Vic-Volume

Reference Manual

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INTRODUCTION

SPECKLE PATTERN AND IMAGE SIZE

The Vic-Volume software package can be used to determine displacement and strain fields from volumetric image data. This data can, for instance, be obtained through computed tomography. As in two- and three-dimensional image correlation, the measurement is performed by tracking the correspondence between small subsets of the image. Whereas in two- and three-dimensional image correlation, a typically square subset is used for this analysis, a sub-volume of the image is used in volumetric image correlation. To obtain good accuracy, it is important that each of the subvolumes used for deformation measurement contains a pattern of sufficient contrast. Ideally, a speckle pattern with a dense distribution of features between 3 to 5 voxels in size should be used to maximize information content and thereby the accuracy of the data. In volumetric image correlation, pattern application is much more challenging than in the traditional optical techniques, where patterns only have to be applied on the surface of the test article, e.g., by spray painting the specimen with a speckle pattern. Therefore, one has to frequently use image material with less than ideal information content. In this situation, one can increase the size of the subvolume used for data analysis and increase the displacement resolution at the expense of spatial resolution. In volumetric image correlation, this trade-off also comes at a rather severe penalty in computation time. Since the subvolumes are three-dimensional, an increase in the subvolume used for analysis time will have a cubic effect on the analysis time. For instance, when doubling the subvolume size, the computation time required increases by a factor of eight. Rather than using large subset sizes, e.g., more than sixty pixels, it is therefore recommended to downsample the volume images by a factor of 2 in each direction before processing.

RECONSTRUCTION CIRCLE

Volumetric images are typically obtained through reconstruction algorithms that produce a circular area of image data on each slice of the volume. This can lead to rather severe artifacts at the border of this circle if care is not taken. If the test article is fully contained within the reconstruction circle throughout the loading cycle, no special consideration has to be given to this problem. If, however, some areas of the specimen move outside the reconstruction circle, the area-of-interest used for analysis must be selected such that it remains fully contained in the reconstruction circle throughout analysis. The reason for this is, that at present, the correlation engine cannot detect if part of the subvolume analyzed disappears in the area outside the reconstruction circle. If even just a few pixels disappear, bias results and the strain data will be biased heavily at the boundary.

An option for suppressing these artifacts automatically will be added to the software in a future release. Until then, please select the area-of-interest so that the analyzed volume remains inside the reconstruction circle.

AREA-OF-INTEREST

To define the area-of-interest (AOI) to be used for correlation analysis, the Vic-Volume software uses the concept of keyframes similar to animation software like Adobe Flash™. In order to minimize the number of slices the AOI has to be edited on, the software can interpolate control point locations in between slices. The slices on which control points are given and can be edited are referred to as keyframes. The process of editing an AOI normally proceeds as follows:

- Navigate to the first slice of the AOI
- Draw an AOI (rectangle, circle, polygon). This automatically creates a keyframe for the current slice.
- The AOI extends from the current slice to the end of the volume. To terminate the AOI earlier, navigate to the last slice for the AOI and add a stop keyframe.
- Keyframes can be added to the AOI on any slice by pressing the Add keyframe tool button while the AOI is selected.
- On keyframes, the control points can be dragged and repositioned to make the AOI conform to the speckled area.

START POINTS

At least one start point has to be defined and set for each of the deformed volume images. It is best to place start points at a point that has a distinctive feature easily recognized by eye. Note that the start point has to be placed inside the area to be analyzed. If the area-of-interest is not contiguous on the slice where the start point is placed, a start point has to be defined for each separate area. This also applies for multiple areas that are disconnected in the depth direction, i.e., at least one start

point is required for each separate area, no matter which of the three directions the separation is in.
After placing the start points, a double-click on the point will bring up the initial guess editor, where the corresponding point has to be determined for each of the deformed volumes.

IMAGE FILES AND DIRECTORIES

Vic-Volume requires that the image files are numbered sequentially, and more importantly, that the image numbers are padded with zeroes so that all file names are the same length. This means that image names formatted like slice_1.tif, slice_2.tif, slice_3.tif ... slice10.tif, slice11.tif etc. will not work. The image must be numbered slice_01.tif, slice_02.tif, slice_03.tif... The slice numbers must always be padded with preceding zeroes such that the lowest slice number has the same number of digits as the highest slice number.

It is best to keep each volume image in its own subdirectory and user a unique image prefix for each load step. The image folders should be kept as subdirectories of a common parent directory, and the Vic-Volume project file should be saved to this directory. If a different directory structure is used, it may not be possible to move or copy the project file to a different location on the hard disk, or to copy the project to a different computer.

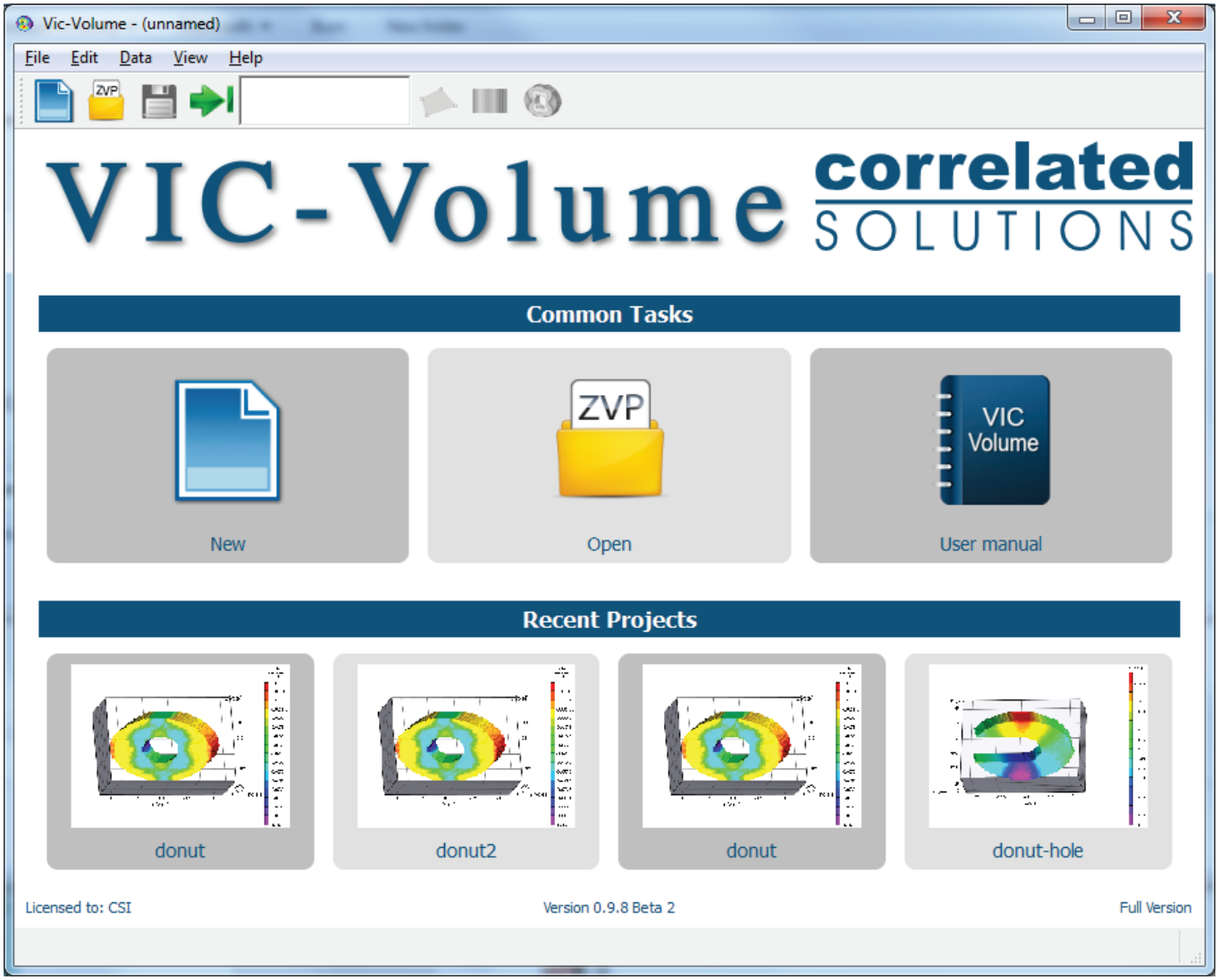
Vic-Volume uses a cache directory to store results of computationally expensive operations, e.g., B-spline transformations or derivatives in the depth direction. These directories are found as sub-folders of the image directories and are called cache. Please, do not remove these directories while the corresponding project is open in the Vic-Volume software, as the software may crash if these files are removed during operation. The cache directories can be safely removed after closing the project.

The data generated by Vic-Volume is stored in a sub-directory of the deformed volume image directory. The sub-folders are named run.XXXXX, where XXXXX is a sequential number indicating how many times the data was processed. These directories or their contents should not be deleted while the corresponding project is open in Vic-Volume.

Exported data is stored in a sub-folder of the deformed volume image directories. Similar to the data directories, a sequential numbering scheme is used, and the sub-folders are named export.XXXXX. These folders and their contents can be safely removed at any time.

