must be adjusted so that the details of the plotters remain visible in the orthoimage, without generating orthoimages of too large sizes (the orthoimage must have approximately the same dimensions as the raw image). The **Calculate default values** button is used to automatically enter the **Xmin**, **Xmax**, **Ymin**, **Ymax** and **Resolution** fields. Finally, the **Water Level**, in the real reference, must be filled in. The orthoimage will only be valid for this height (see the **principles for creating orthoimages**). Clicking **Apply** will produce an orthorectified image. Adjust the setting as necessary, then **Validate**. The transformation parameters are stored in the **outputs.dir\img_ref.dat** file.



- The **Orthorectification** → **Orthorectification** → **Transformation parameters** → **Import** menu allows you to load the orthorectification parameters of an existing study using an **img_ref.dat** file. This file has the following format:

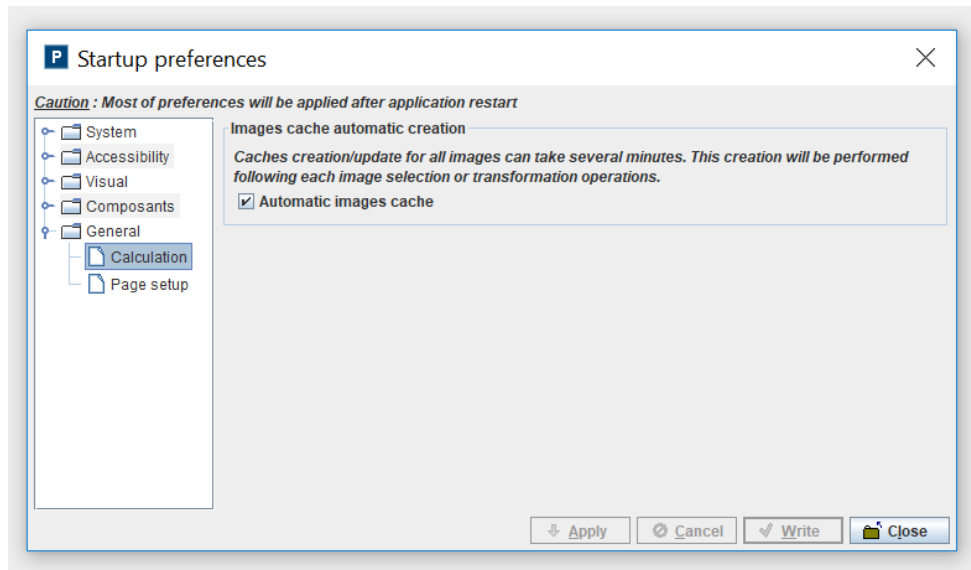
```
img_ref.dat - Bloc-notes
Fichier Edition Format Affichage ?
xmin,ymin
-15.0 -0.01
xmax,ymax
-4.0 8.477
resolution
0.0168
taille des images de base : ni - nj
720 1280
```

Transformation of all the images

The **Orthorectification** → **Transform images** menu starts the orthorectification of all selected images. Orthorectified images are stored in the **img_transf** folder.

The cache folder contains the same .gif images, which are smaller in size.

The creation of these images can take time, especially if a large number of high-resolution images need to be transformed. As an option, it is possible to disable the creation of cache images, except the first in the series, via the **Edit → Preferences → General → Calculation** menu. Only the first image will then be available in the 2D Views **Real Space** and **Transformed Image Space**.



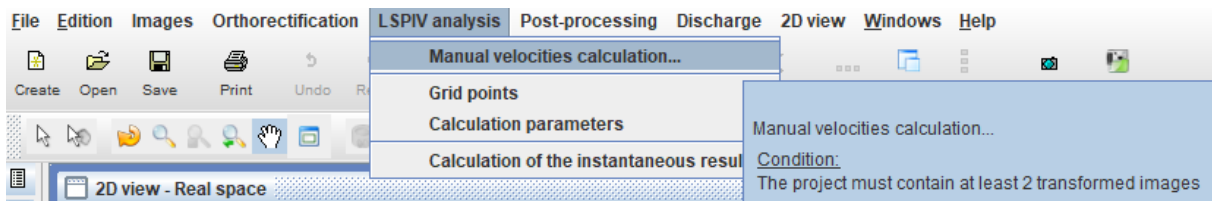
6. Calculation of the tracers velocities

Principles

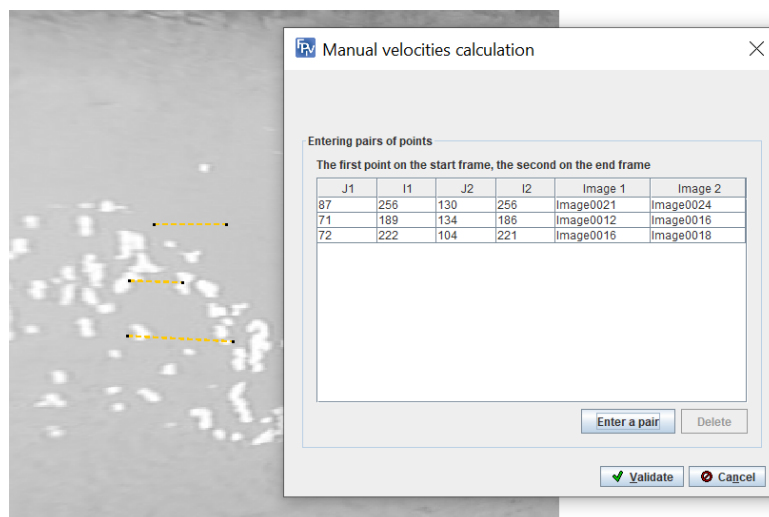
LSPIV uses a cross correlation statistical method on orthorectified images to determine the displacement of tracers visible on the surface. The principles are detailed on the [Principles of tracer velocity measurement](#).

Alternatively, some velocities can be determined manually. This is particularly useful to compare with LSPIV computed velocities and validate them.

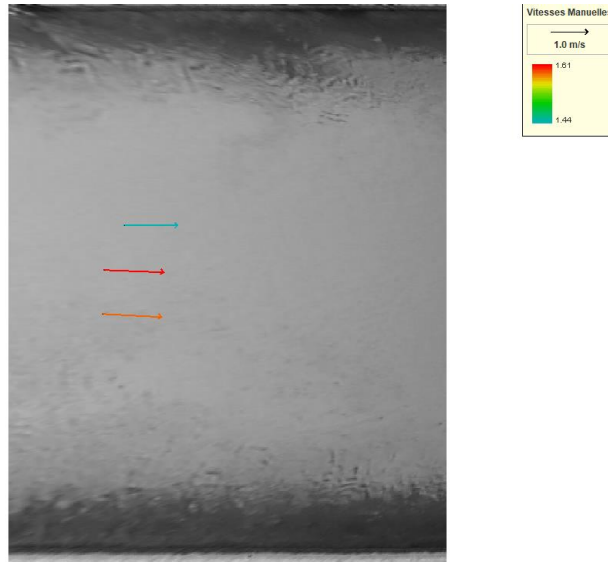
Manual velocity computation



- The **LSPIV Analysis** → **Manual velocities calculation...** menu launches the interface for the manual determination of tracer motion. After clicking on the **Enter a pair** button, the user can select the position of any tracer in any pair of images of the sequence, by scrolling the image file name list and clicking on the images. The selected images and positions are listed in the table:

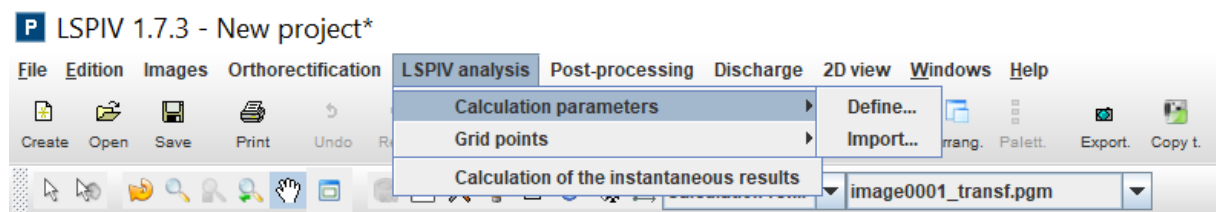


When the manual selection of tracer positions is finished, clicking on the **Validate** button will display the velocity results of the **Manual velocities** layer:



Parameters of displacement calculation

Two methods are possible to define the parameters of the tracer displacement calculation:

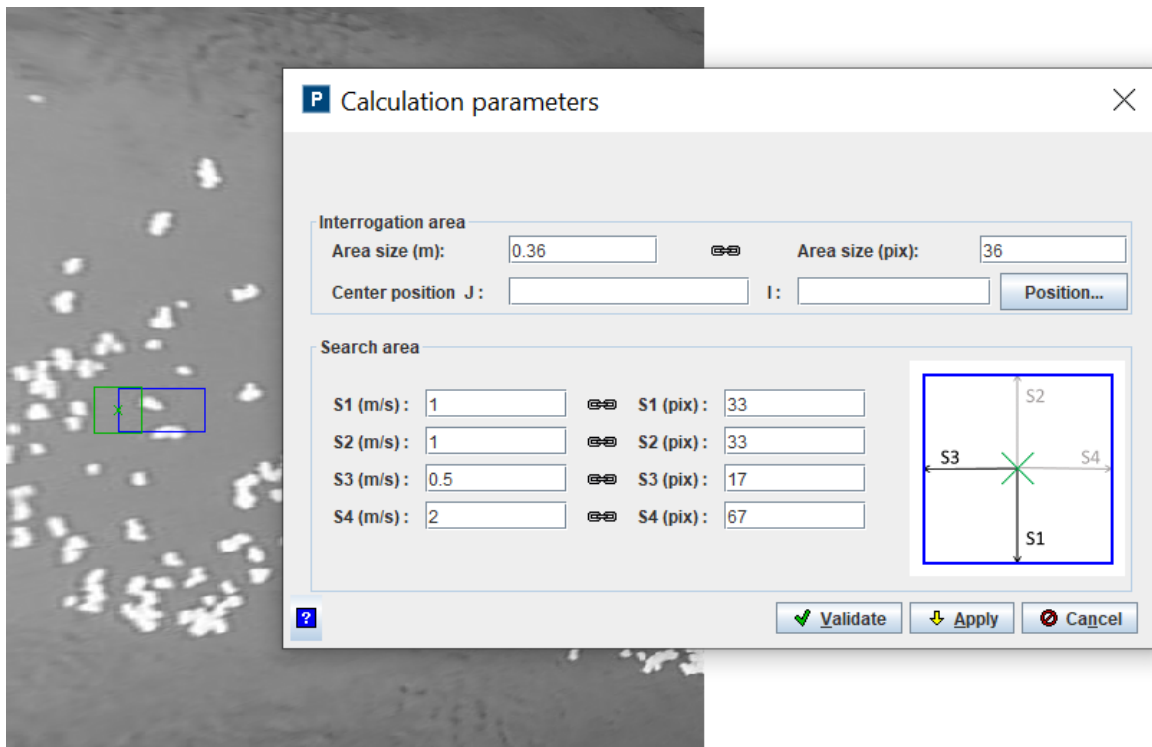


- The **LSPIV Analysis** → **Calculation parameters** → **Define** menu launches the interface for the tracer motion **Calculation Parameters**. Several parameters are to be entered:

- the **Interrogation Area (IA)** size, in meters or in pixels (linked units), see the **Principles of tracer velocity measurement** for details. This area must be large enough to

incorporate tracers, but small enough to be representative of the flow (velocity gradients in an AI must be negligible). As a good practice, it should be noted that the IA must have a metric size in adequacy with the size of the tracers to follow and the scale characteristic of the measured flow, while keeping a sufficiently small size to allow a calculation in a reasonable time. A size of about 30 pixels is preferred (the size must be an even number). The **Apply** button allows a graphic display of the size of the IA on an orthorectified image. The user can choose the location of the center of the window by entering their coordinates in **Center position** or by clicking on a pixel in the image after activating the **Position** button.

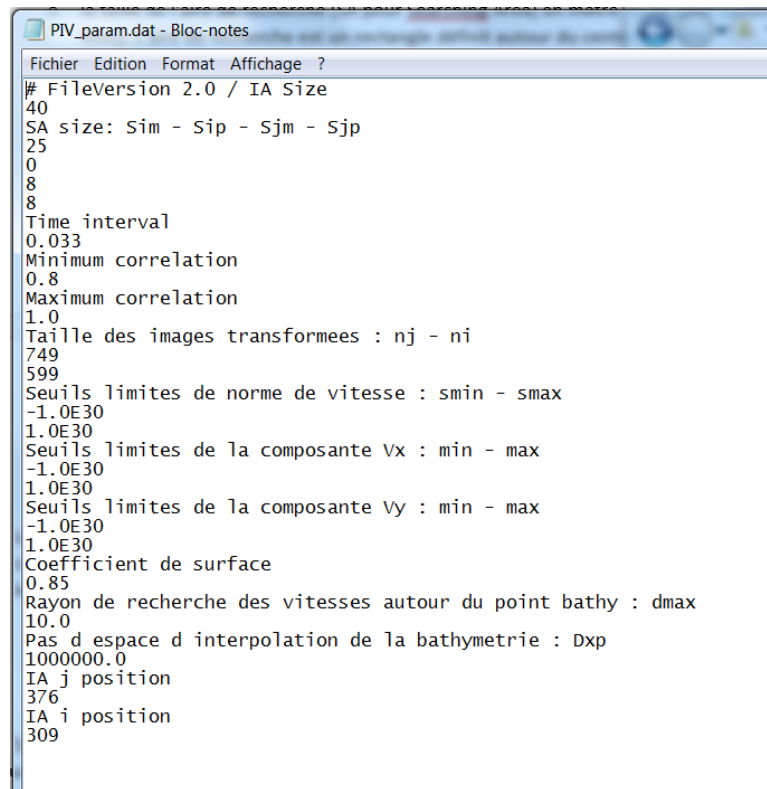
- the **Search Area (SA)** size in meters or pixels (linked units), see the Principles of Tracer Velocity Measurement page for more details. The search area is a rectangle defined around the center of the interrogation area. It corresponds to the zone in which the patterns are searched on the successive images. When the flow has a preferred direction, the search area can be extended in this direction. The SA is defined by 4 parameters, Sim, Sip, Sjm and Sjp. The **Apply** button allows a graphical visualization of the size of the SA on an orthorectified image.



- The **Preview...** button applies the configuration to the first image pair and displays the velocity results, as a test of the parameters.
- The parameters of the calculation of the tracer movements are stored in the file **outputs.dir\PIV_param.dat** after the validation.
- The **?** button pops up a tooltip providing recommendations on the velocity calculation parameters.