THE START PAGE

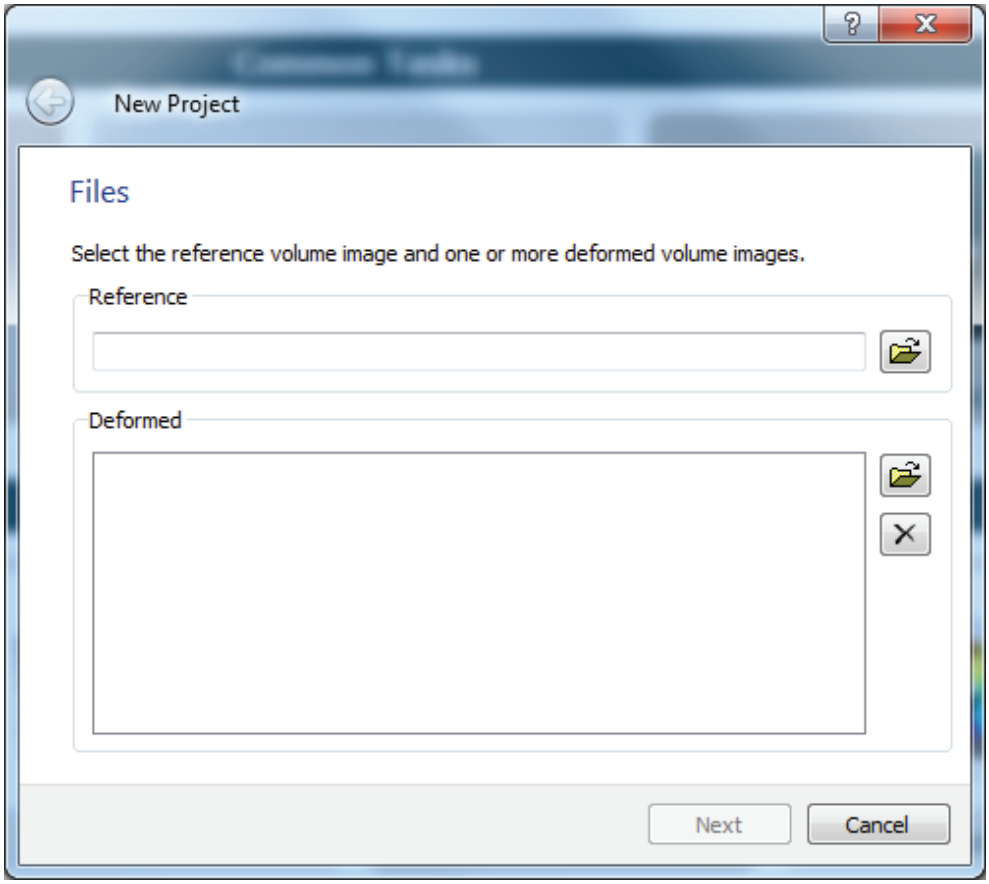
When you first run Vic-Volume, you will be presented with a start page.



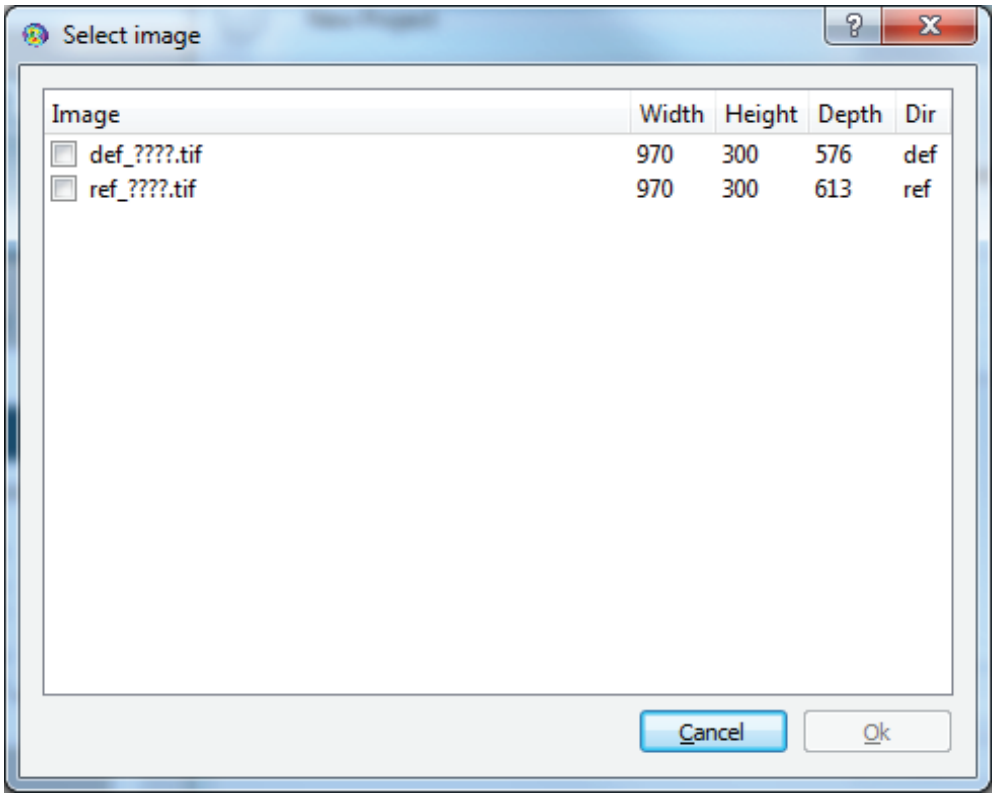
You can start a new project; open a existing project; select from recently accessed projects; or open this manual.

STARTING A NEW PROJECT

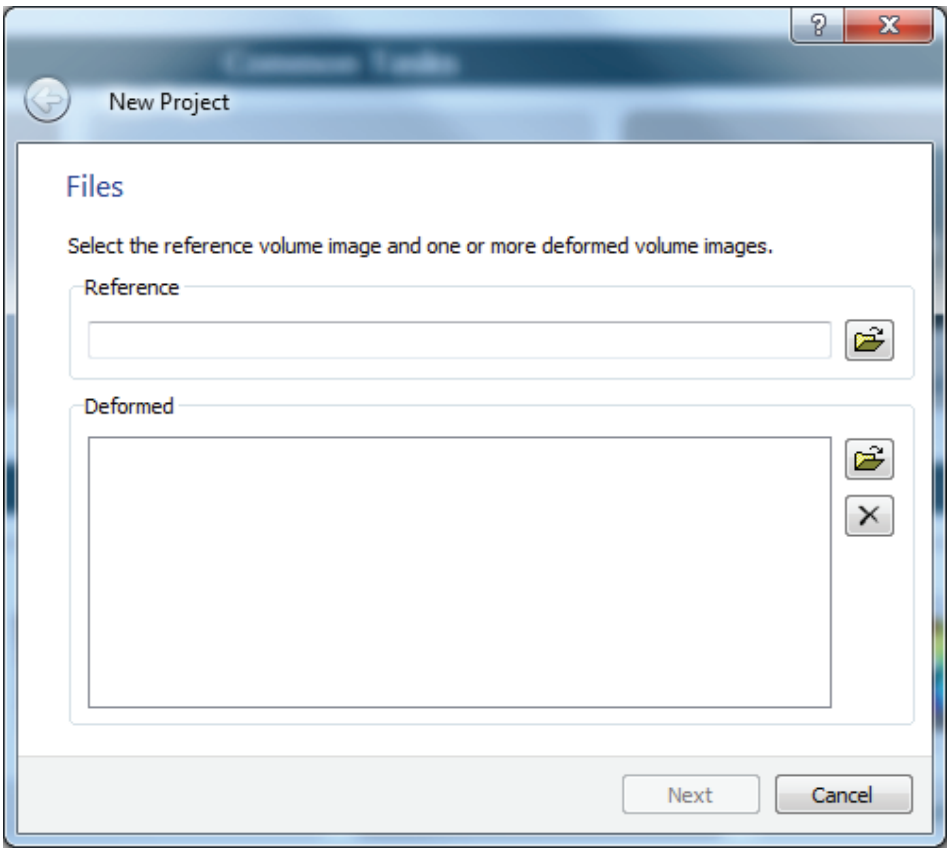
Start a new project by clicking the New Project button on the start page; selecting the toolbar icon; or clicking File... New from the main menu. The New Project wizard will appear.



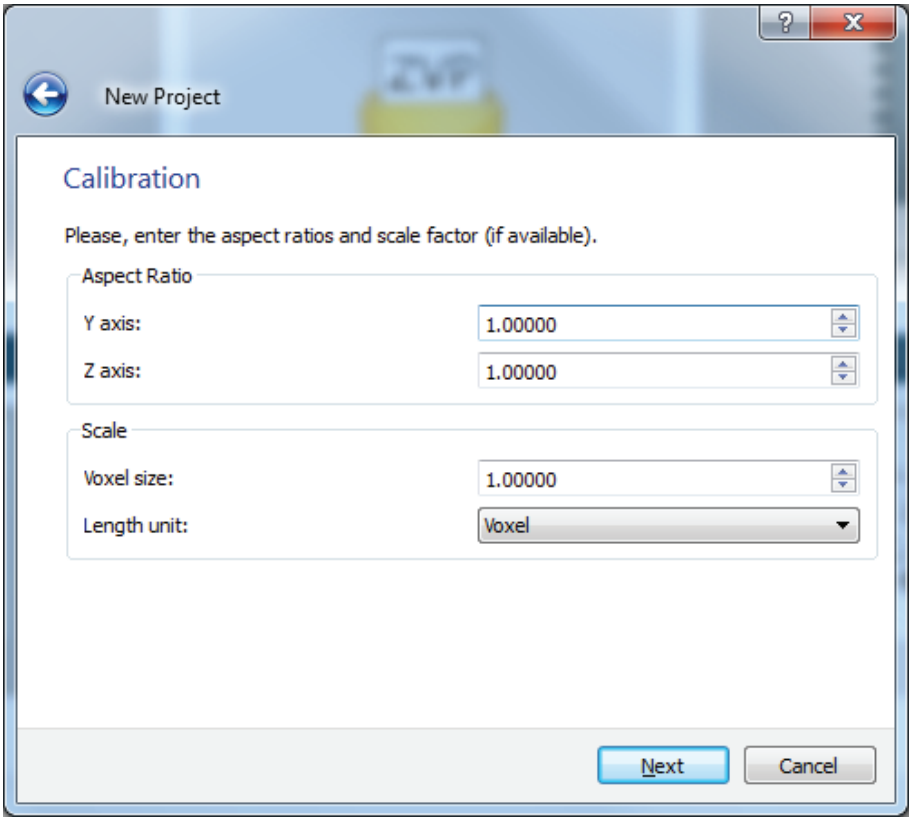
To select reference images, click the folder icon, and navigate to the folder where the reference image files are found (or a higher level folder). Click Open, and you will be given a list of image file groups.



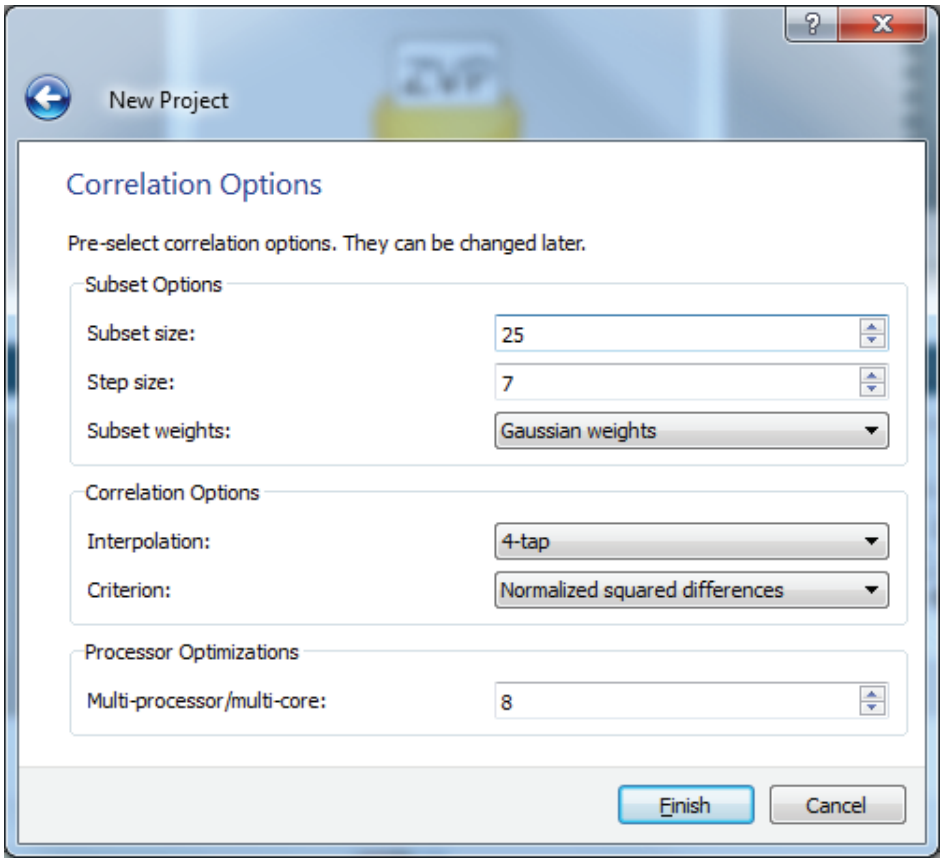
Choose the checkbox next to the appropriate reference images (here, ref_????.tif) and click **Ok**.
Next, choose the folder for the deformed images, and repeat the selection for the deformed image set or sets (here, def_????.tif). The wizard should now show both the reference and deformed files selected:



Click Next to proceed. The next page will allow you to select calibration options:



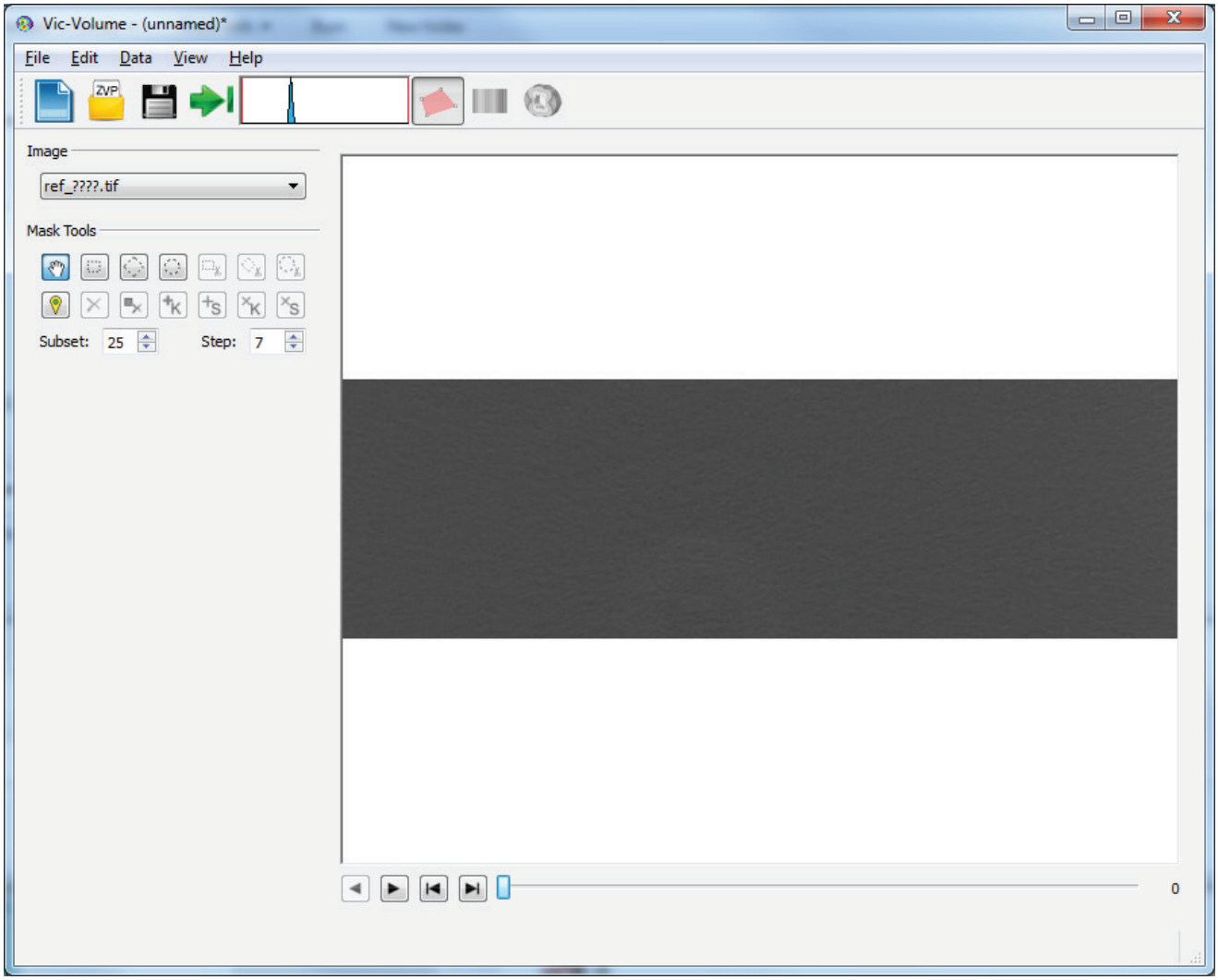
Here, you can select the appropriate scaling factors for the Y and Z axis (relative to the X axis) as well as the scaling factor and unit for each voxel. After entering the corrrect data, click **Next** to choose project options.



Here, you can choose the subset size and step size, as well as the subset weights, interpolation method, and correlation criterion. The number of processors can also be edited if the default value is incorrect for the processor configuration. Click **Finish** to close the wizard and proceed to AOI editing.

AOI EDITING

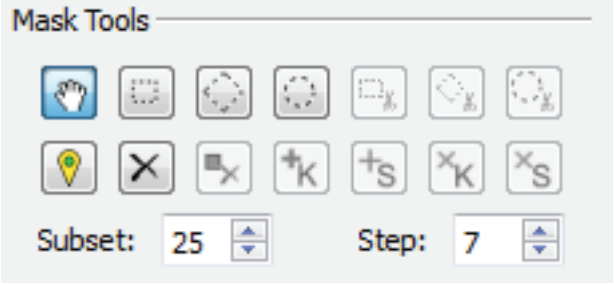
Before running a volumetric correlation, an Area of Interest (AOI) must be created for each slice that contains image data. This is accomplished by drawing AOI's at key frames as necessary; then, Vic-Volume interpolates between the key frames to cover remaining frames.



The AOI editor window displays the image for the selected slice; a slider at the bottom for moving up or down in the slices; and a set of mask drawing and editing tools at the top left.

TOOLS AND CONCEPTS

The AOI drawing tools are located at the top left of the screen. The first row contains tools for adding and editing slice masks:



- Select the hand tool to pan around the image; click and drag on AOI nodes to edit.
- The rectangle tool creates rectangular AOI's. Click once to define the top left; click again to define the bottom right.
- The nodes may be edited after drawing to better match the shape of the object.
- The polygon tool creates arbitrary polygons. Click once to define each vertex; double-click to finalize.
- The circle tool creates circles; click three points on the circumference to define the circle.
- For each tool, there is a corresponding cut tool which creates the same shapes, but as cutouts from existing AOI's.

The center row contains tools for editing and creating key and stop key frames.