• The **LSPIV Analysis → Calculation Parameters → Import** menu allows you to load the calculation

parameters of the displacements of an existing study thanks to a file **PIV_param.dat**. This file has the following format:

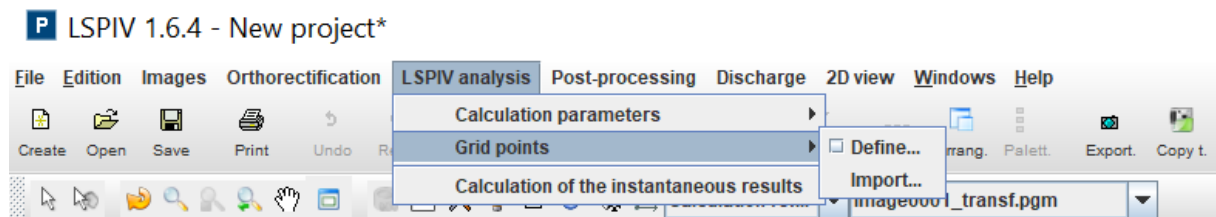


```

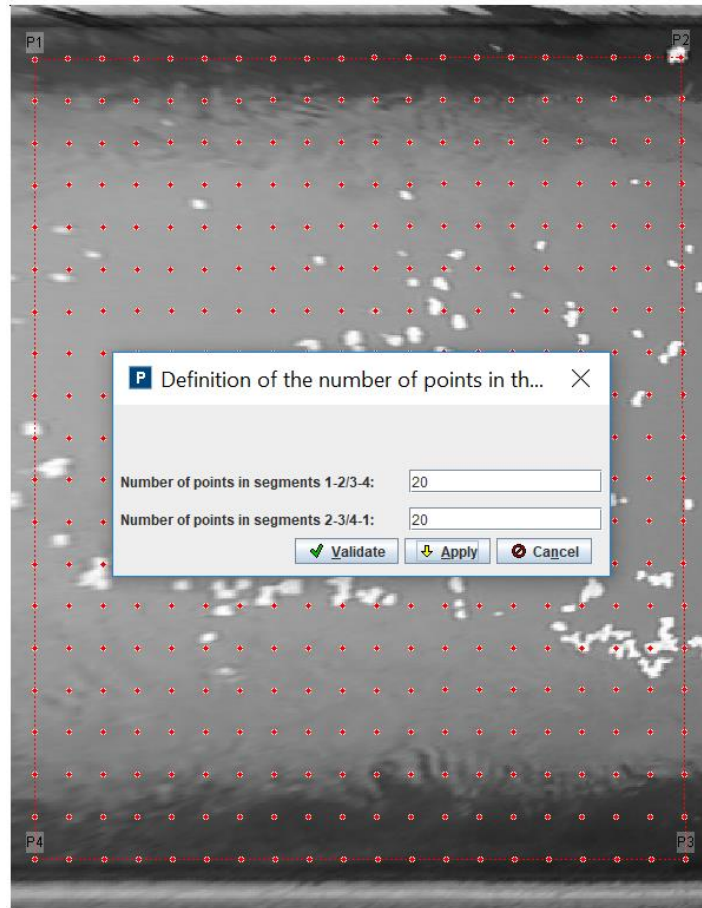
PIV_param.dat - Bloc-notes
Fichier Edition Format Affichage ?
# FileVersion 2.0 / IA Size
40
SA size: Sim - Sip - Sjm - Sjp
25
0
8
8
Time interval
0.033
Minimum correlation
0.8
Maximum correlation
1.0
Taille des images transformees : nj - ni
749
599
Seuils limites de norme de vitesse : smin - smax
-1.0E30
1.0E30
Seuils limites de la composante Vx : min - max
-1.0E30
1.0E30
Seuils limites de la composante Vy : min - max
-1.0E30
1.0E30
Coefficient de surface
0.85
Rayon de recherche des vitesses autour du point bathy : dmax
10.0
Pas d espace d interpolation de la bathymetrie : Dxp
1000000.0
IA j position
376
IA i position
309
  
```

Calculation grid

The calculation grid represents all the points for which a velocity will be calculated, see the **Principles of tracer velocity** measurement for more details. Two methods are possible to define the calculation grid:



- The **LSPIV Analysis** → **Grid points** → **Define** menu launches the interface for the **Grid outline**. The outline of the grid is a quadrilateral defined by its four corners thanks to clicks on the orthoimage. The density of the grid is defined by a spacing pitch on the opposite segments of the quadrilateral. The **Apply** button allows a graphical display of the grid on the orthoimage. The calculation grid is stored in the **outputs.dir\grid.dat** file and the grid parameters are stored in the **outputs.dir\grid_param.dat** file during validation.

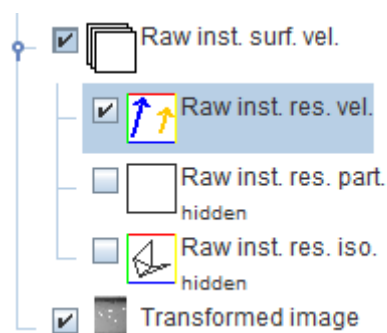


- The **LSPIV Analysis** → **Grid Points** → **Import** menu allows you to load a grid from an existing study using a **grid.dat** file. This text file is a list of the I, J coordinates of all the grid nodes in the orthoimage frame.

Calculation of the movement velocities of the tracers

The **LSPIV analysis** → **Calculation of instantaneous results** menu launches the statistical analysis of plotter displacements for all image pairs in the sequence. See the **Principles of Measuring Tracer Movement Velocity** for more details. An "instantaneous" velocity field (at the step of the time interval between two images) is obtained for all consecutive image pairs. Thus, for N selected images, we obtain N-1 velocity fields, stored in the **vel_raw** folder.

The layer group **Raw inst. surf. vel.** (for raw instantaneous surface velocities) is created.



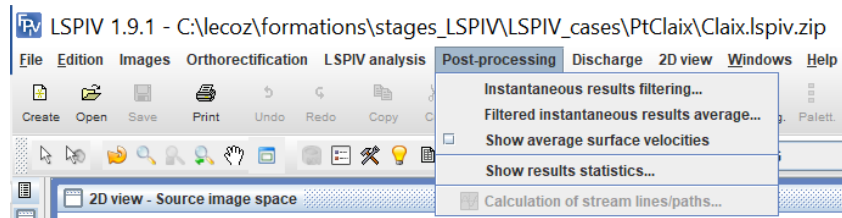
It allows to visualize the calculated velocities for the image pairs in the form of a vector field (**Raw inst. res. vel.**), streamlines (**Raw inst. res. part.**, see how to compute it [here](#)) or isocontours (**Raw inst. res. iso.**). More details on the visualization and setting of velocity layers [here](#). The graphical interface makes it possible to link the visualization of the images and velocities calculated thanks to the



button to **Link/Unlink** the images and the velocities.

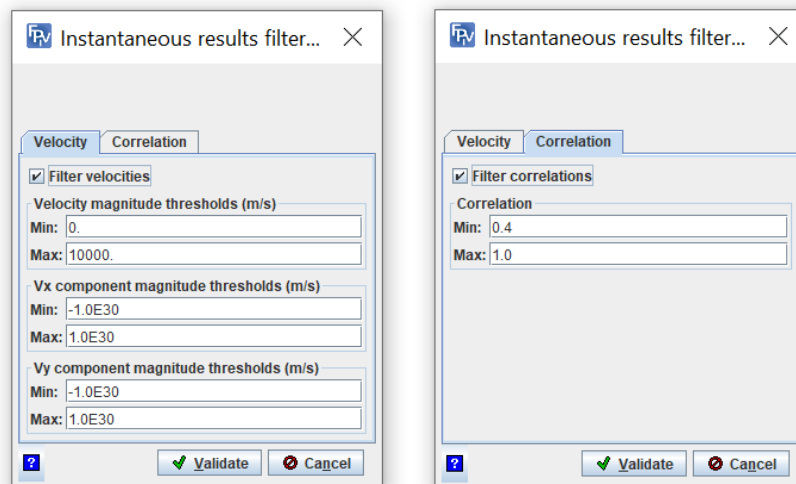
7. Postprocessing of calculated velocities

The post-processing step includes filtering and averaging the velocity results. It is also possible to display some simple statistics on the speed results.



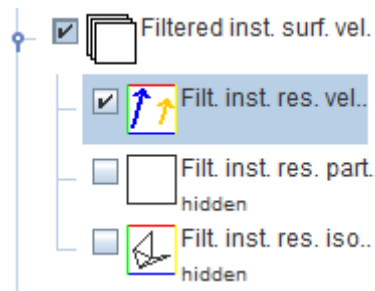
Filtering instant results


The **Post-Processing** → **Instantaneous results filtering** menu launches the filtering interface. Two tabs are available:



- The **Velocity** tab allows you to define thresholds to filter velocity magnitudes, Vx or Vy components. To use this filter, select the Filter velocities check box and enter the minimum and maximum values for the different filters. By default, the minimum velocity magnitude threshold is zero and it cannot be negative.
- The **Correlation** tab allows the calculated velocities to be kept within a certain range of correlation values, see the Tracer Motion Velocity Measurement Principles page for more details. To use this filter, select the Filter correlations check box and enter the minimum and maximum values for the correlation range for which the velocities are to be maintained. The minimum value depends on the quality of the tracers and their temporal conservation. For non-deformable tracers (hard objects, artificial tracers) high correlations (of the order of 0.7) may be required. For deforming tracers (turbulence figures, foam), we will ask for a lower minimum threshold (of the order of 0.4. By fixing a maximum bound at 0.98, we will avoid artifices if the calculation grid overflows the flow and encroaches on static areas (bank, edge image). The default correlation thresholds are set as 0.4 (min) and 0.98 (max).

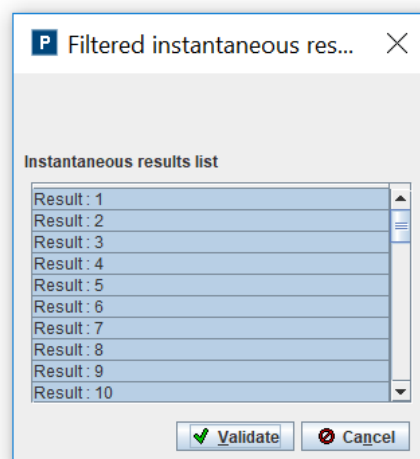
Filtered instant velocity fields are stored in the **vel_filter** folder. The layer group **Filtered inst. surf. vel.** (for filtered instantaneous surface velocities) is created.



It makes it possible to visualize the calculated velocities for the image pairs in the form of a vector field (**Filt. inst. res. vel.**), Of lines of current (**Filt. inst. res. part.**, see how to calculate it [here](#) (see how to calculate it here) or isocontours (**Filt. inst. res. iso.**) More details on the visualization and the parameterization of the velocity layers [here](#). The graphical interface makes it possible to link the visualization of the images and velocities calculated thanks to the  button to **Link/Unlink** the images and the velocities.

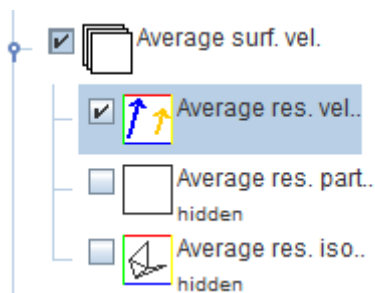
Averaging the results


The **Post-Processing** → **Filtered average instantaneous results** menu launches the average field calculation interface.



We select the filtered velocity fields to be averaged (a priori, all the filtered results are selected) and the validation button is used to calculate the averaged velocity field on all the image pairs of the sequence.

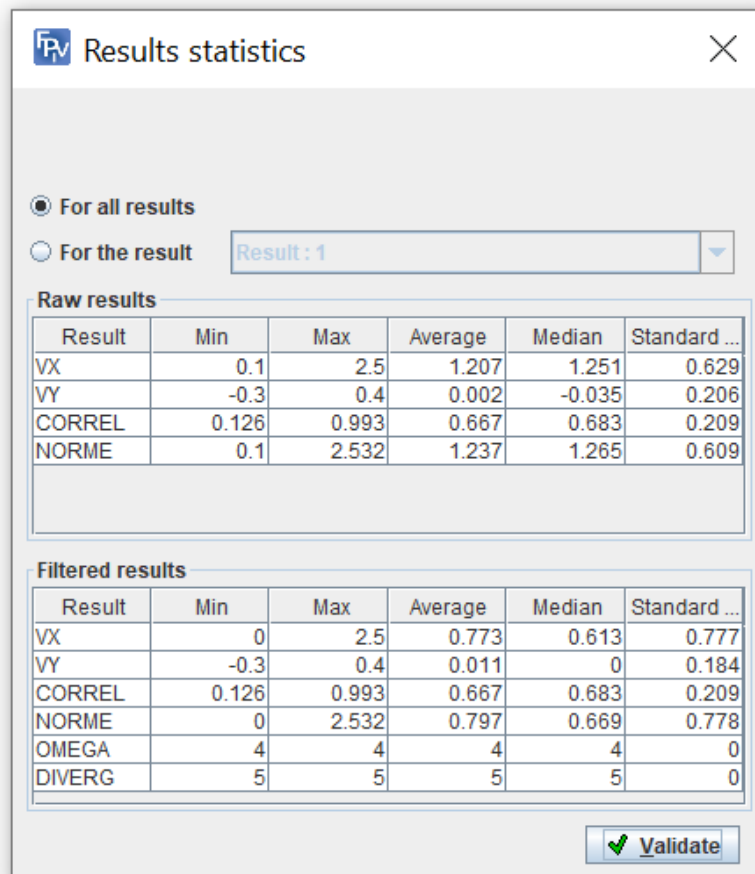
The averaged velocity field is stored in the file **outputs.dir/average_vel.out**. The layer group **Average surf. vel.** (for averaged surface velocities) is created.



It makes it possible to visualize the calculated velocities for the image pairs in the form of a vector field (**Average res. vel.**), Of lines of current (**Average res. part.**, see how to calculate it [here](#) (see how to calculate it here) or isocontours (**Average res. iso.**) More details on the visualization and the parameterization of the velocity layers [here](#). The graphical interface makes it possible to link the visualization of the images and velocities calculated thanks to the  button to **Link/Unlink** the images and the velocities.

Velocity results statistics


The **Post-Processing** → **Show results statistics...** menu displays a summary (min, max, average, median, standard deviation) of raw and filtered velocity results: components Vx and Vy, correlation level (CORREL), magnitude (NORME), curl (OMEGA, not implemented yet), divergence (DIVERG, not implemented yet). The statistics can be computed over the results of all the image pairs or for a given image pair.