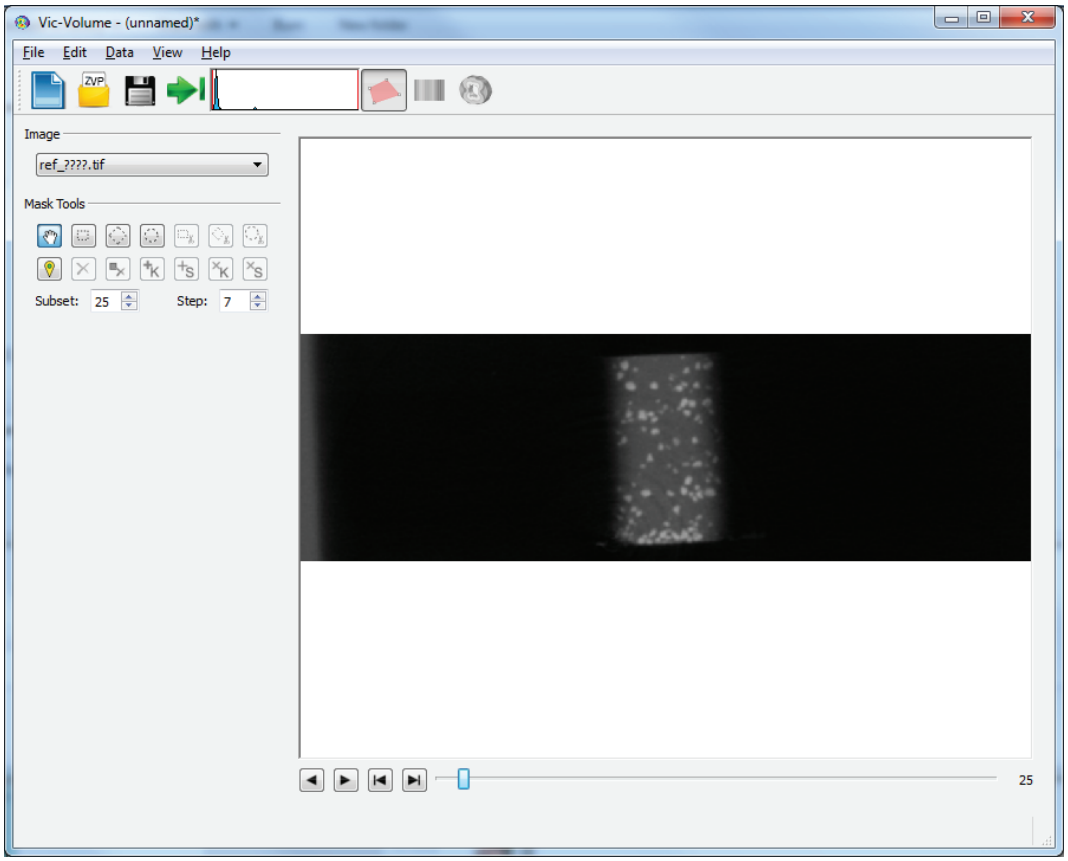
- Click the start point tool to add an initial guess location; double click on that point to edit.
- Select the delete tool, and then click on an AOI to remove it.
- Click the delete control point tool, and then click on an AOI node or start point to remove it.
- Click the Add key frame tool to set the current AOI as a key frame. Only key frame AOI's may be edited; then, remaining
- AOI's in non-key frames will be interpolated evenly between existing key frames.
- Click the Add stop key frame tool to set the current AOI as a stop key frame. When an AOI is set as a stop key frame, the AOI will disappear in the following slice.
- Click the Remove key frame tool to delete the current key frame. The frame will revert to an interpolated configuration.
- Click the Remove stop frame tool to delete the current stop frame. The frame will be unchanged in the following slice.

The final row controls the subset and step size.

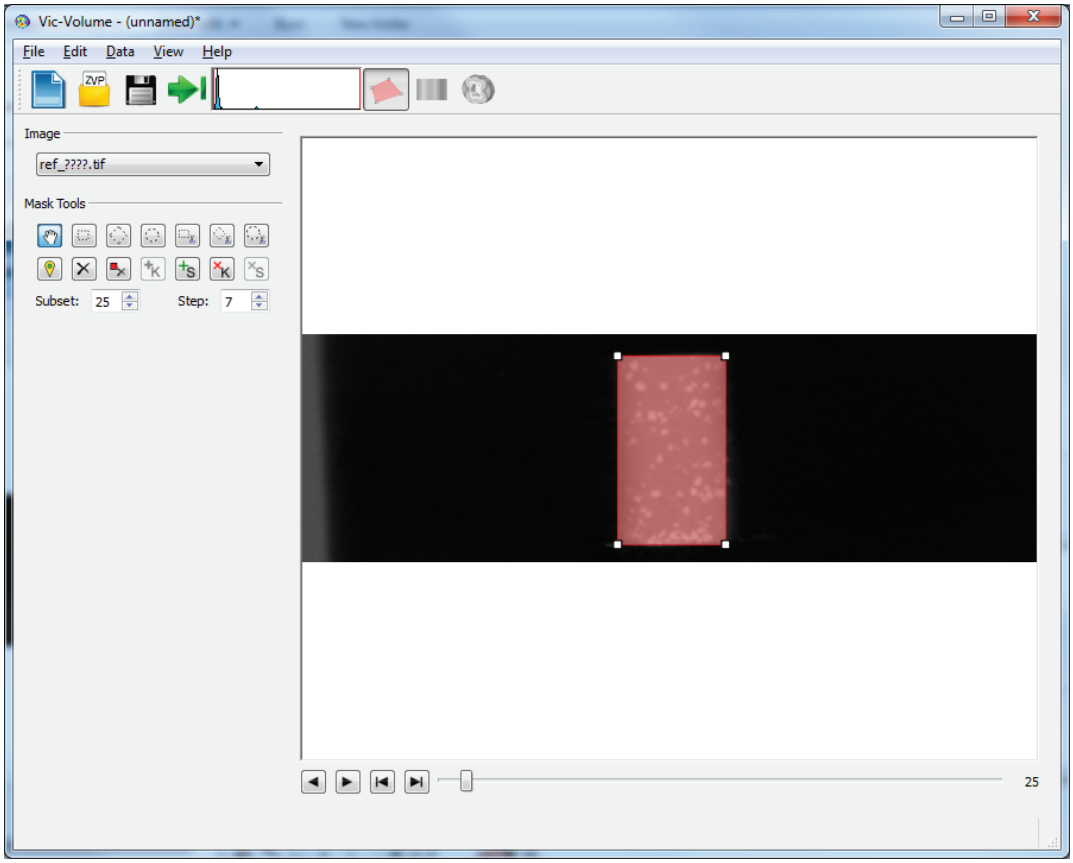
- The subset size is the dimension in each axis of the cubic analysis subset, in voxels.
- The step size is the pitch, in voxels, of the analysis grid. Smaller step sizes will result in denser output data at the expense of a significant increase in processing time.

CREATING THE FIRST KEY FRAME

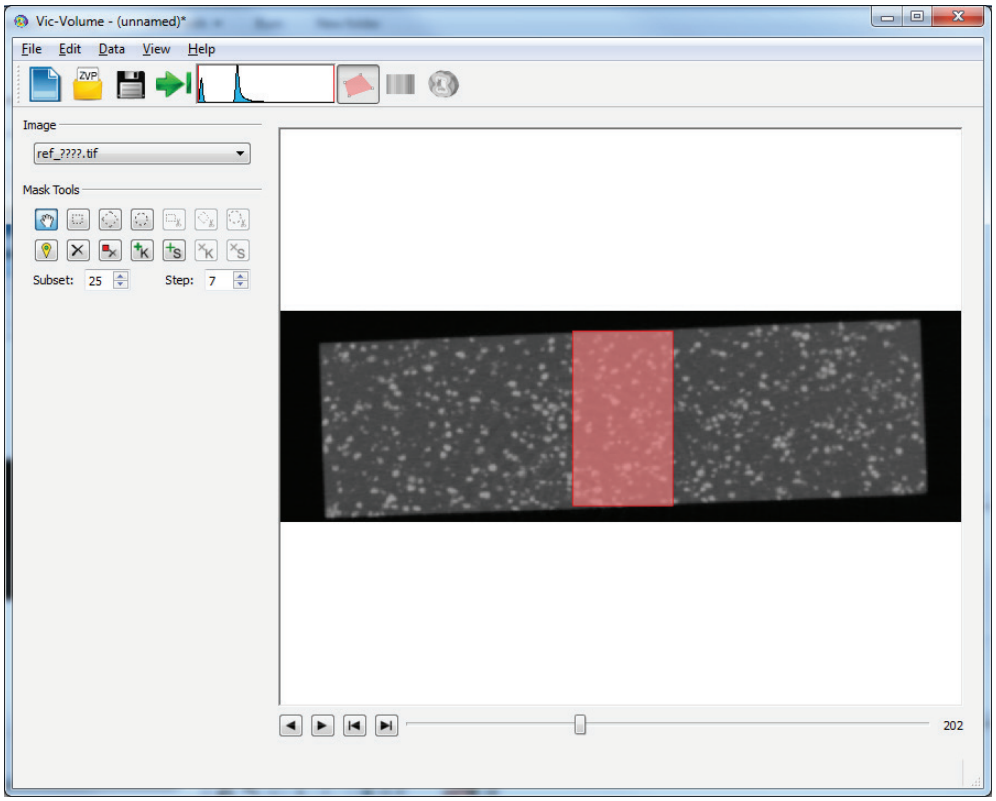
To create the first key frame, use the slider or buttons at the bottom to find the first frame with image data. As a shortcut, you can click the , or . keys on the keyboard to go forward or back. Knowing the keyboard shortcuts will make generation of complex AOI's much quicker. If the image is dim, you can use the histogram in the toolbar to adjust the appearance of the slices; double-click to auto-adjust, or move the left and right red bars to make manual adjustments.



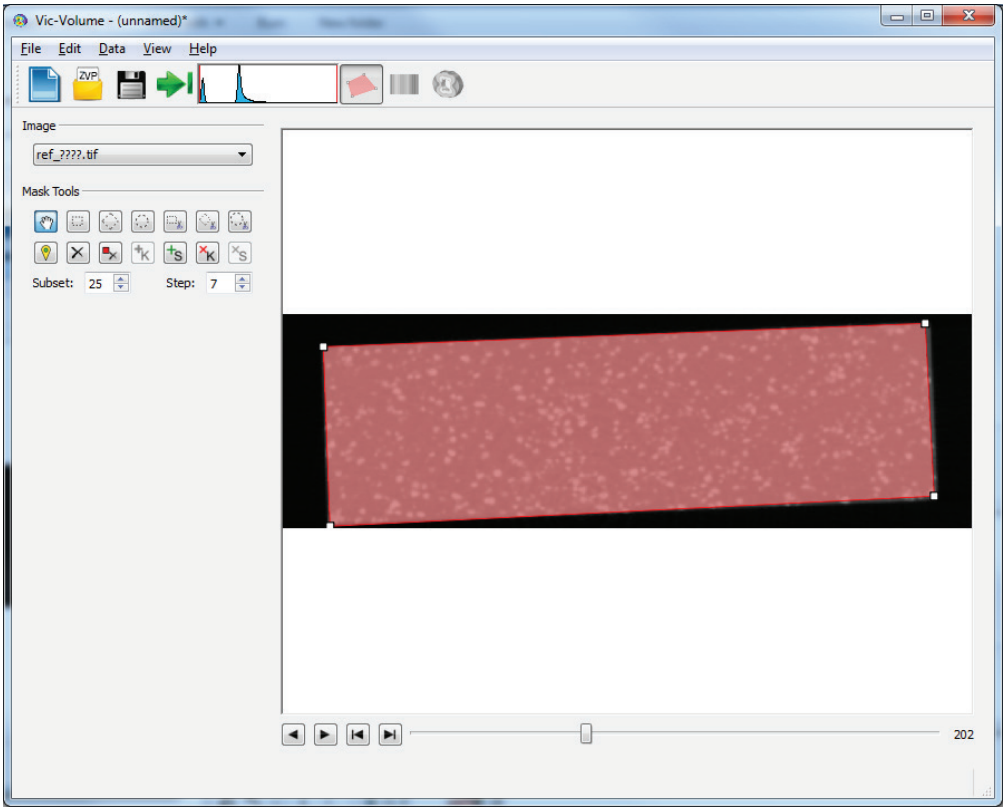
Here, the first frame with data is frame 25. The AOI is drawn with either the rectangle tool (and then adjusting the nodes), or the polygon tool. Draw the polygon by clicking once at each vertex and then double-clicking on the final point. Drawing a new AOI **will automatically create a key frame.**



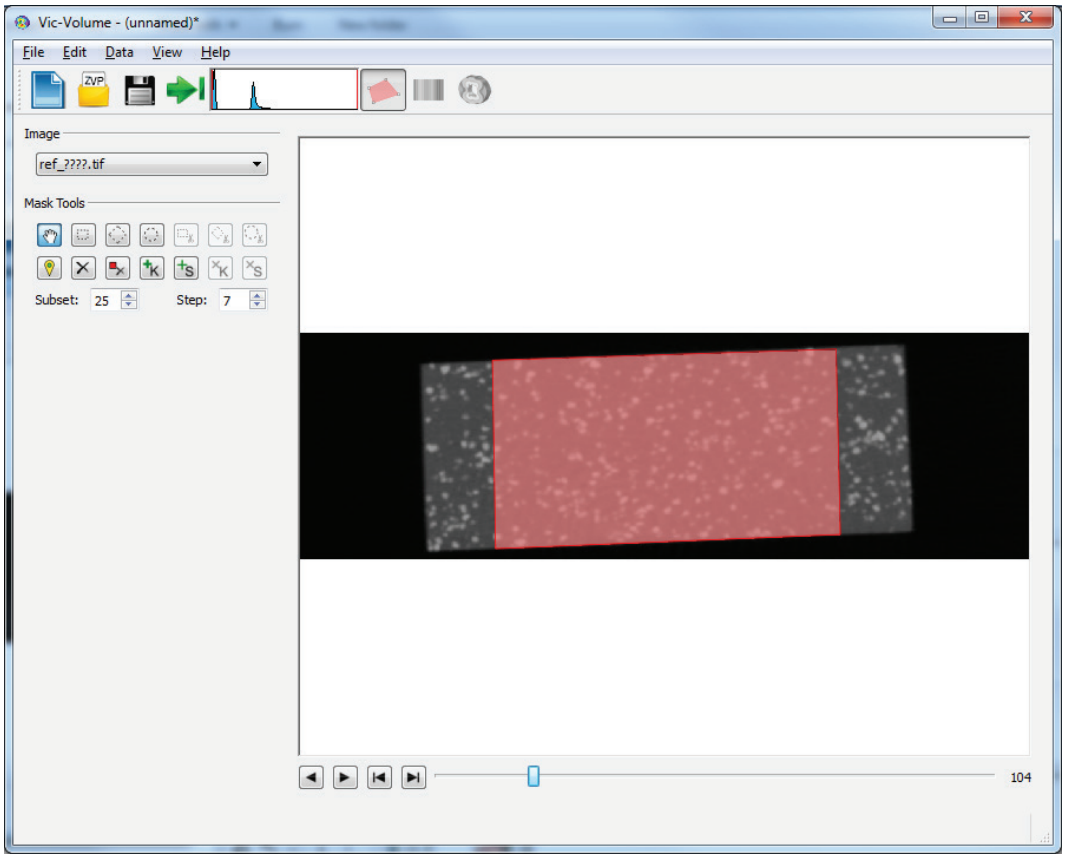
This AOI will then exist for this frame, as well as all the higher-numbered frames. The shape in the example is a torus; navigating to higher-numbered frames will show the shape get wider and wider.



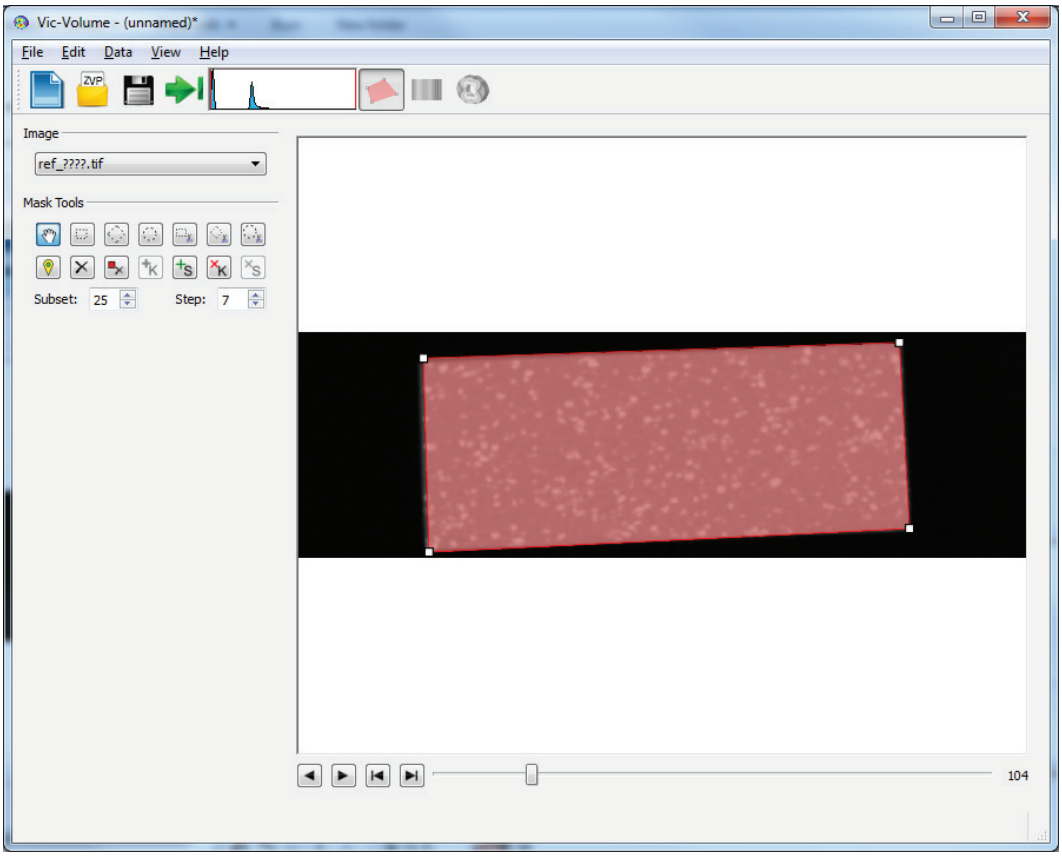
Here, another key frame will be created at the widest point. To create a key frame here, select the AOI by clicking on it, and then click the $+_K$ button, or press A on the keyboard. Nodes will appear to indicate the AOI is now editable, and we can drag them to the new proper location.



Navigating backwards towards the first key frame will show that the interpolated motion doesn't match the object very well:

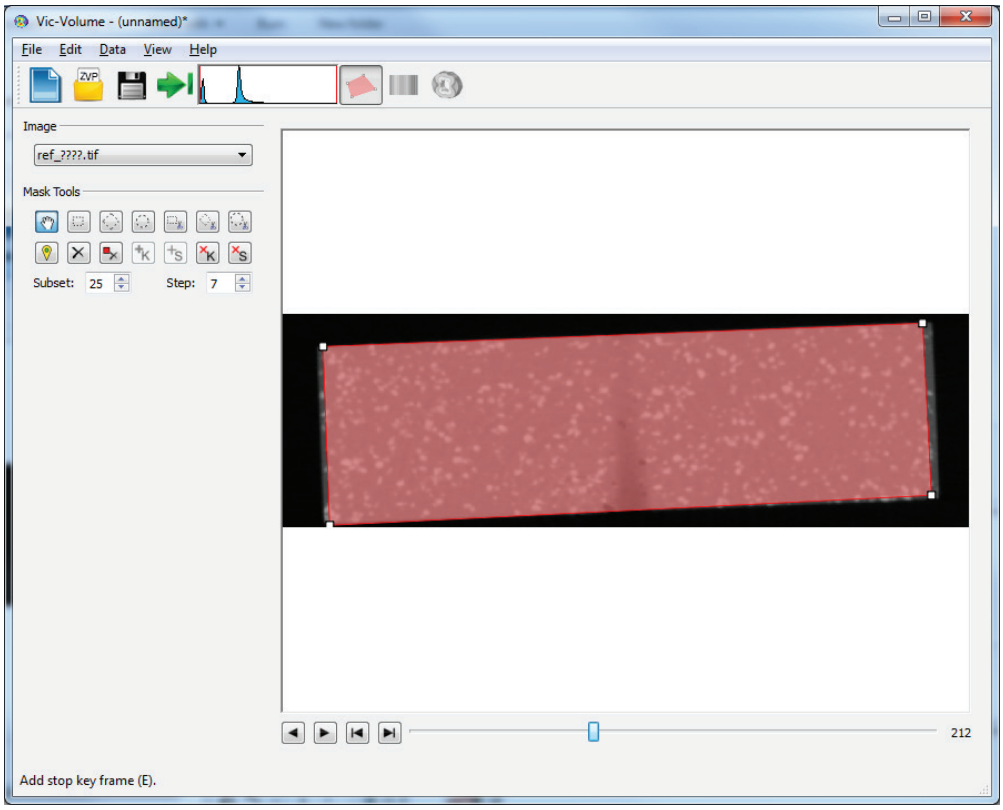


Each time there is a mismatch like this, you can add a keyframe and adjust the AOI.