8. Viewing velocity results

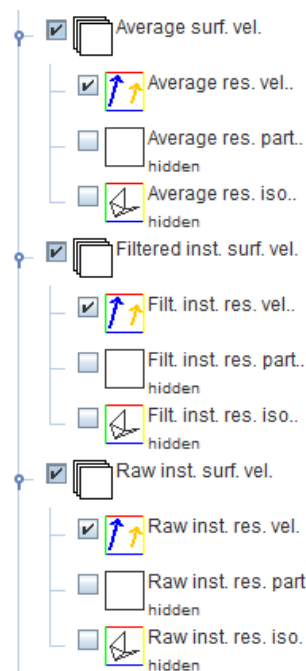
Description of result layers for velocity calculations

During each velocity calculation stage (instantaneous, filtered and averaged velocities), a specific layer group is created. This group systematically includes 3 types of layers:

- Res. vel. layers 

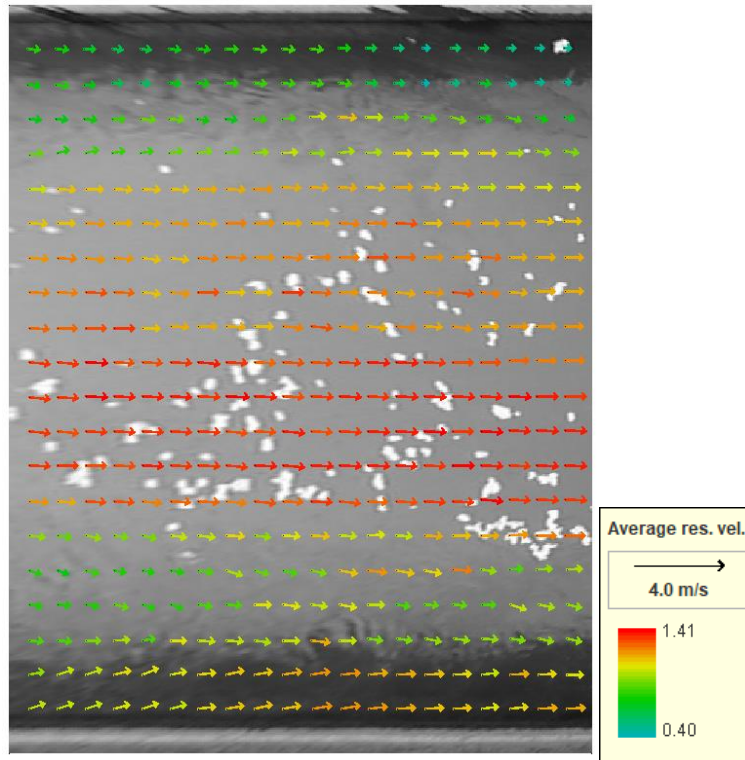
- Res. part layers 

- Res. iso layers 




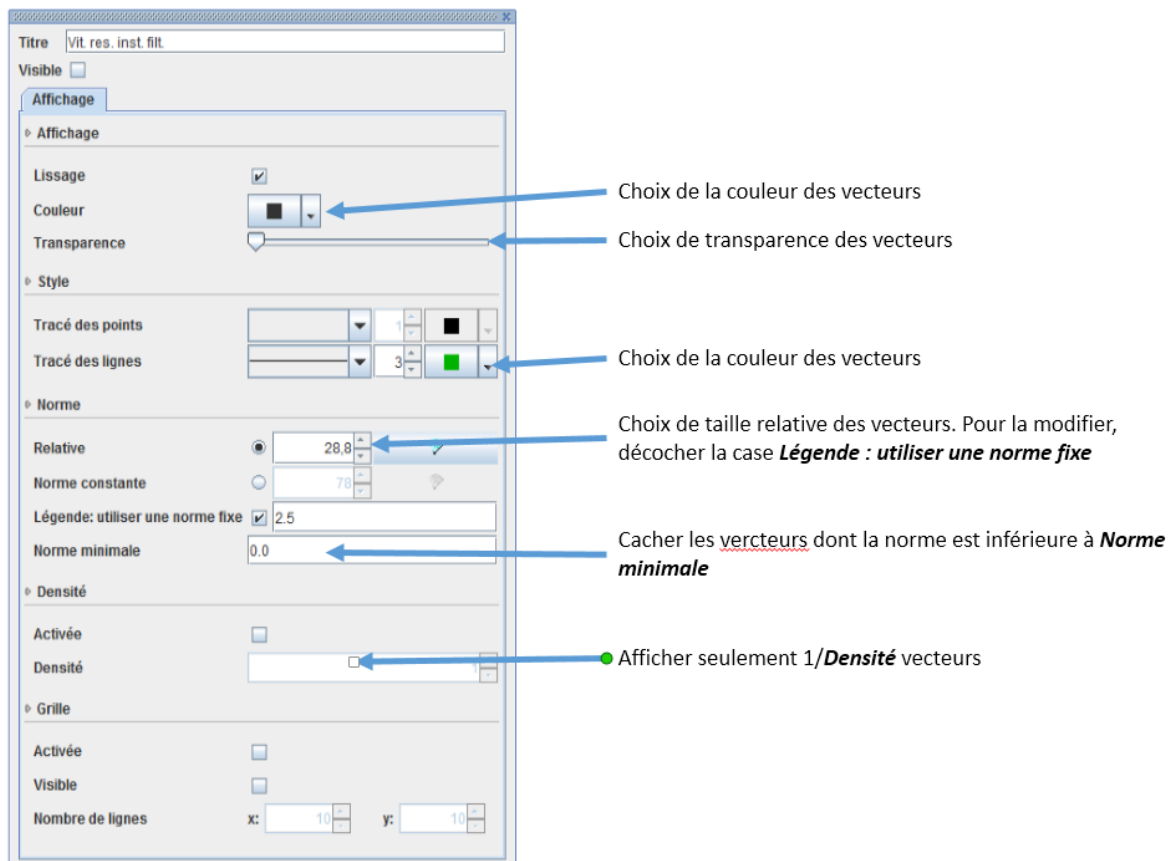
Layer Res. vel.

This layer allows the visualization of results as vectors, as shown below.



The following display options are available through the graph toolbar (be sure to select the layer on which the display options wish to be applied):

- Configuration  opens the configuration window. This allows

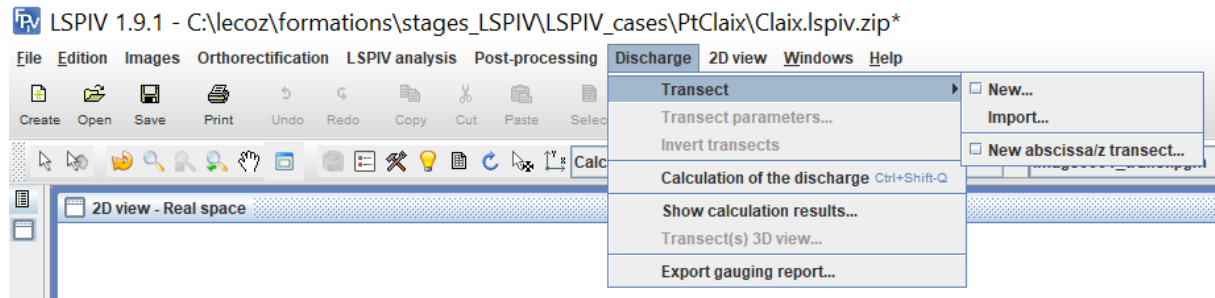


9. Calculation of the discharge

Fudaa-LSPIV can calculate a discharge from averaged velocities if one or more known bathymetry transects are filled in, see the [Principles of Discharge Calculation page](#) for more details.

Specify one or more bathymetry transects

Three methods are possible to specify one or several bathymetry transects:

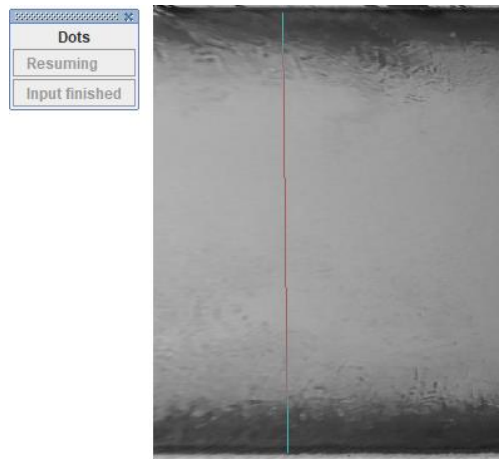





- The **Discharge → Transect → New** menu launches the interface to define a bathymetric profile. A profile is indicated on a straight line, preferably perpendicular to the discharge. First, enter the Z coordinate in the real coordinate system of the edge on the left bank of the transect, then click on the corresponding point in the orthorectified image. Repeat for all points of the bathymetric transect. The first two points indicated define the orientation of the bathymetric profile. The bathymetric profiles are stored in **outputs.dir/bathy_p.dat**. The single velocity coefficient defaults to 0.85 and applies to all points in the transect. By unchecking the **Velocity single coef.** box, it becomes possible to define a coefficient for each node of the transect. If coefficient values are missing for some nodes, they will be interpolated linearly along the transect, with constant extrapolation to the edges.

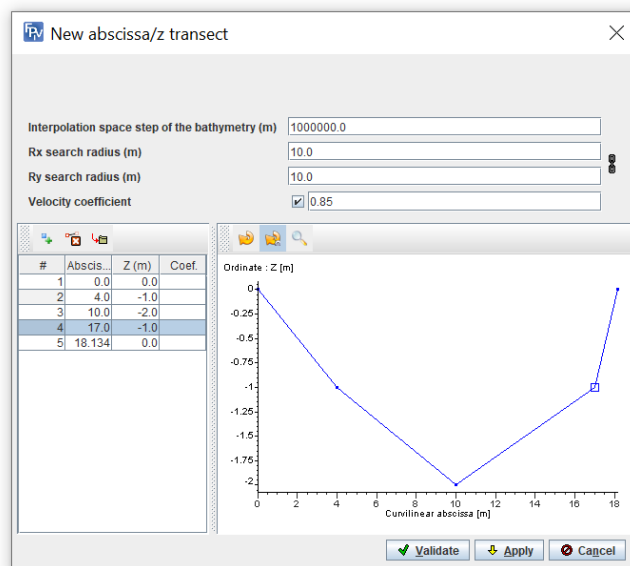


- The **Discharge → Transect → Import** menu allows you to load an existing bathymetric profile as an X, Y, Z text file. If the points of this transect are not perfectly aligned on a straight line, they are projected on the right defined by the first and the last point of the transect. It is possible to import several transects at the same time.
- The **Discharge → Transect → New abscissa-z transect...** menu allows the automatic calculation of the XYZ coordinates of a transect defined in XZ coordinates. First, an input window opens for the user to define the origin of the transect (given by a first point to be


clicked) and its orientation (given by a second point to be clicked, which will not necessarily be the end of the transect):

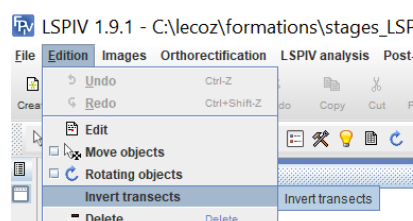


Then, a window opens for defining the transect parameters (see details in the next section), adding points with the  button, deleting points with the  button, and freely editing their XZ coordinates in the table. The  button allows you to import a transect as a simple text file with two columns for abscissa and elevation, separated by a space or a tab. The window also proposes a visualization of the transect points in the vertical XZ plane:

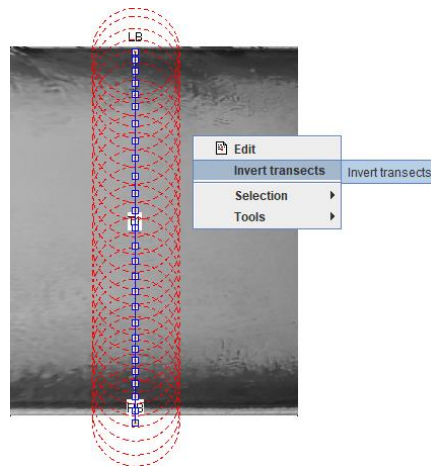


Reverse transects


If the orientation of the transects is not good (right bank and left bank inverted), select the ***Transects*** layer of the ***Discharge*** layer group, select the wrong transect(s) with the selection tool  and use the **Edit → Invert transects** menu.

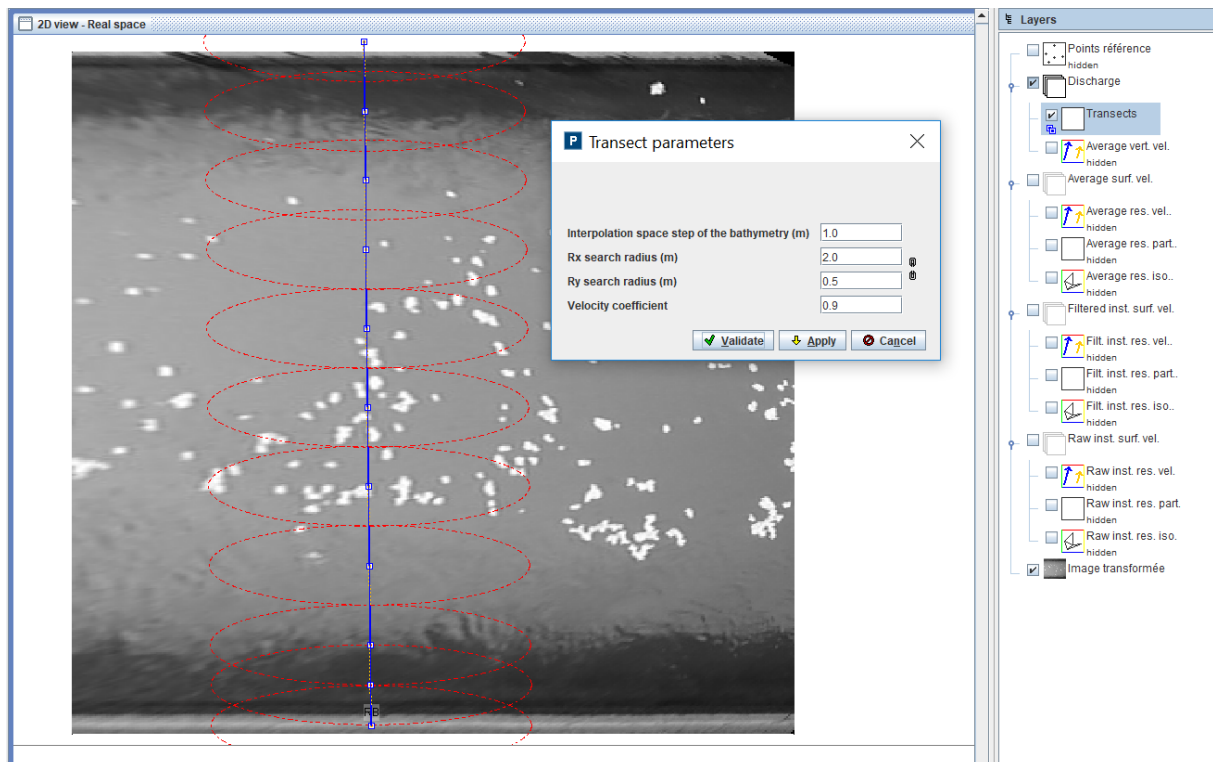


Or **right-click** → **Invert transects**:





Transects parameters

Select the **Transects** layer of the **Discharge** layer group, select the transect (s) to be set with the selection tool , and use the **Discharge** → **Transect parameters** menu.