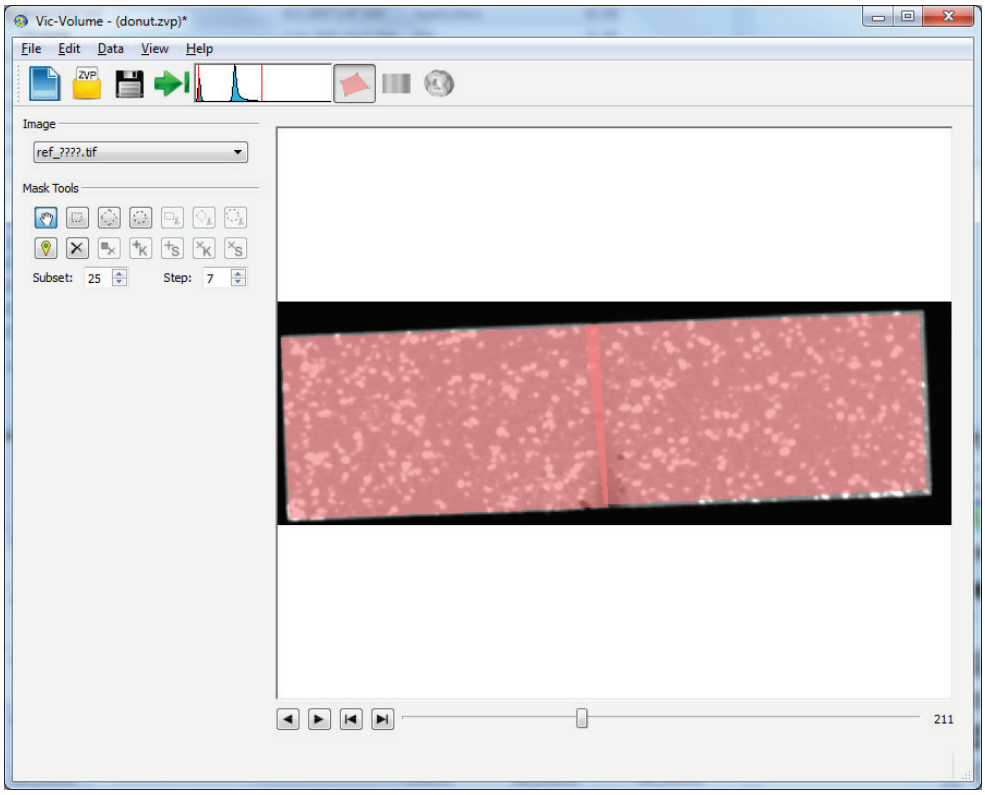


Repeat until the AOI matches the outline of the data well.

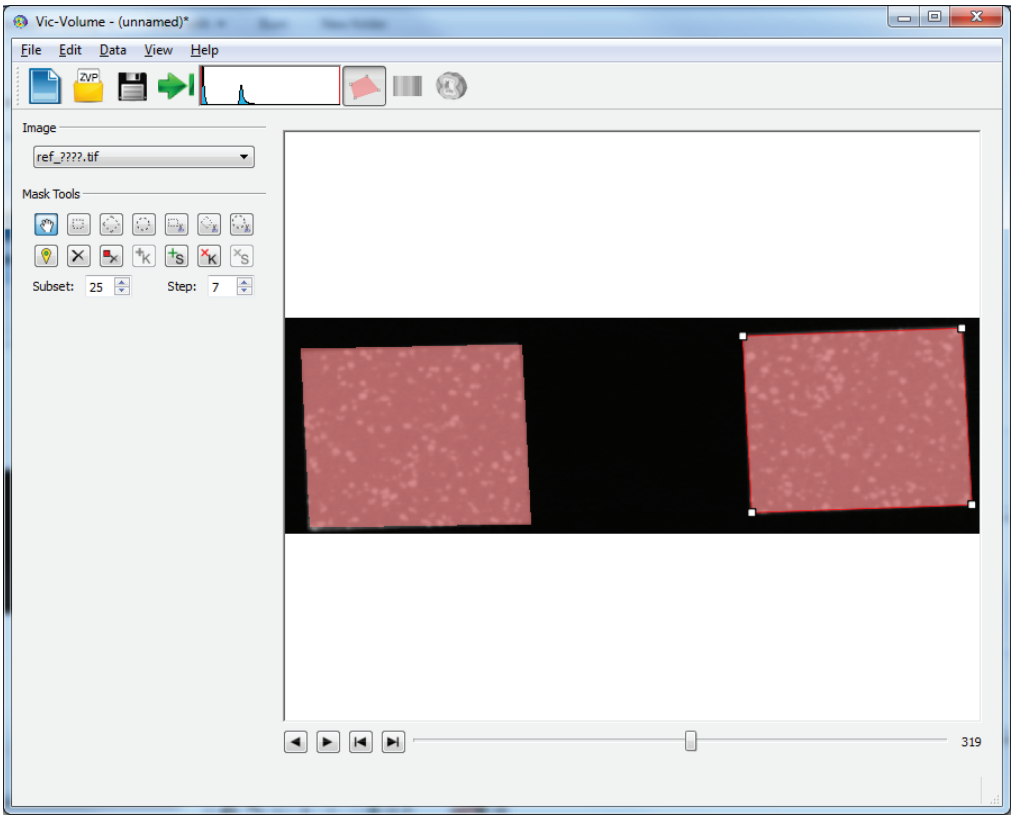
Because the shape here is a torus, it will begin to split into two separate areas:



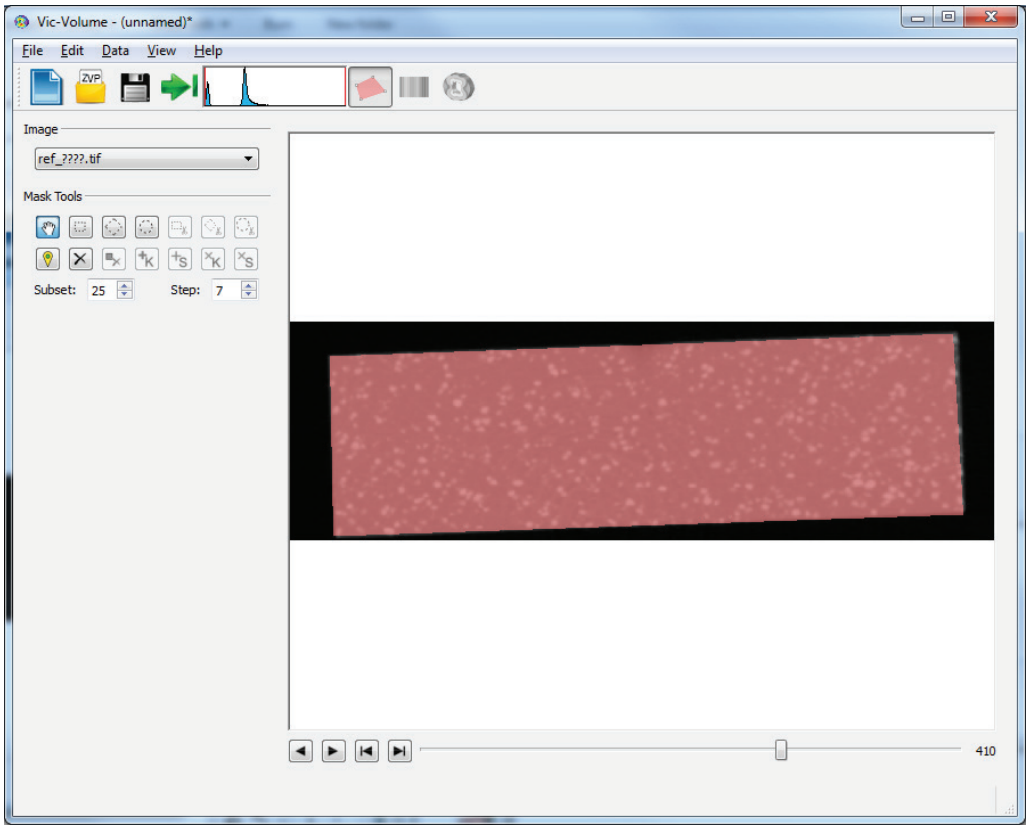
To handle this, put an end to the single AOI and create two new ones in the following frame. Clicking on the AOI follow by the $^{+}_{S}$ button (or **E** on the keyboard)will signal the software to end this AOI at this frame. Navigate to the next frame, and draw the two new overlapping AOI's.



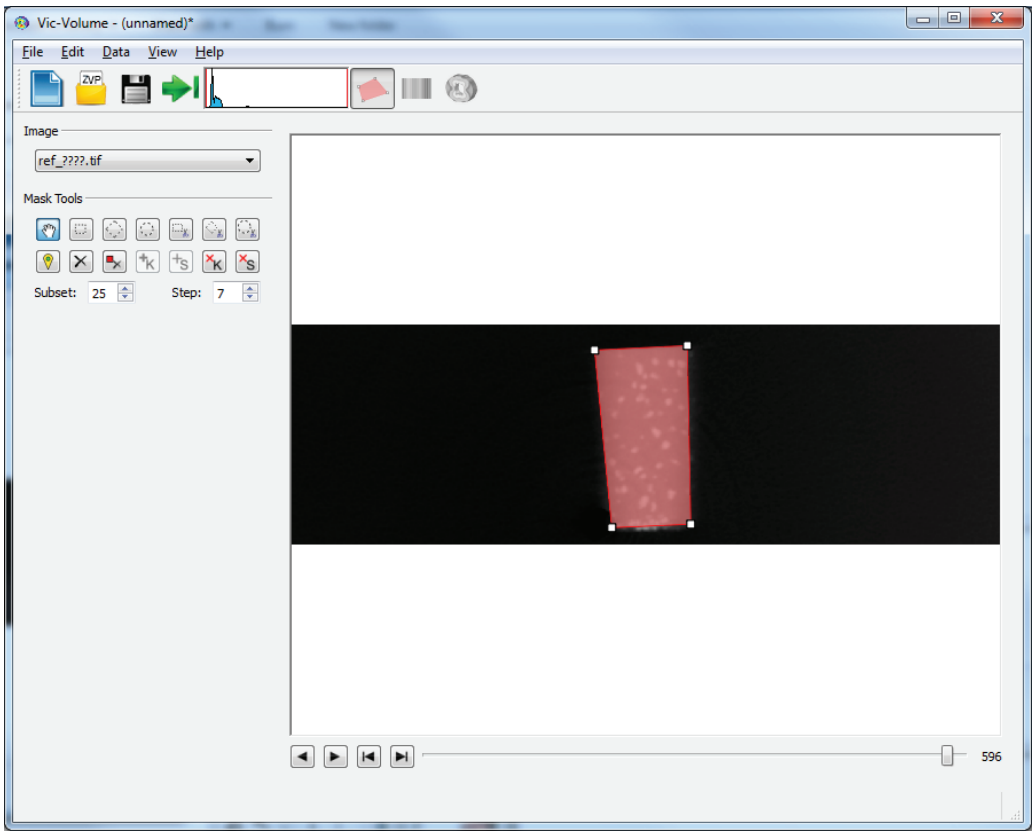
(The AOIs may overlap with no issue.) Then, navigate forward frame by frame and add keyframes, adjusting the position to match the object. You will have to click on **each AOI** and add the keyframes.



When the object starts to show as contiguous again, repeat the process by click on each AOI and adding a stop frame. Navigate to the next frame by clicking the . key; the AOI's will be gone and you can draw a single one in their place.



Proceed to very last frame where the object appears, and click A to add a keyframe; adjust the AOI to match the specimen.

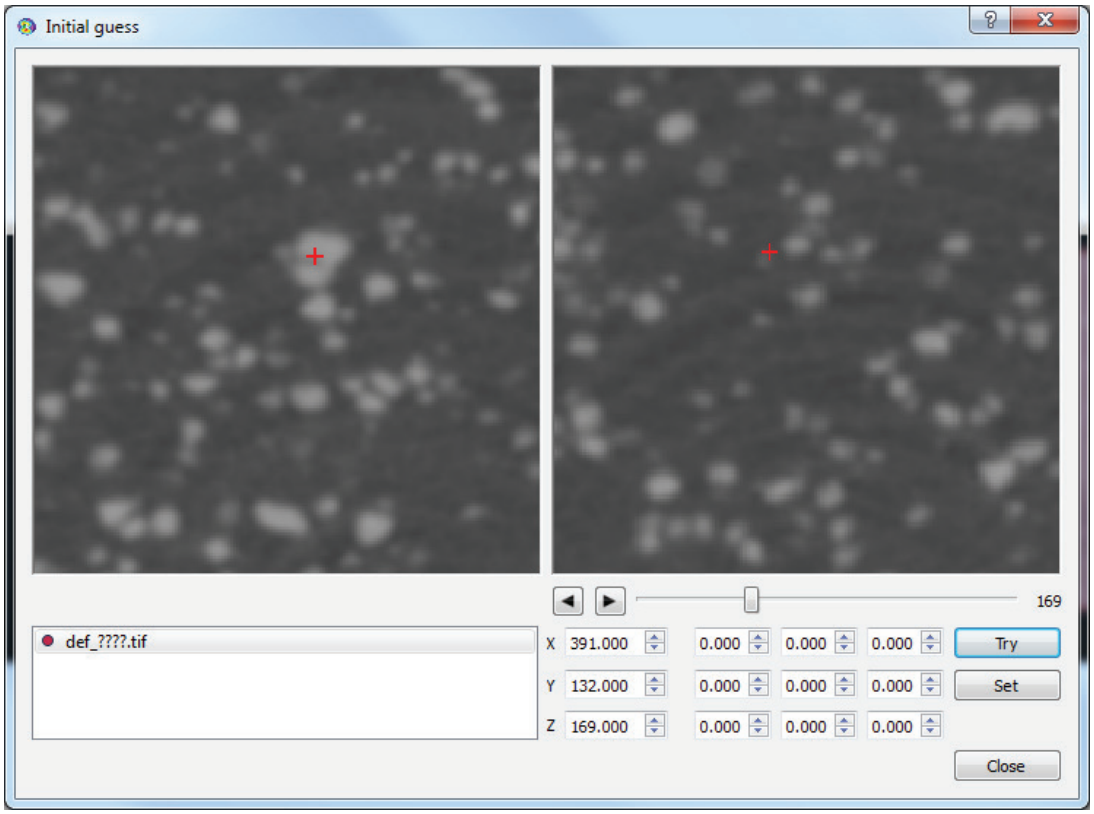


Finally, go back through and add necessary keyframes as before. When the process is complete, you should run through the whole slice sequence and check the match.

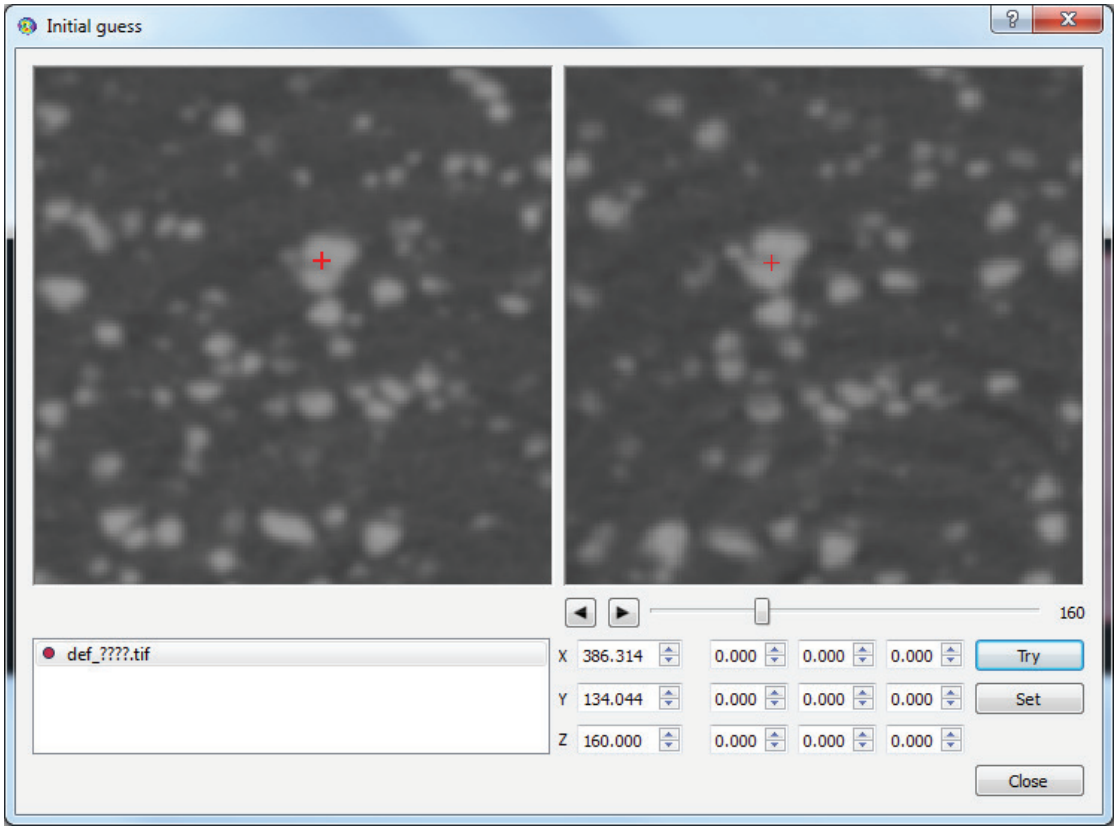
ADDING START POINTS

Before running the correlation, you will have to provide one or more start points to seed the correlation process. The start point must not lie too close to either an AOI boundary, or an object boundary in the Z-axis. Navigate to a frame in the middle of the object; click the button; and click in an AOI to set the point location. Ideally this will be somewhere with a easy-to-identify speckle or feature such as a particularly large speckle.

Double-click on the start point to open the Initial guess dialog.



Next, you will have to navigate both in the XY axis and the slice axis to try to find the matching point. For this object, you can use the rough outline of the image to get close, and then look for similar features. In this case you will have to navigate down several frames to see a similar point:

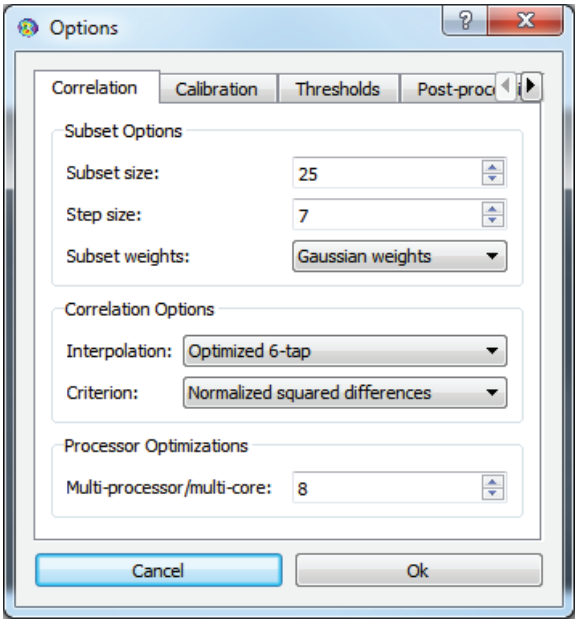


Complete the guess by clicking on a matching location in the right image, and clicking Set. The red dot next to the deformed file will turn green; repeat for any additional deformed files.

Once the AOI drawing and initial guess selection is complete, you can run the correlation.

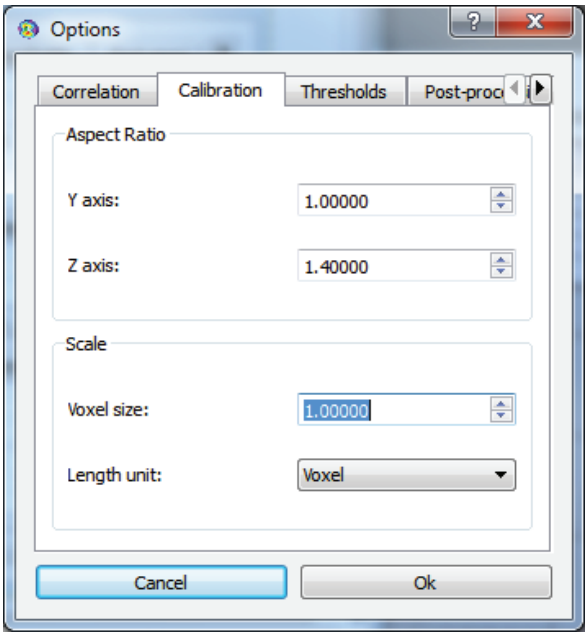
PROJECT OPTIONS

You can adjust selected project options prior to running the correlation by clicking Edit... Project settings from the main menu.