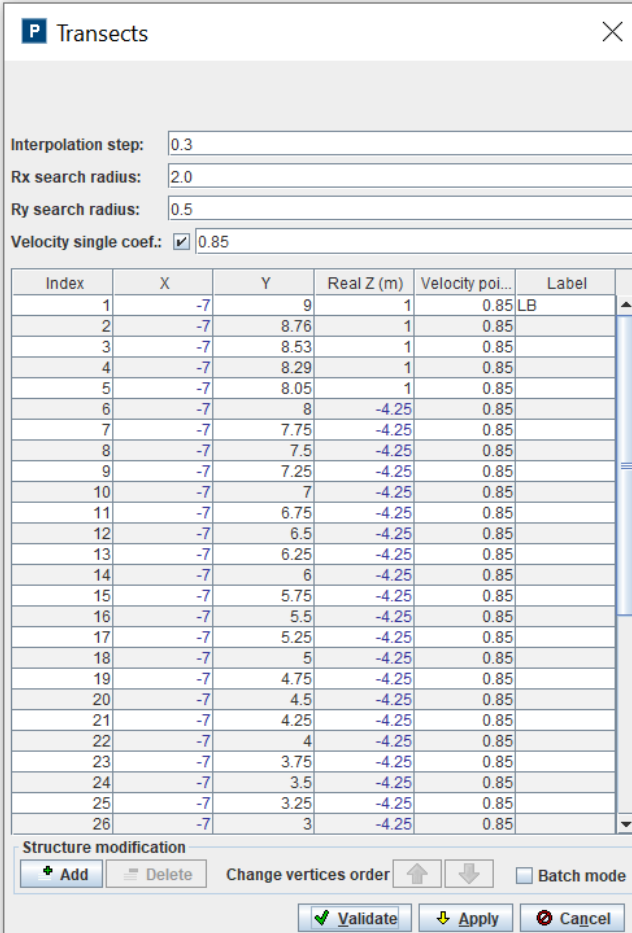


- The **Interpolation space step of the bathymetry (m)** interpolates a bathymetric transect that is not sufficiently sampled. Since discharge is calculated using velocities at known bathymetry points (see **Principles of Discharge Calculation**), the transect should have about 20 points in the wet zone. The Z interpolation is done linearly from the neighboring data. The graphic display shows the effect of the interpolation on the orthorectified image.
- The **Velocity searching radii (m)** define the ellipsoid area around the known bathymetry point in which the calculated LSPIV velocities will be averaged to assign a surface velocity value (see **Principles of Discharge Calculation**). The Rx and Ry search radii define the demi-axes of the

ellipsoids along the horizontal and vertical axes, respectively. If the **Link/Unlink** icon  is checked , then the Rx and Ry values are forced to be equal, i.e. circular search areas are defined. The graphic display shows the footprint of the search radii around each bathymetric point.

- The **Velocity coefficient** is the ratio of the velocity averaged over the depth to the surface velocity. It makes it possible to calculate a velocity averaged over the depth from the surface velocity assigned to the bathymetric point (see **Principles of discharge calculation**).

Alternatively, the data and parameters of a transect can be edited node by node: select the transect then click-right **Edit**.



P Transects

Interpolation step: 0.3

Rx search radius: 2.0

Ry search radius: 0.5

Velocity single coef.: ☒ 0.85

| Index | X | Y | Real Z (m) | Velocity poi... | Label |
|-------|----|------|------------|-----------------|-------|
| 1 | -7 | 9 | 1 | 0.85 | LB |
| 2 | -7 | 8.76 | 1 | 0.85 | |
| 3 | -7 | 8.53 | 1 | 0.85 | |
| 4 | -7 | 8.29 | 1 | 0.85 | |
| 5 | -7 | 8.05 | 1 | 0.85 | |
| 6 | -7 | 8 | -4.25 | 0.85 | |
| 7 | -7 | 7.75 | -4.25 | 0.85 | |
| 8 | -7 | 7.5 | -4.25 | 0.85 | |
| 9 | -7 | 7.25 | -4.25 | 0.85 | |
| 10 | -7 | 7 | -4.25 | 0.85 | |
| 11 | -7 | 6.75 | -4.25 | 0.85 | |
| 12 | -7 | 6.5 | -4.25 | 0.85 | |
| 13 | -7 | 6.25 | -4.25 | 0.85 | |
| 14 | -7 | 6 | -4.25 | 0.85 | |
| 15 | -7 | 5.75 | -4.25 | 0.85 | |
| 16 | -7 | 5.5 | -4.25 | 0.85 | |
| 17 | -7 | 5.25 | -4.25 | 0.85 | |
| 18 | -7 | 5 | -4.25 | 0.85 | |
| 19 | -7 | 4.75 | -4.25 | 0.85 | |
| 20 | -7 | 4.5 | -4.25 | 0.85 | |
| 21 | -7 | 4.25 | -4.25 | 0.85 | |
| 22 | -7 | 4 | -4.25 | 0.85 | |
| 23 | -7 | 3.75 | -4.25 | 0.85 | |
| 24 | -7 | 3.5 | -4.25 | 0.85 | |
| 25 | -7 | 3.25 | -4.25 | 0.85 | |
| 26 | -7 | 3 | -4.25 | 0.85 | |

Structure modification

In addition to the aforementioned transect parameters, the XYZ coordinates of the transect nodes can be modified. Extra nodes can be added and defined. Selected nodes can be deleted or moved up and down in the list.

If the **Velocity single coef.** Box is unticked, different velocity coefficients can be specified for each node of the transect. If coefficient values are missing for some nodes, they will be linearly interpolated along the transect distance, with constant extrapolation to the edges. The same applies in case new nodes are created, i.e. if the **interpolation step** is smaller than the largest distance between two successive nodes in the transect. Coefficient interpolation is done when the **Apply** or **Validate** buttons are pushed. The interpolation results can be seen when the transect edition window opened again.

Discharge calculation

The **Discharge** → **Calculation of the discharge** menu (shortcut: **CTRL+shift+Q**) starts the discharge calculation for the bathymetric transects present. For details of the discharge calculation, see **Discharge Calculation Principles**. At the end of the calculation, the discharge results window opens.

P

Calculation successfully completed

×

Water level (m):

0.0

Transects list

| # | Vel. coef. | Total Q (m³/s) | Gap (%) | Wetted area (m²) | Gap (%) | Ave. vel. (m/s) | Gap (%) | Measured Q / Total Q (%) |
|---------|------------|----------------|---------|------------------|---------|-----------------|---------|--------------------------|
| 1 | 0.850 | 30.844 | -1.6 | 32.837 | +0.0 | 0.939 | -1.6 | 99.958 |
| 2 | 0.850 | 31.707 | +1.2 | 32.837 | +0.0 | 0.966 | +1.2 | 96.326 |
| 3 | 0.850 | 31.488 | +0.5 | 32.837 | +0.0 | 0.959 | +0.5 | 96.395 |
| Average | 0.850 | 31.346 | +0.0 | 32.837 | +0.0 | 0.955 | +0.0 | 97.540 |

✓

Validate

The **Water level** used in the computation is displayed for memory (not editable).

The table (not editable) allows you to see the calculated parameters for all transects (one row per transect) and compare each result to the average of all transects (last row): the difference from the average is expressed as **Gap (%)**.

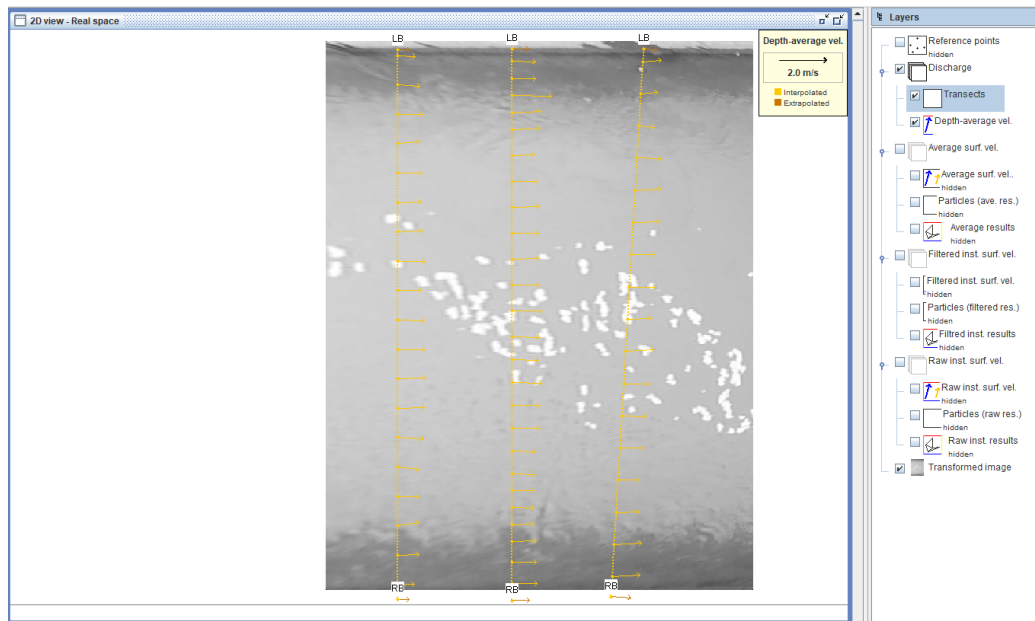
The **Vel. Coef.** column displays the mean velocity coefficient. In the case of variable coefficients along a transect, it is the single constant coefficient that would have yielded the same discharge result. It is computed by dividing the total discharge by the virtual discharge computed with a constant coefficient equal to 1.

The **Total Q**, **Wetted area**, and **Ave. vel.** Columns display the discharge, wetted area and bulk velocity.

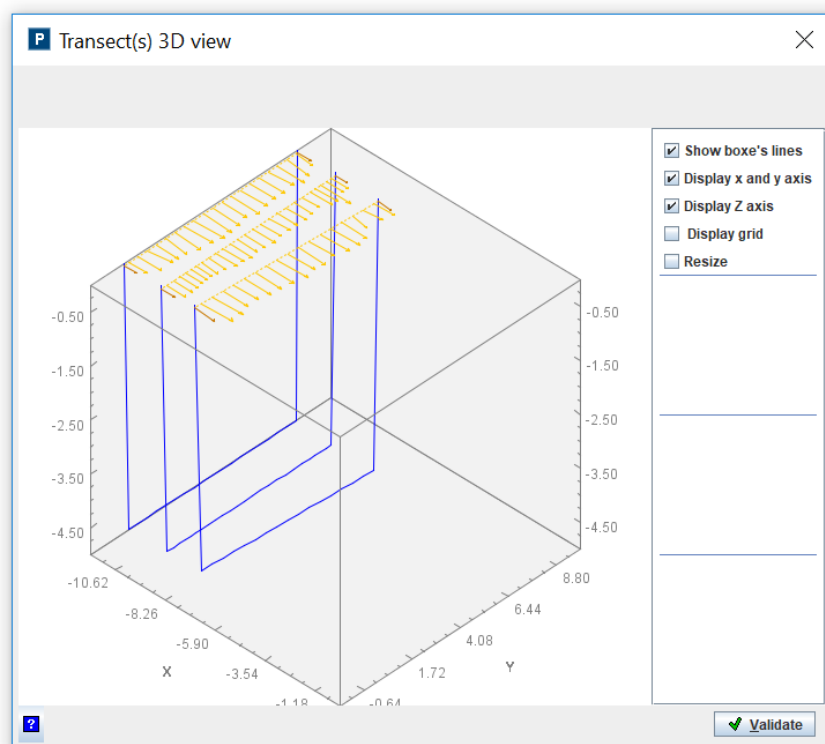
The **Measured Q / Total Q** column displays the ratio of the discharge computed from measured velocities only (i.e. interpolated from neighbouring LSPIV velocities) to the total discharge (including extrapolation of missing transect velocities). It is a measure of the weight of velocity extrapolation in the total discharge result.

The **Discharge** → **Show calculation results** menu allows you to review the discharge calculation table without restarting the calculation.

The layer **Depth-average vel.** (for depth-average velocities) is created and displayed on the orthoimage. It makes it possible to visualize the averaged velocities on the depth at each bathymetric point.



After selecting the transects of interest, the **Discharge → Transect(s) 3D View** menu allows a 3D visualization of the bathymetry of the transects, the height of water and velocities averaged over the depth.



Export the gauging report

The **Discharge → Export gauging report** menu allows you to make a gauging report containing all study parameters and results. Fill in the fields of the dialog concerning information about the place, the date and the realization of the measurement. Also available from the **File → Export → Export gauging report** menu.

P
Fields to fill

Fields to fill

| Field | Value |
|-----------------------------|-------|
| Bathymetry survey date/time | |
| Comment | |
| Computation date/time | |
| Measurement computed by | |
| Measurement date/time | |
| Measurement number | |
| Measurement realized by | |
| Station code | |
| Station name | |
| Type of camera | |
| Weather conditions | |

?

✓ Validate

✗ Cancel

After validation, choose the backup directory of the gauging report. The report is an Excel file printable on a double-sided A4.

Project name: Claix.lspiv.zip
 Station code: -
 Station name: -

Fudaa-LSPIV version: 1.6.4
 Measurement number: -
 Measurement date/time: -

| | | | |
|---------------|---------|---------------------------|--------------------------|
| Stage: | -0.05 m | Mean discharge: | 42.673 m ³ /s |
| Measured by: | - | Measured discharge ratio: | 99.6 % |
| Computed by: | - | Weather conditions: | - |
| | | Computation date/time: | - |

Image parameters

| | | | |
|-------------------|----|-------------------------------|-------|
| Camera: | - | Number of images par seconde: | 5 |
| Number of images: | 47 | Time interval between images: | 0.2 s |

Orthorectification parameters

| | | | |
|-----------------------------|------------|-----------------|----------------|
| Number of GRPs: | 8 | Xmin: -12.917 m | Xmax: -6.319 m |
| Max error on GRP positions: | 0.118 m | Ymin: -0.01 m | Ymax: 8.477 m |
| Resolution: | 0.02 m/pix | | |

LSPIV parameters

| | | | | | |
|-----------------------------|------------|-----|---------|-------------|-------------|
| Size of interrogation area: | 16 pix | <-> | 0.32 m | | |
| Size of search area | Sim: 4 pix | <-> | 0.4 m/s | Sip: 4 pix | <-> 0.4 m/s |
| | Sjm: 0 pix | <-> | 0 m/s | Sjp: 25 pix | <-> 2.5 m/s |

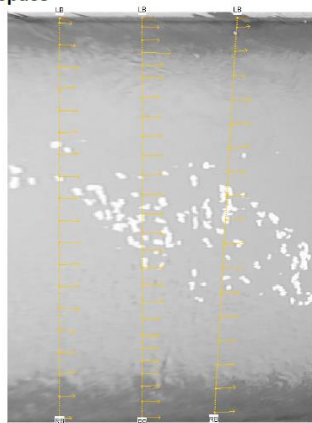
Filters

| | | |
|----------------------------------|----------|----------|
| Velocity magnitude thresholds | Min: - | Max: - |
| Vx velocity component thresholds | Min: - | Max: - |
| Vy velocity component thresholds | Min: - | Max: - |
| Correlation | Min: 0.2 | Max: 0.8 |

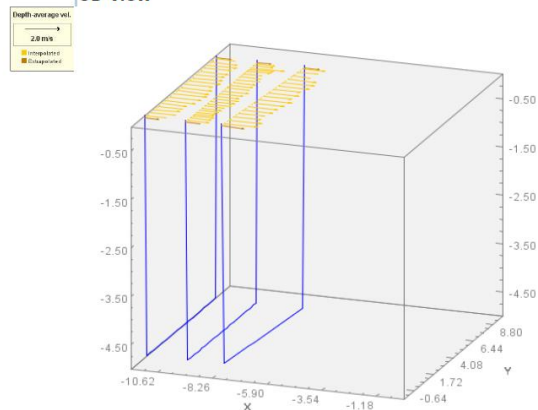
Discharge computation parameters

| | | | |
|---------------------------------|---|------------------------------|------------|
| Number of transects: | 3 | Bathymetry survey date/time: | - |
| Velocity search radius | | Min: 1 m | Max: 1 m |
| Interpolation step of discharge | | Min: 0.5 m | Max: 0.5 m |
| Velocity coefficient | | Min: 0.85 | Max: 0.85 |

2D view - Real space



3D view



Fudaa-LSPIV version: 1.6.4
Measurement number: -
Measurement date/time: -

| | | | |
|--------------|---------|---------------------------|-------------|
| Stage: | -0.05 m | Mean discharge: | 42.673 m³/s |
| Measured by: | - | Measured discharge ratio: | 99.6 % |
| Computed by: | - | Weather conditions: | - |
| | | Computation date/time: | - |

Table of results

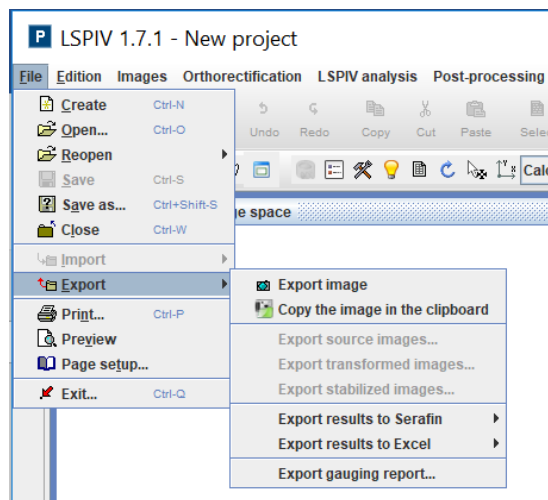
[illegible]

Comment:

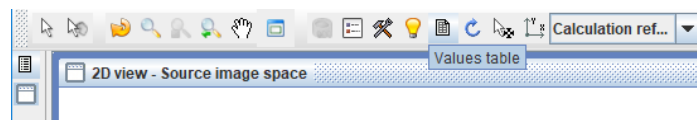
10. Exporting data

Several export formats are possible from the **File** → **Export** menu:

- Current view
- Raw / transformed / stabilized images
- Export of velocities in spreadsheet format (Excel...)
- Export of velocities in TELEMAC Serafin format (.slf) to be imported into another software (QGIS, BlueKenue...)
- Gauging report

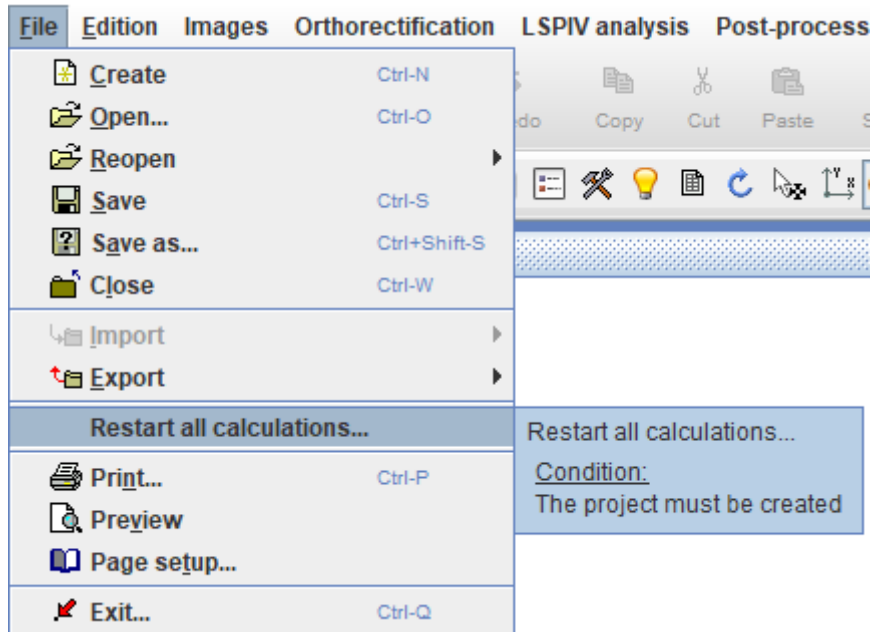


It is also possible to export results in spreadsheet format by selecting the layer and the desired results, then clicking on the **Values Table** icon in the toolbar:

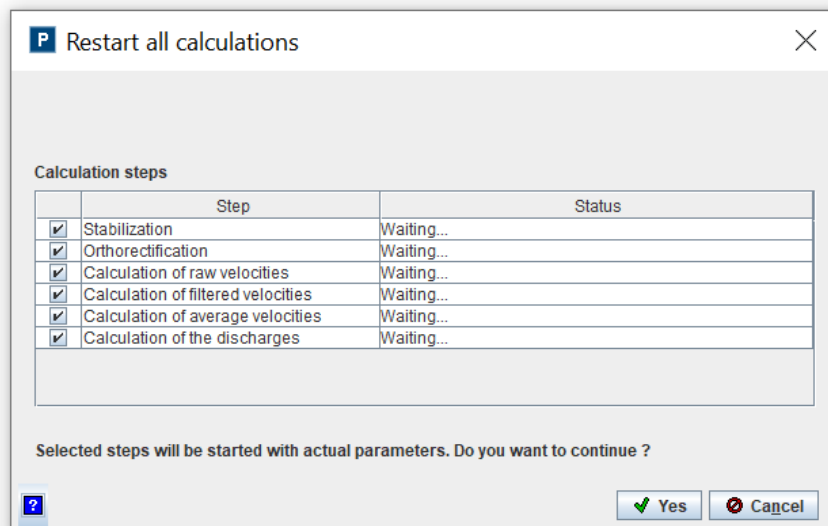


11. Redo the calculations of an existing study

For convenience, it is possible to restart all or several calculation steps from the **File** → **Restart all calculations...** menu.



In the **Restart all calculations** window, the user can select the calculation steps to be redone.



12. Known bug and solutions

The gauging report is not created

At the request of creation of the gauging report, the following message can appear:



The solution is to copy the **templates** directory from the software installation source directory to the **bin** directory.

13. Insights

Principle of image stabilization

Stabilization is used to remove the effects of the camera movements on the scene. The movement between two frames can be modelled through a geometrical transformation: rotation, translation, zooming or other complex models. The idea is then to apply the reverse transformation on the second image in order to “cancel” the movement. The main steps are the following:

- Extraction of key points on the two frames
- Points matching
- Estimation of the geometrical transformation
- Correction of the movement

Key points extraction

Remarkable points on an image –“edges” or “corners” – are areas where the variations of intensity (gradients) are important. SURF library (Oyallon, 2015) is used to extract key points. The idea is to extract only the points where the variations of intensity are substantial in the two directions. The determinant of the Hessian matrix (second derivatives) is used to do so. It is defined as:

$$DoH = \det \begin{pmatrix} \frac{d^2 I(x,y)}{dx^2} & \frac{d^2 I(x,y)}{dxdy} \\ \frac{d^2 I(x,y)}{dxdy} & \frac{d^2 I(x,y)}{dy^2} \end{pmatrix}$$

With I the intensity of the pixel at the point of coordinate (x, y) . We finally retain the key points where the DoH is above a threshold t_H . The value of this threshold is computed automatically to ensure that we reach the desired amount of key points. Three intervals are defined:

- **Low** density of points: Number of points $\in [300 ; 500]$
- **Average** density of points: Number of points $\in [1000 ; 2000]$
- **High** density of points: Number of points $\in [3000 ; 5000]$

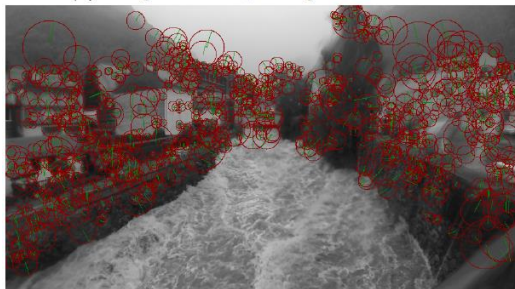
To ensure that stabilization is performed on the river banks the user defines a “flow area” that doesn’t contain any key points.



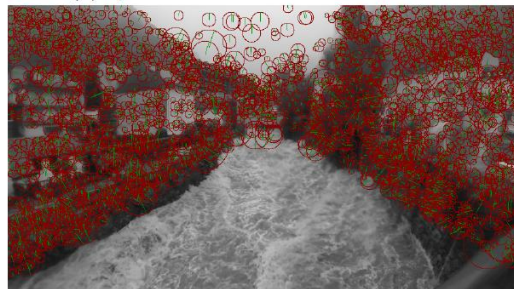
(a) Image Source + masque écoulement



(b) Qualité basse : 474 Points d'intérêt



(c) Qualité moyenne : 1001 Points d'intérêt



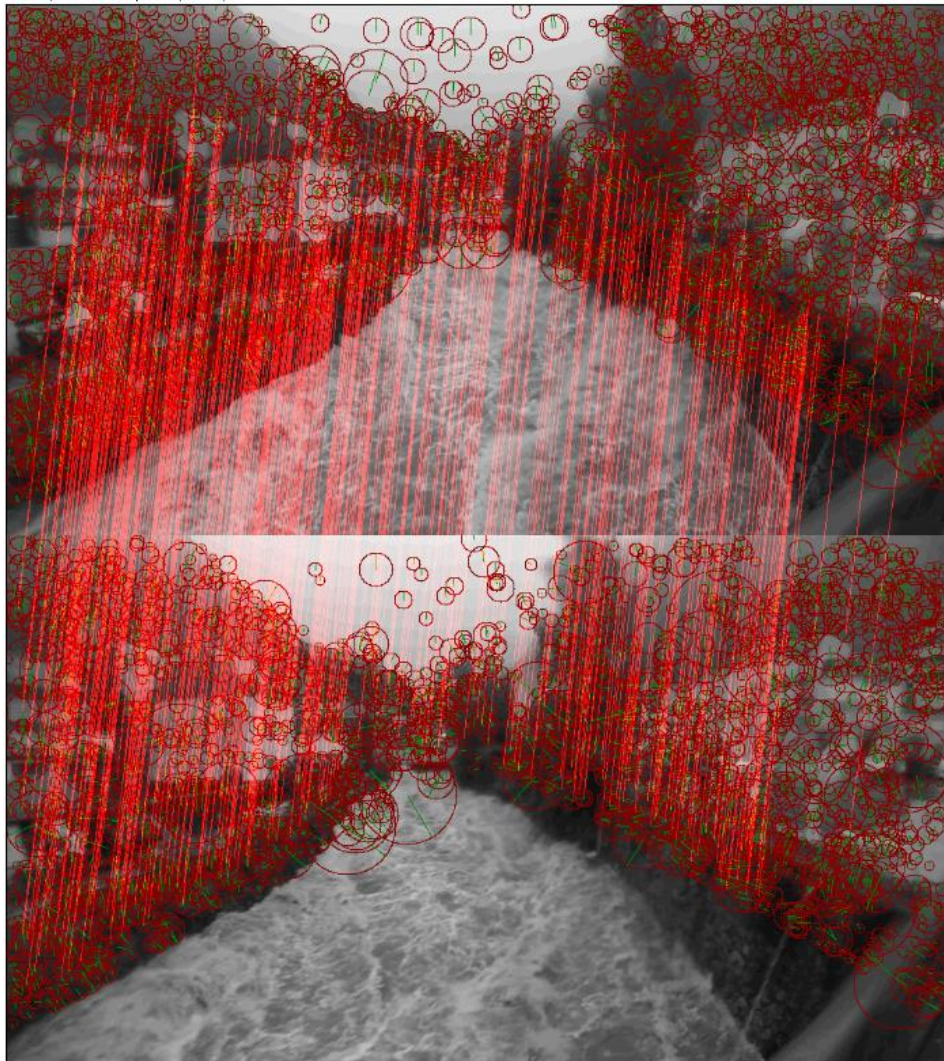
(d) Qualité haute : 2993 Points d'intérêt

Points matching

Now that we get the key points we have to match them from one frame to another. To do so we use the SURF descriptor which could be seen as the “ID” of each point. It contains information such as:

- Scale of the point (its “size”)
- Orientation
- Distribution of the gradients in its neighborhood

Neighborhood depends on the “size” of the points and the gradients are expressed relatively to the orientation of the point. Thanks to these particularities the SURF descriptor is invariant to rotation, translation and zoom. The key points with same descriptor are then matched. The picture below emphasizes the matching with a red line. For each point the diameter of the circle represents the size of the point and the green line represents its orientation.



Errors may occur in matching. To avoid these “false match” we use the ORSA method (Moisan 2004). They’re identified thanks to a stochastic process applied with epipolar geometry constraint (not detailed here).

Estimation of the transformation

We now have 2 sets of matched points, which means that we know the position of each point on frame 1 and 2. Our goal is now to determine the homography H between positions X and X' .

$$X = H \cdot X' = \begin{pmatrix} h_1 & h_2 & h_3 \\ h_4 & h_5 & h_6 \\ h_7 & h_8 & h_9 \end{pmatrix} \cdot \begin{pmatrix} x' \\ y' \\ 1 \end{pmatrix}$$

In image processing we usually consider linear transformations: affine or projective models. Linear transformations conserve parallelism, angles and ratio. For affine models only parallelism is conserved. With the projective model, nothing is conserved so this is the most sensitive one. Nevertheless this is the best to represent perspective effects, and so the change of point of view of the camera.

The similarity and projective models, used in the stabilization module, are defined as:

$$H_{similarity} = \begin{pmatrix} sr_{11} & sr_{12} & t_x \\ sr_{21} & sr_{22} & t_y \\ 0 & 0 & 1 \end{pmatrix}$$

$$H_{projective} = \begin{pmatrix} h_{11} & h_{12} & h_{13} \\ h_{21} & h_{22} & h_{23} \\ h_{31} & h_{32} & h_{33} \end{pmatrix}$$



(a) Image Source - Gave de Cauterets



(b) Transformation de similarité - 4 D.L.



(c) Transformation affine - 6 D.L.



(d) Transformation projective - 8 D.L.

Each point is used as a control point. The values of coefficients on the homography matrix are then estimated with them. DLT method (Direct Linear Transform) is used to reorganize equations above and estimate H coefficients. Indeed we can't find a unique solution to this system, so we determine the "best solution" that fits with the control points.

Image transformation

We use the H matrix determined above to transform the images. This scheme is standard in image processing, it helps to deal with the spatial discretization on the image (pixels with index as integer):

- We determine the inverse matrix that changes X' to X
- We browse pixels on X' image (image to be rectified)
- We apply inverse transformation to the coordinates of the treated pixel (i,j)-integers- to get (i',j')-real.
- We use a bicubic interpolation (Hermitte splines on 2 dimensions) to determine the intensity at the coordinates (i',j') as integers.

Principle of orthorectification

The pinhole model and its resolution: general 3D case
 We consider a pinhole model to move from an object of coordinates X, Y, Z in a real reference to its representation i, j in an image reference. The link between these coordinates can be written in the form called DLT (for Direct Linear Transformation) as:

$$i = (a_1.X + a_2.Y + a_3.Z + a_4) / (a_9.X + a_{10}.Y + a_{11}.Z + 1) \text{ and } j = (a_5.X + a_6.Y + a_7.Z + a_8) / (a_9.X + a_{10}.Y + a_{11}.Z + 1) \quad (1)$$

The coefficients a_i have no physical meaning but are combinations of the intrinsic and extrinsic parameters of the shot. The previous system can be written in matrix form:

$$\begin{bmatrix} X & Y & 0 & 0 \\ Z & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 0 & 0 & 0 & 0 \\ Y & Z & 1 & 0 \\ -iX & -iY & -iZ & -jX & -jY & -jZ \end{bmatrix} \cdot \begin{bmatrix} a_1 & a_2 & a_3 & a_4 & a_5 & a_6 & a_8 & a_9 & a_{10} & a_{11} \end{bmatrix}^T = \begin{bmatrix} i \\ j \end{bmatrix}$$

It is possible to solve the equation system above if we are in possession of reference points whose coordinates in the real marks (X, Y, Z) and image (i, j) are known. These are points visible on the images, and whose real coordinates could be measured in the field. The equation system above has 11 unknowns (the coefficients a_i), and each landmark provides a coordinate i and j. At least 6 benchmarks are needed to resolve this system (which will then be overdetermined). The measurement of the real coordinates and the pointing of the image coordinates being tainted with uncertainty, it is advisable to use more than 6 reference points. For a number $N \geq 6$ of reference points, the following matrices are defined:

$T = [2N \times 11] = \begin{bmatrix} X_1 & Y_1 & Z_1 & 1 & 0 & 0 & 0 & 0 & -i_1 X_1 & -i_1 Y_1 & -i_1 Z_1 \\ X_2 & Y_2 & Z_2 & 1 & 0 & 0 & 0 & 0 & -i_2 X_2 & -i_2 Y_2 & -i_2 Z_2 \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ X_N & Y_N & Z_N & 1 & 0 & 0 & 0 & 0 & -i_N X_N & -i_N Y_N & -i_N Z_N \end{bmatrix}$
 $A = [11 \times 1] = \begin{bmatrix} a_1 & a_2 & a_3 & a_4 & a_5 & a_6 & a_7 & a_8 & a_9 & a_{10} & a_{11} \end{bmatrix}^T$
 $Z = [2N \times 1] = \begin{bmatrix} i_1 & i_2 & \dots & i_N & j_1 & j_2 & \dots & j_N \end{bmatrix}^T$

And the pinhole model is written:
 $TA = Z$

The system being overdetermined calculating the elements of A is done by a least squares regression. We search for the solutions of A which minimize the quadratic difference: $\|TA-Z\|^2$, which amounts to seeking a solution to

$(\partial \|TA-Z\|^2) / \partial A = 0 \rightarrow 2T^T (TA-Z) = 0 \rightarrow T^T TA - T^T Z = 0$
 So we have the following solution for matrix A:
 $A = (T^T T)^{-1} T^T Z$

The pinhole model and its resolution: special 2D case
 If one tries to represent a 2D scene in the real world, a simplified model can be deduced from the complete model. If we consider that the discharge that we wish to measure is a plane, that all the reference points belong to the plane of the river, and that this plane has a coordinate $Z = 0$ the system of equation (1) writes:

$i = (a_1.X + a_2.Y + a_4) / (a_9.X + a_{10}.Y + 1) \text{ and } j = (a_5.X + a_6.Y + a_8) / (a_9.X + a_{10}.Y + 1)$
 We therefore have a solution with 8 coefficients a_i , and the system can be solved with at least 4 reference points.

Creation of orthoimages
 An orthoimage represents a corrected view of the perspective and scaling effects of the real world, for a given plane. In the case of LSPIV analyzes, it is desirable to orthoreject the plane of the surface of the

discharge (it is therefore assumed that our discharge is plane). This plane can be expressed as a function of X and Y such that $Z = b_1 X + b_2 Y + b_3$. Assuming that the longitudinal and transverse slopes are negligible at the scale of the shot, or that the actual coordinate system is expressed relative to the plane of the river (XY plane parallel to the plane of the river), we reduce the equation of the plane to $Z = b_3$, where b_3 is the free surface height in the real reference, h . The system of equation (1) is reduced, in the plane of discharge, to: $i = (a_1.X + a_2.Y + a_3.h + a_4) / (a_9.X + a_{10}.Y + a_{11}.h + 1)$ and $j = (a_5.X + a_6.Y + a_7.h + a_8) / (a_9.X + a_{10}.Y + a_{11}.h + 1)$ (2)

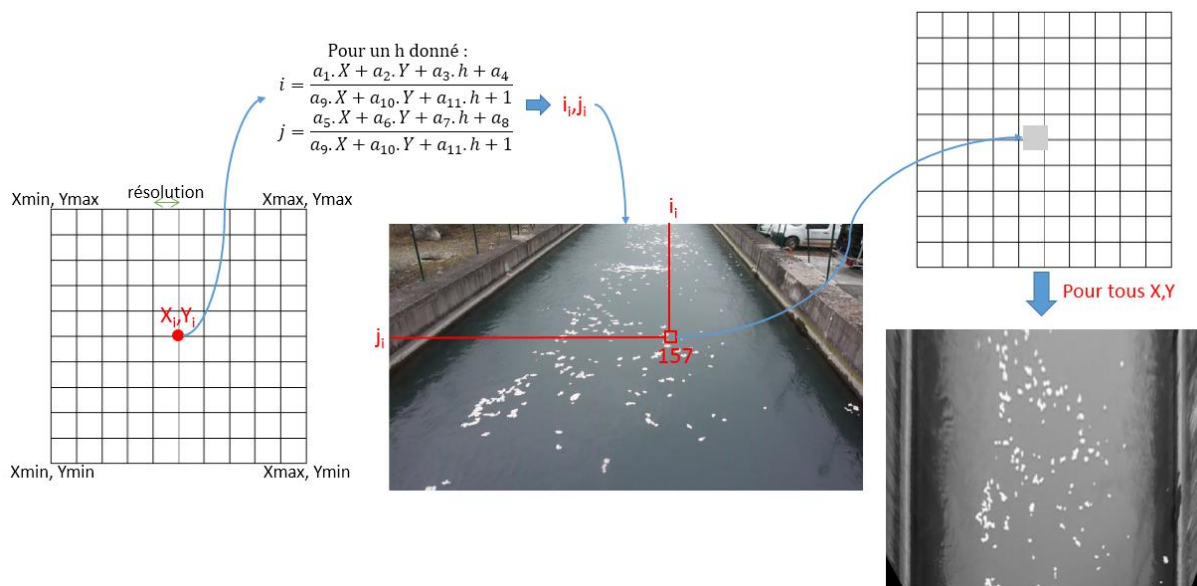
The coefficients a_i were calculated as presented in the previous parts. The method for constructing orthoimages consists of: Define the zone to be imaged in the real coordinate system, ie give the coordinates (X, Y) of the 4 corners of the orthoimage (done in the Orthorectification menu) Sample this area with a given resolution in order to create a grid, knowing that each of the nodes of this grid will be the center of a pixel of the orthorectified image. For each node of the grid, with coordinates (X_i, Y_i) , the corresponding coordinates in the source image (i_i, j_i) are calculated with equation (2). The coordinates (i_i, j_i) thus calculated are reals and not integers. Each center pixel (X_i, Y_i) is assigned a gray level intensity corresponding to the pixel (i_i, j_i) of the source image. Since the coordinates (i_i, j_i) are real, we use an interpolation on the neighboring pixels to define the intensity in gray level, with a cubic convolution:

$$f(i_i, j_i) = \sum_{k=-3}^3 \sum_{l=-3}^3 [f(i_{i+k}, j_{i+l}) C(i_{i+k} - i_i) C(j_{i+l} - j_i)]$$

Où $f(i_{i+k}, j_{i+l})$ est l'intensité du pixel (i_{i+k}, j_{i+l}) dans l'image source et C prend la forme :

$$C(s) = \begin{cases} 1 - 2|s|^2 + |s|^3 & \text{si } 0 \leq |s| \leq 1 \\ 4 - 8|s| + 5|s|^2 - |s|^3 & \text{si } 1 \leq |s| \leq 2 \\ 0 & \text{sinon} \end{cases}$$

Où $s = k$ ou l



14. Approfondissements

Principe de l'orthorectification

Le modèle sténopé et sa résolution : cas général 3D

On considère un modèle sténopé permettant de passer d'un objet de coordonnées X,Y,Z dans un repère réel à sa représentation i,j dans un repère image. Le lien entre ces coordonnées peut s'écrire sous la forme dite DLT (pour Direct Linear Transformation) comme :

$$i = \frac{a_1 \cdot X + a_2 \cdot Y + a_3 \cdot Z + a_4}{a_9 \cdot X + a_{10} \cdot Y + a_{11} \cdot Z + 1} \text{ et } j = \frac{a_5 \cdot X + a_6 \cdot Y + a_7 \cdot Z + a_8}{a_9 \cdot X + a_{10} \cdot Y + a_{11} \cdot Z + 1} \quad (1)$$

Les coefficients a_i n'ont pas de sens physique mais sont des combinaisons des paramètres intrinsèques et extrinsèques de la prise de vue. Le système précédent peut s'écrire sous forme matricielle :

$$\begin{bmatrix} X & Y & Z & 1 & 0 & 0 & 0 & 0 & -iX & -iY & -iZ \\ 0 & 0 & 0 & 0 & X & Y & Z & 1 & -jX & -jY & -jZ \end{bmatrix} \cdot [a_1 \ a_2 \ a_3 \ a_4 \ a_5 \ a_6 \ a_7 \ a_8 \ a_9 \ a_{10} \ a_{11}]^T = \begin{bmatrix} i \\ j \end{bmatrix}$$

Il est possible de résoudre le système d'équation ci-dessus si on est en possession de points de référence dont les coordonnées dans les repères réel (X,Y,Z) et image (i,j) sont connus. Il s'agit de point visibles sur les images, et dont les coordonnées réelles ont pu être mesurées sur le terrain.

Le système d'équation ci-dessus possède 11 inconnues (les coefficients a_i), et chaque point de repère apporte une coordonnée i et j . Il faut donc a minima 6 points de repère pour résoudre ce système (qui sera dès lors surdéterminé). La mesure des coordonnées réelles et le pointage des coordonnées image étant entaché d'incertitude, il est conseillé d'utiliser plus que 6 points de référence. Pour un nombre $N \geq 6$ de points de référence, on définit les matrices suivantes :

$$T = [2N \times 11] = \begin{bmatrix} X_1 & Y_1 & Z_1 & 1 & 0 & 0 & 0 & 0 & -i_1 X_1 & -i_1 Y_1 & -i_1 Z_1 \\ X_2 & Y_2 & Z_2 & 1 & 0 & 0 & 0 & 0 & -i_2 X_2 & -i_2 Y_2 & -i_2 Z_2 \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ X_N & Y_N & Z_N & 1 & 0 & 0 & 0 & 0 & -i_N X_N & -i_N Y_N & -i_N Z_N \\ 0 & 0 & 0 & 0 & X_1 & Y_1 & Z_1 & 1 & -j_1 X_1 & -j_1 Y_1 & -j_1 Z_1 \\ 0 & 0 & 0 & 0 & X_2 & Y_2 & Z_2 & 1 & -j_2 X_2 & -j_2 Y_2 & -j_2 Z_2 \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ 0 & 0 & 0 & 0 & X_N & Y_N & Z_N & 1 & -j_N X_N & -j_N Y_N & -j_N Z_N \end{bmatrix}$$

$$A = [11 \times 1] = [a_1 \ a_2 \ a_3 \ a_4 \ a_5 \ a_6 \ a_7 \ a_8 \ a_9 \ a_{10} \ a_{11}]^T$$

$$Z = [2N \times 1] = [i_1 \ i_2 \ \dots \ i_N \ j_1 \ j_2 \ \dots \ j_N]^T$$

Et le modèle sténopé s'écrit :

$$TA = Z$$

Le système étant surdéterminé calcul des éléments de A se fait par une régression en moindres carrés. On cherche les solutions de A qui minimisent l'écart quadratique : $\|TA - Z\|^2$, ce qui revient à chercher une solution à

$$\frac{\partial \|TA - Z\|^2}{\partial A} = 0 \rightarrow 2T^T(TA - Z) = 0 \rightarrow T^T TA - T^T Z = 0$$

On a donc la solution suivante pour la matrice A :

$$A = (T^T T)^{-1} T^T Z$$

Le modèle sténopé et sa résolution : cas particulier 2D

Si on cherche à représenter une scène 2D dans le monde réel, un modèle simplifié peut être déduit du modèle complet. Si on considère que l'écoulement que l'on souhaite mesurer est un plan, que tous les points de référence appartiennent au plan de la rivière, et que ce plan a une coordonnée Z=0 le système d'équation (1) s'écrit :

$$i = \frac{a_1 \cdot X + a_2 \cdot Y + a_4}{a_9 \cdot X + a_{10} \cdot Y + 1} \text{ et } j = \frac{a_5 \cdot X + a_6 \cdot Y + a_8}{a_9 \cdot X + a_{10} \cdot Y + 1}$$

On a donc une solution à 8 coefficients a_i , et le système peut être résolu avec a minima 4 points de référence.

Création des orthoimages

Une orthoimage représente une vue corrigée des effets de perspective et mise à l'échelle du monde réel, pour un plan donné. Dans le cas des analyses LSPIV, on souhaite orthorectifier le plan de la surface de l'écoulement (on fait donc l'hypothèse que notre écoulement est plan). Ce plan peut être exprimé en fonction de X et Y tel que $Z = b_1 X + b_2 Y + b_3$. En faisant l'hypothèse que les pentes longitudinales et transverse sont négligeables à l'échelle de la prise de vue, ou que le système de coordonnées réel est exprimé par rapport au plan de la rivière (plan XY parallèle au plan de la rivière), on réduit l'équation du plan à $Z = b_3$, où b_3 est la hauteur de surface libre dans le repère réel, h .

Le système d'équation (1) se réduit, dans le plan de l'écoulement, à :

$$i = \frac{a_1 \cdot X + a_2 \cdot Y + a_3 \cdot h + a_4}{a_9 \cdot X + a_{10} \cdot Y + a_{11} \cdot h + 1} \text{ et } j = \frac{a_5 \cdot X + a_6 \cdot Y + a_7 \cdot h + a_8}{a_9 \cdot X + a_{10} \cdot Y + a_{11} \cdot h + 1} \quad (2)$$

Les coefficients a_i ont été calculés tels que présenté dans les parties précédentes.

La méthode pour construire les orthoimages consiste à :

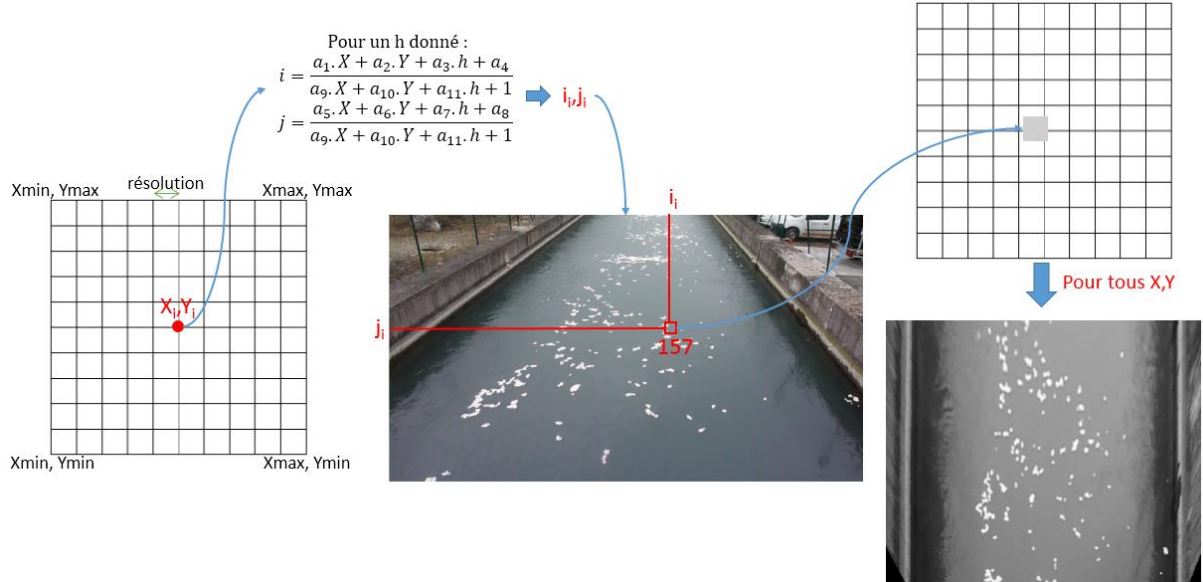
- Définir la zone à imager dans le repère réel, c'est-à-dire donner les coordonnées (X,Y) des 4 coins de l'orthoimage (fait dans le menu [Orthorectification](#))
- Échantillonner cette zone avec une résolution donnée afin de créer une grille, sachant que chacun des nœuds de cette grille sera le centre d'un pixel de l'image orthorectifiée.
- Pour chaque nœud de la grille, de coordonnées (X_i, Y_i) , on calcule les coordonnées correspondantes dans l'image source (i_i, j_i) avec l'équation (2). Les coordonnées (i_i, j_i) ainsi calculées sont des réels et non des entiers.
- On affecte à chaque pixel de centre (X_i, Y_i) une intensité en niveau de gris correspondant au pixel (i_i, j_i) de l'image source. Puisque les coordonnées (i_i, j_i) sont des réels, on utilise une interpolation sur les pixels voisins pour définir l'intensité en niveau de gris, avec une convolution cubique :

$$f(i_i, j_i) = \sum_{k=-3}^3 \sum_{l=-3}^3 [f(i_{i+k}, j_{i+l}) C(i_{i+k} - i_i) C(j_{i+l} - j_i)]$$

Où $f(i_{i+k}, j_{i+l})$ est l'intensité du pixel (i_{i+k}, j_{i+l}) dans l'image source et C prend la forme :

$$C(s) = \begin{cases} 1 - 2|s|^2 + |s|^3 & \text{si } 0 \leq |s| \leq 1 \\ 4 - 8|s| + 5|s|^2 - |s|^3 & \text{si } 1 \leq |s| \leq 2 \\ 0 & \text{sinon} \end{cases}$$

Où $s = k$ ou l



Principles of measuring the velocity of movement of tracers

A cross-correlation statistical analysis is performed on the orthorectified images to determine the displacement of the tracers visible on the surface. Fudaa-LSPIV software uses an optimized algorithm for large-scale spatial applications with low image resolutions. The correlation between an interrogation window (IA for interrogation area) centered on a point a_{ij} in an image and the same IA centered on a b_{ij} point in the next image is calculated, images separated by a time interval of Δt seconds. . The size of the query window can be set in Fudaa-LSPIV. The correlation coefficient $R(a_{ij}, b_{ij})$ is calculated as follows:

$$R(a_{ij}, b_{ij}) = \frac{\sum_{i=1}^{M_i} \sum_{j=1}^{M_j} [(A_{ij} - \bar{A})(B_{ij} - \bar{B})]}{\left[\sum_{i=1}^{M_i} \sum_{j=1}^{M_j} (A_{ij} - \bar{A})^2 \sum_{i=1}^{M_i} \sum_{j=1}^{M_j} (B_{ij} - \bar{B})^2 \right]^{1/2}}$$

where M_i and M_j are the sizes of the interrogation window (in pixels) and A_{ij} and B_{ij} are the distributions of the intensities of the pixels in the two interrogation windows. This calculation is performed only for b_{ij} points included in a search window defined by the user, saving computing time. It is assumed that the most probable displacement of the discharge from the point a_{ij} during the time Δt is that corresponding to the correlation maximum, with the possibility of defining a minimal correlation required.

The accuracy of the calculation being at the pixel near, it is interesting to perform a sub-pixel interpolation. Let b_i be the position of the maximum correlation. In Fudaa-LSPIV, an adjustment of a unidimensional Gaussian law is used on the axes i and j to obtain a precision of displacement of the order of 0.2 pixels in the form:

$$\Delta i = \frac{\ln(b_{i-1, j}) - \ln(b_{i+1, j})}{2 \left[\ln(b_{i-1, j}) - 2\ln(b_{i, j}) + \ln(b_{i+1, j}) \right]}$$

$$\Delta j = \frac{\ln(b_{i, j-1}) - \ln(b_{i, j+1})}{2 \left[\ln(b_{i, j-1}) - 2\ln(b_{i, j}) + \ln(b_{i, j+1}) \right]}$$

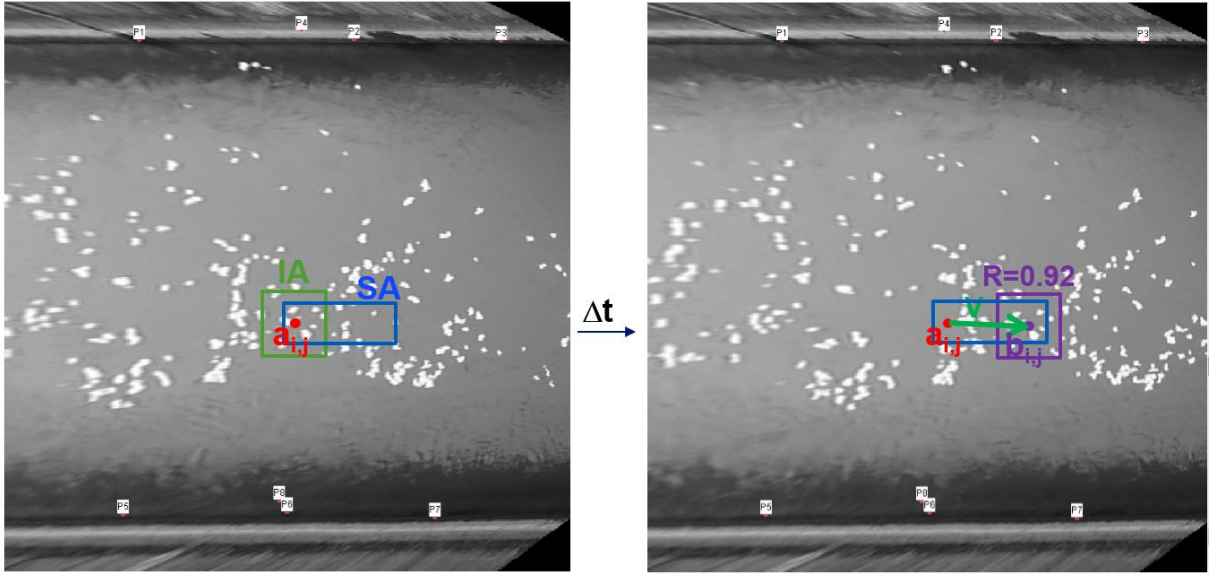
The sub-pixel position of the correlation maximum is given as $b_i + \Delta i, j + \Delta j$. Surface velocities are calculated from displacements $b_i + \Delta i, j + \Delta j - a_i, j$ divided by Δt . The calculation is repeated iteratively over the entire image for each node of the calculation grid. Thus, a surface 2D velocity field "instantaneous" (between two successive images) is calculated. Fudaa-LSPIV makes it possible to apply filters to eliminate the aberrant velocities resulting from the statistical computation. Filters on the minimum value of the correlation coefficient, the amplitude and the orientation of the velocities are implemented in the software. Finally, Fudaa-LSPIV makes it possible to average the filtered instantaneous velocity fields to calculate an averaged velocity field over the duration of the image sequence.

Principes de la mesure de la vitesse de déplacement des traceurs

Une analyse statistique en corrélation croisée est effectuée sur les images orthorectifiées afin de déterminer le déplacement des traceurs visibles en surface. Le logiciel **Fudaa-LSPIV** utilise un algorithme optimisé pour les applications de grande échelle spatiale avec des résolutions d'images pouvant être faible. On calcule la corrélation entre une fenêtre d'interrogation (IA pour interrogation area) centrée sur un point a_{ij} dans une image et la même IA centrée sur un point b_{ij} dans l'image suivante, images séparées par un intervalle de temps de Δt secondes. La [taille de la fenêtre d'interrogation est paramétrable](#) dans **Fudaa-LSPIV**. Le coefficient de corrélation $R(a_{ij}, b_{ij})$ est calculé ainsi :

$$R(a_{i,j}, b_{i,j}) = \frac{\sum_{i=1}^{M_i} \sum_{j=1}^{M_j} [(A_{ij} - \overline{A_{ij}})(B_{ij} - \overline{B_{ij}})]}{\left[\sum_{i=1}^{M_i} \sum_{j=1}^{M_j} (A_{ij} - \overline{A_{ij}})^2 \sum_{i=1}^{M_i} \sum_{j=1}^{M_j} (B_{ij} - \overline{B_{ij}})^2 \right]^{1/2}}$$

où M_i et M_j sont les tailles de la fenêtre d'interrogation (en pixel) et A_{ij} et B_{ij} sont les distributions des intensités des pixels dans les deux fenêtres d'interrogation. Ce calcul n'est effectué que pour des points b_{ij} inclus dans une [fenêtre de recherche \(SA pour Searching Area\) définie par l'utilisateur](#), permettant d'économiser du temps de calcul. On suppose que le déplacement le plus probable de l'écoulement à partir du point a_{ij} pendant le temps Δt est celui correspondant au maximum de corrélation, avec possibilité de définir une corrélation minimale requise.



La précision du calcul étant au pixel près, il est intéressant de réaliser une interpolation sub-pixel. Soit $b_{i,j}$ la position du maximum de corrélation. Dans **Fudaa-LSPIV**, un ajustement d'une loi Gaussienne unidimensionnelle est utilisé sur les axes i et j pour obtenir une précision de déplacement de l'ordre de 0,2 pixels sous la forme :

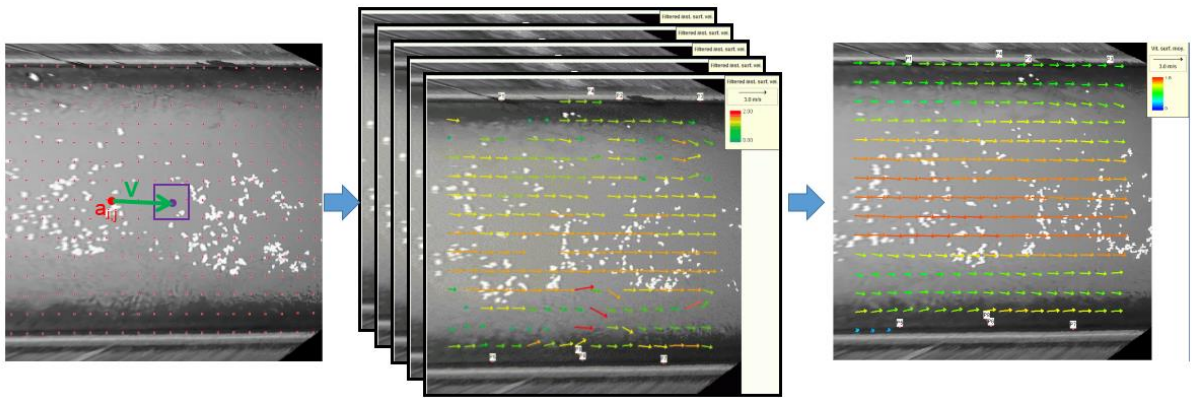
$$\Delta i = \frac{\ln(b_{i-1,j}) - \ln(b_{i+1,j})}{2[\ln(b_{i-1,j}) - 2\ln(b_{i,j}) + \ln(b_{i+1,j})]} \text{ et } \Delta j = \frac{\ln(b_{i,j-1}) - \ln(b_{i,j+1})}{2[\ln(b_{i,j-1}) - 2\ln(b_{i,j}) + \ln(b_{i,j+1})]}$$

La position sub-pixel du maximum de corrélation est donc calculée comme $b_{i+\Delta i, j+\Delta j}$.

Les vitesses de surface sont calculées à partir des déplacements $b_{i+\Delta i, j+\Delta j} - a_{i,j}$ divisés par Δt . Le calcul est reproduit de manière itérative sur toute l'image pour chaque nœud de la [grille de calcul](#). On calcule ainsi un champ de vitesse 2D de surface, "instantané" (entre deux images successives).

Fudaa-LSPIV permet [d'appliquer des filtres](#) pour éliminer les vitesses aberrantes issues du calcul statistique. Des filtres sur la valeur minimale du coefficient de corrélation, sur l'amplitude et l'orientation des vitesses sont implémentés dans le logiciel.

Enfin, **Fudaa-LSPIV** permet de [moyenner](#) les champs de vitesses instantanées filtrées pour calculer un champ de vitesses moyennées sur la durée de la séquence d'images.



Principles of discharge calculation

Fudaa-LSPIV can calculate the discharge passing through one or several cross-sections located in the area where surface velocities have been computed. The geometry of the cross-sections must be provided in the form of the 3-D XYZ coordinates of points of the stream bed, ordered from a bank to the other.

The bathymetric transect can be interpolated at a user-defined pitch, and a surface velocity is calculated for each step from the nearest LSPIV velocities (distance weighted). The user also defines a coefficient connecting the surface velocity to the averaged velocity over the depth for each calculation step. The discharge is then calculated by the method of the median section, the interpolation of the velocities towards the edges being done according to the hypothesis of the number of Froude varying linearly towards zero at the edge. Definition and interpolation of the bathymetric profile. The bottom points must be ordered from the left bank to the right bank. The transect must contain at least one point whose rating is less than that of the water and the points at the ends must have a higher rating than that of the water. It is possible to have points above the water level (islands) framed by water areas. Orthogonal projection on the line defined by the extreme points of the transect (first and last point). Linear interpolation by adding points (from the left bank) whenever the specified maximum space step is exceeded.

Estimated average velocity at each point of the transect. For each transect, the user defines a search radius. In this neighborhood around each node, the maximum 3 closest velocity results are searched. If at least one result is found, then the average velocity on vertical V_i at node i is computed as the average of neighboring velocities weighted by the inverse of distances, multiplied by the user specified surface coefficient α for transect considered:

$$V_i = \alpha \sum_{j=1}^{N_i} [v_{(i,j)} / d_{(i,j)}] / \sum_{j=1}^{N_i} [1 / d_{(i,j)}]$$

With N_i the number of velocity results $v_{(i,j)}$ found in the neighborhood of the node i of the transect ($N_i \leq 3$); the distance $d_{(i,j)}$ is that between the position (x_j, y_j) of the grid node of the velocity result $v_{(i,j)}$ and the position (x_i, y_i) of the node i with a safety distance fixed to 1 mm:

$$d_{(i,j)} = \max [0.001; (x_j - x_i)^2 + (y_j - y_i)^2]$$

When no LSPIV velocity result is found in the neighborhood of a transect node, the average transect normal velocity is reconstructed by linear interpolation of local Froude numbers between the two nearest nodes, right and left. left, with interpolated velocity. Indeed, in order to optimize the depth measurement performed on the bathymetric vertical, it is interesting to use a hydraulic hypothesis of linear evolution of the local Froude number, instead of simply correcting the surfaces of the wet subsections, or to interpolate the velocities linearly. The linear interpolation of local Froude numbers is proposed by several references: Boiten (2000), Despax (2016), Fulford and Sauer (1986), ISO / TR 9823 (1990), Le Coz et al. (2008, 2012, 2014). Either a bathymetric vertical positioned at abscissa x_i , whose full verticals (with depth and velocities) closest to each side are positioned at x_{i-1} and x_{i+1} (Figure 1). In $i-1$, the full vertical allows to have the depth h_{i-1} and the average velocity on the depth V_{i-1} . The number of local Froude is calculated:

$$[Fr]_{(i-1)} = V_{(i-1)} / \sqrt{g \cdot h_{(i-1)}}$$

with g the acceleration of gravity on the surface of the Earth ($9.81 \text{ m} \cdot \text{s}^{-2}$).

In $i + 1$, the local Froude number is:

$$Fr_{i+1} = V_{i+1} / \sqrt{g \cdot h_{i+1}}$$

The Froude number of the bathymetric vertical, positioned in i , is calculated by linear interpolation as:

$$Fr_i = \frac{(x_{i+1} - x_i) Fr_{i+1} + (x_i - x_{i-1}) Fr_{i-1}}{x_{i+1} - x_{i-1}}$$

Knowing the depth in i , h_i , we calculate the associated average velocity as:

$$V_i = Fr_i \cdot \sqrt{g \cdot h_i}$$

Figure 1: Calculation of the average velocity associated with a bathymetric vertical by interpolation of the number of Froude local Fr_i

In the case of a bathymetric vertical located between the shore and the other verticals, it is advisable to make an assumption about the velocity at the bank: it is theoretically null, but a constant extrapolation or a fictitious shoreline velocity calculated with a coefficient of bank (case of the Bareme software) may be more realistic than a linear extrapolation to zero, in practice. The calculation of the discharge can finally be done normally on all the verticals, now all provided with an estimated average velocity.

Calculation of the discharge through each transect
Median velocity, normal velocity at transect
Edge discharges?
Measured discharge rate / extrapolated

Principes du calcul de débit

Connaissant [le profil bathymétrique](#) d'au moins une section en travers incluse dans la zone d'analyse, **Fudaa-LSPIV** peut calculer le débit transitant par cette section. Le transect bathymétrique peut être [interpolé à un pas défini par l'utilisateur](#), et une vitesse de surface est calculée pour chaque pas à partir des vitesses LSPIV les plus proches (pondération en fonction de l'éloignement). L'utilisateur définit également un coefficient reliant la vitesse de surface à la vitesse moyennée sur la profondeur pour chaque pas de calcul. Le débit est alors calculé par la méthode de la section médiane, l'interpolation des vitesses vers les bords se faisant selon l'hypothèse du nombre de Froude variant linéairement vers zéro au bord.

Définition et interpolation du profil bathymétrique

Les points du fond doivent être ordonnés depuis la rive gauche jusqu'à la rive droite.

Le transect doit contenir au moins un point dont la cote est inférieure à celle de l'eau et les points aux extrémités doivent avoir une cote supérieure à celle de l'eau. Il est possible d'avoir des points situés au-dessus du niveau d'eau (îles) encadrés par des zones en eau.

Projection orthogonale sur la droite définie par les points extrêmes du transect (premier et dernier point).

Interpolation linéaire en ajoutant des points (depuis la rive gauche) chaque fois que le pas d'espace maximum spécifié est dépassé.

Estimation de la vitesse moyenne en chaque point du transect

Pour chaque transect, l'utilisateur définit un rayon de recherche. Dans ce voisinage autour de chaque nœud, les au maximum 3 résultats de vitesse les plus proches sont recherchés. Si au moins un résultat est trouvé, alors la vitesse moyenne sur la verticale V_i au nœud i est calculée comme la moyenne des vitesses voisines pondérée par l'inverse des distances, multipliée par le coefficient de surface α spécifié par l'utilisateur pour le transect considéré :

$$V_i = \alpha \sum_{j=1}^{N_i} \frac{v_{i,j}}{d_{i,j}} / \sum_{j=1}^{N_i} \frac{1}{d_{i,j}}$$

Avec N_i le nombre de résultats de vitesse $v_{i,j}$ trouvés au voisinage du nœud i du transect ($N_i \leq 3$) ; la distance $d_{i,j}$ est celle entre la position (x_j, y_j) du nœud de grille du résultat de vitesse $v_{i,j}$ et la position (x_i, y_i) du nœud i avec une distance de sécurité fixée à 1 mm :

$$d_{i,j} = \max[0.001; (x_j - x_i)^2 + (y_j - y_i)^2]$$

Lorsqu'aucun résultat de vitesse LSPIV n'est trouvé dans le voisinage d'un nœud du transect, la vitesse moyenne normale au transect est reconstituée par interpolation linéaire des nombres de Froude locaux, entre les deux nœuds les plus proches, à droite et à gauche, dotées d'une vitesse interpolée. En effet, afin de valoriser au mieux la mesure de profondeur réalisée sur la verticale bathymétrique, il est intéressant d'utiliser une hypothèse hydraulique d'évolution linéaire du nombre de Froude local, au lieu de simplement corriger les surfaces des sous-sections mouillées, ou encore d'interpoler linéairement les vitesses. L'interpolation linéaire des nombres de Froude locaux est proposée par plusieurs références : Boiten (2000), Despax (2016), Fulford et Sauer (1986), ISO/TR 9823 (1990), Le Coz et al. (2008, 2012, 2014).

Soit une verticale bathymétrique positionnée à l'abscisse x_i , dont les verticales complètes (avec profondeur et vitesses) les plus proches de chaque côté sont positionnées en x_{i-1} et x_{i+1} (Figure 1).

En $i-1$, la verticale complète permet d'avoir la profondeur h_{i-1} ainsi que la vitesse moyenne sur la profondeur V_{i-1} . On calcule le nombre de Froude local :

$$Fr_{i-1} = \frac{V_{i-1}}{\sqrt{g \cdot h_{i-1}}},$$

avec g l'accélération de la pesanteur à la surface de la Terre ($9,81 \text{ m} \cdot \text{s}^{-2}$).

En $i+1$, le nombre de Froude local vaut :

$$Fr_{i+1} = \frac{V_{i+1}}{\sqrt{g \cdot h_{i+1}}}$$

Le nombre de Froude de la verticale bathymétrique, positionnée en i , est calculé par interpolation linéaire comme :

$$Fr_i = \frac{[(x_{i+1} - x_i) \cdot Fr_{i-1} + (x_i - x_{i-1}) \cdot Fr_{i+1}]}{x_{i+1} - x_{i-1}}$$

Connaissant la profondeur en i , h_i , on calcule la vitesse moyenne associée comme :

$$V_i = Fr_i \cdot \sqrt{g \cdot h_i}$$

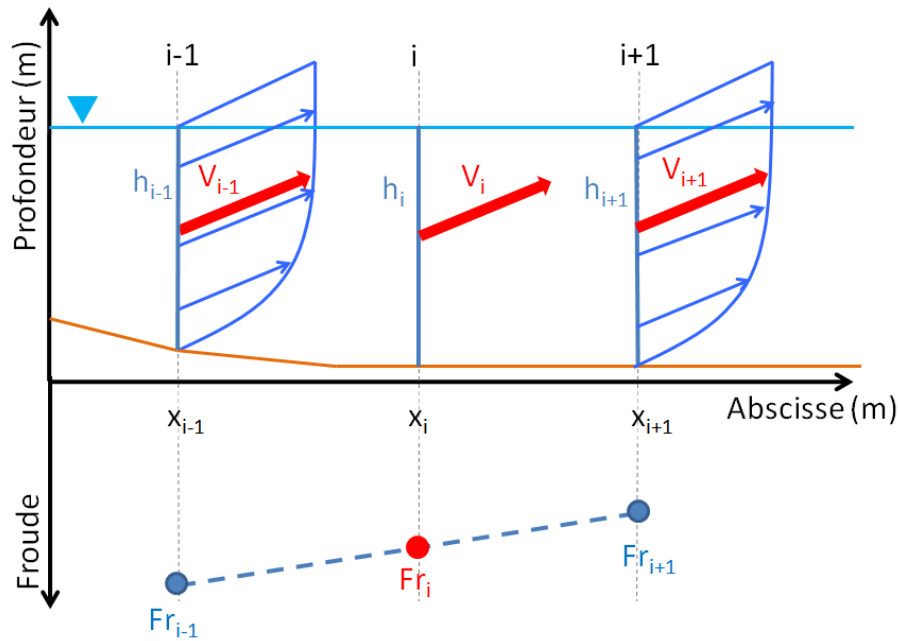


Figure 1 : Calcul de la vitesse moyenne associée à une verticale bathymétrique par interpolation du nombre de Froude local Fr_i

Dans le cas d'une verticale bathymétrique située entre la rive et les autres verticales, il convient de faire une hypothèse sur la vitesse en rive : elle est théoriquement nulle, mais une extrapolation constante ou vers une vitesse fictive en rive calculée avec un coefficient de rive (cas du logiciel Barème) peut être plus réaliste qu'une extrapolation linéaire vers zéro, en pratique.

Le calcul du débit peut finalement se faire normalement sur l'ensemble des verticales, désormais toutes munies d'une vitesse moyenne estimée.

Calcul du débit à travers chaque transect

Vitesse médiane, vitesse normale au transect

Débits de bords ?

Taux débit mesuré / extrapolé

15. References

- Creutin, J.-D., Muste, M., Bradley, A.A., Kim, S.C., Kruger, A. (2003) River gauging using PIV techniques: a proof of concept experiment on the Iowa River, *Journal of Hydrology* 277: 182–194
- Dramais, G., Le Coz, J., Camenen, B., Hauet, A. (2011) Advantages of a mobile LSPIV method for measuring flood discharges and improving stage-discharge curves, *Journal of Hydro-Environment Research*, 5, 301-312
- Fujita, I., Muste, M., Kruger, A. (1998) Large-scale particle image velocimetry for discharge analysis in hydraulic engineering applications, *Journal of Hydraulic Research* 36(3): 397–414
- Hauet, A. (2006) Estimation de débit et mesure de vitesse en rivière par Large-Scale Particle Image Velocimetry, thèse de doctorat, Université de Grenoble
- Hauet, A., Kruger, A., Krajewski, W., Bradley, A., Muste, M., Creutin, J.-D., Wilson, M. (2008) Experimental system for real-time discharge estimation using an image-based method, *Journal of Hydrologic Engineering* 13(2):105–110
- Hauet, A., Muste, M., Ho, H.-C. (2009) Digital mapping of riverine waterway hydro-dynamic and geomorphic features, *Earth Surface Processes and Landforms*, 34(2), 242-252
- Jodeau, M., Hauet, A., Paquier, A., Le Coz, J., Dramais, G. (2008) - Application and evaluation of LS-PIV technique for the monitoring of river surface velocities in high discharge conditions, *Discharge Measurement and Instrumentation*, 19(2), 117-127
- Le Boursicaud, R., Pénard, L., Hauet, A., Le Coz, J. (2016) Gauging extreme floods on YouTube: Application of LSPIV to home movies for the post-event determination of stream discharges, *Hydrological Processes*, 30, 90-105
- Le Coz, J., Hauet, A., Pierrefeu, G., Dramais, G., Camenen, B. (2010) - Performance of image-based velocimetry (LSPIV) applied to flash-flood discharge measurements in Mediterranean rivers, *Journal of Hydrology*, 394 (1-2), 42-52
- Le Coz, J., Michálková, M., Hauet, A., Čomaj, M., Dramais, G., Holubová, K., Piégay, H., Paquier, A. (2010) Morphodynamics of the exit of a cut-off meander: experimental findings from field and laboratory cases, *Earth Surface Processes and Landforms*, 35 (3), 249-261
- Le Coz, J., Jodeau, M., Hauet, A., Marchand, B., Le Boursicaud, R. (2014) Image-based velocity and discharge measurements in field and laboratory river engineering studies using the free Fudaa-LSPIV software, *Proceedings of the International Conference on Fluvial Hydraulics, RIVERDISCHARGE 2014*, 1961-1967
- Le Coz J., Patalano A., Collins D., Guillén N. F., García C. M., Smart G. M., Bind J., Chiaverini A., Le Boursicaud R., Dramais G., Braud I. (2016) Crowdsourced data for flood hydrology: feedback from recent citizen science projects in Argentina, France and New Zealand, *Journal of Hydrology*, 541, 766-777
- Legout, C., Darboux, F., Nédélec, Y., Hauet, A., Esteves, M., Renaux, B., Denis, H., Cordier, S. (2012) High spatial resolution mapping of surface velocities and depths for shallow overland discharge, *Earth Surface Processes and Landforms*, 37(9), 984-993

Moisan, L., Stival, B., A, (2004) A Probabilistic Criterion to Detect Rigid Point Matches Between Two Images and Estimate the Fundamental Matrix, *International Journal of Computer Vision*, 57(3), 201-208

Muste, M., Fujita, I., Hauet, A. (2008) Large-scale particle image velocimetry for measurements in riverine environments. *Water Resources Research* 44W00D19

Nord, G., Esteves, M., Lapetite, J.-M., Hauet, A. (2009) Effect of particle density and discharge concentration of suspended sediment on bedload transport in rill discharge, *Earth Surface Processes and Landforms*, 34(2), 253-263

Oyallon, E., Rabin, J., An Analysis of the SURF Method, *Image Processing On Line*, 5 (2015), 176-218

Piton, G., Recking, A., Le Coz, J., Bellot, H., Hauet, A., Jodeau, M. (2018) - Reconstructing depth-averaged open-channel discharges using image velocimetry and photogrammetry, *Water Resources Research* (in press)

Theule, J.I., Crema, S., Marchi, L., Cavalli, M., Comiti, F. (2018) Exploiting LSPIV to assess debris-discharge velocities in the field, *Natural Hazards and Earth System Sciences*, 18(1), 1-13