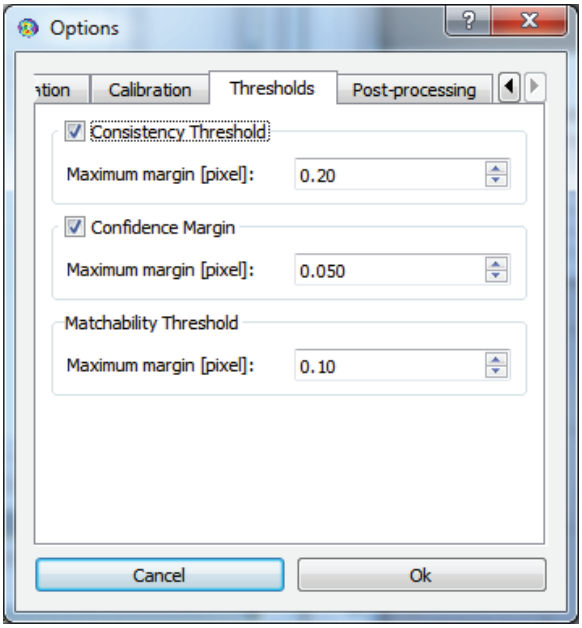
The correlation tab controls correlation options.

- Subset size: this is the size in all axes of the cubical analysis subset, in voxels.
- Step size: this is the pitch of the grid of data returned, in voxels. Larger step sizes will run faster.
- Subset weights: choose between Gaussian (center-weighted), and uniform.
- Interpolation: choose the order of the interpolation. Higher orders offer more accuracy at the expense of speed.
- Criterion: choose a correlation function that is either not normalized, normalized, or normalized and offset.
- Multi-processor: this is the number of threads that will be used. It will normally be selected automatically.



The thresholding tab contains three level settings that determine which data points are discarded.

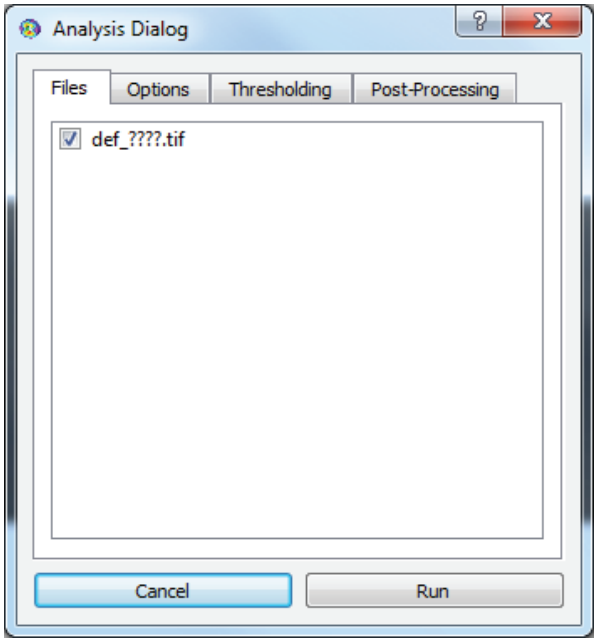
- Consistency Threshold: this threshold discards points whose predicted locations do not agree with their neighbors. Set the number higher to allow more points, or turn off completely.
- Confidence Margin: this threshold operates on the sigma value; points whose location is more uncertain will be thrown out. Higher numbers allow more points.
- Matchability Threshold: this will remove points that do not contain enough image contrast to correlated effectively. Raise the number to allow more points.



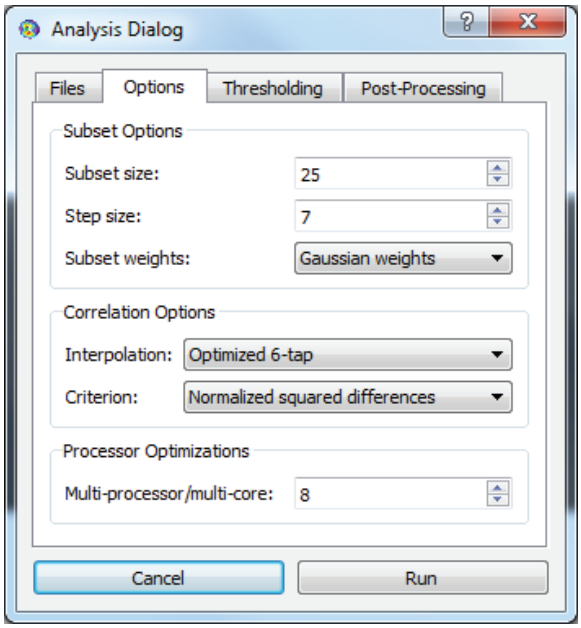
The postprocessing tab gives the option to compute strain during correlation. If this is not selected, you can calculate it afterwards with the Strain dialog.

THE RUN DIALOG

Once the AOI is set, you can run the correlation by clicking the icon in the toolbar or pressing **Ctrl-R**. The Analysis Dialog appears. You can either click **Run** to run immediately, or edit the options first.

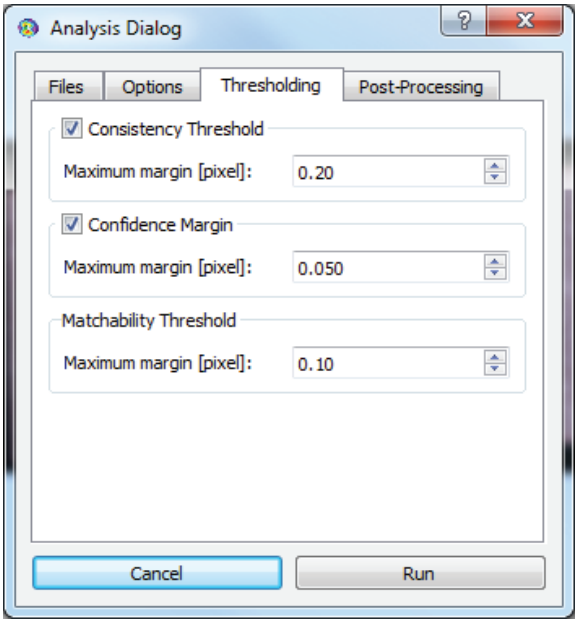


In the first tab, you can select the deformed sets to run; all are selected by default.



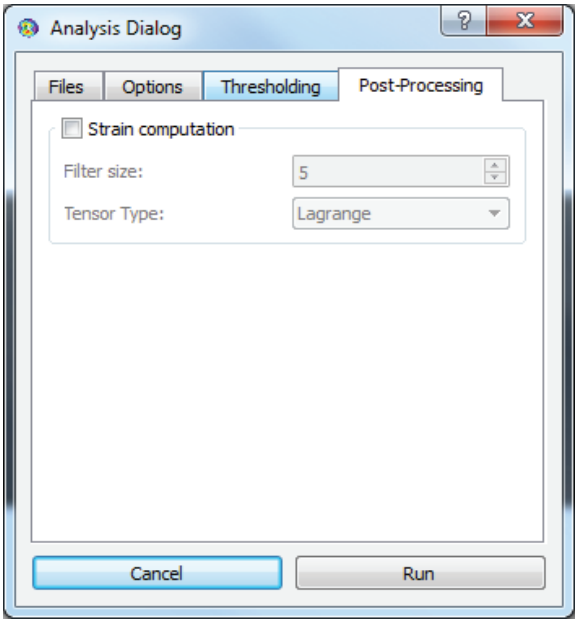
The options tab controls correlation options.

- Subset size: this is the size in all axes of the cubical analysis subset, in voxels.
- Step size: this is the pitch of the grid of data returned, in voxels. Larger step sizes will run faster.
- Subset weights: choose between Gaussian (center-weighted), and uniform.
- Interpolation: choose the order of the interpolation. Higher orders offer more accuracy at the expense of speed.
- Criterion: choose a correlation function that is either not normalized, normalized, or normalized and offset.
- Multi-processor: this is the number of threads that will be used. It will normally be selected automatically.



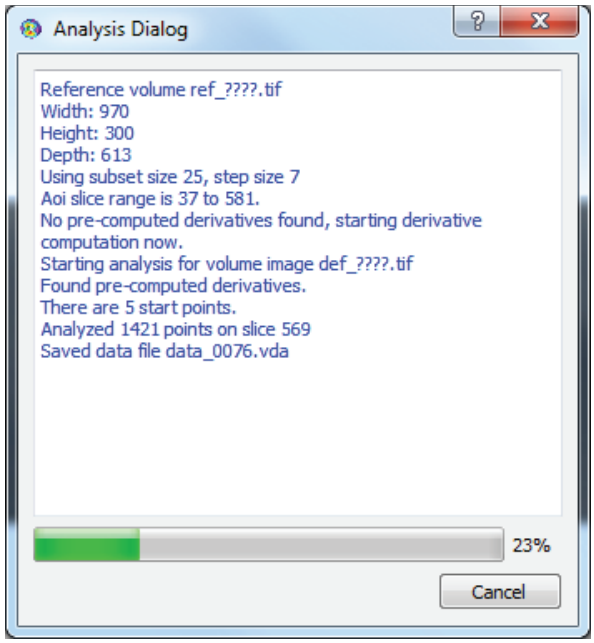
The thresholding tab contains three level settings that determine which data points are discarded.

- Consistency Threshold: this threshold discards points whose predicted locations do not agree with their neighbors. Set the number higher to allow more points, or turn off completely.
- Confidence Margin: this threshold operates on the sigma value; points whose location is more uncertain will be thrown out. Higher numbers allow more points.
- Matchability Threshold: this will remove points that do not contain enough image contrast to correlated effectively. Raise the number to allow more points.



The postprocessing tab gives the option to compute strain during correlation. If this is not selected, you can calculate it afterwards with the Strain dialog.

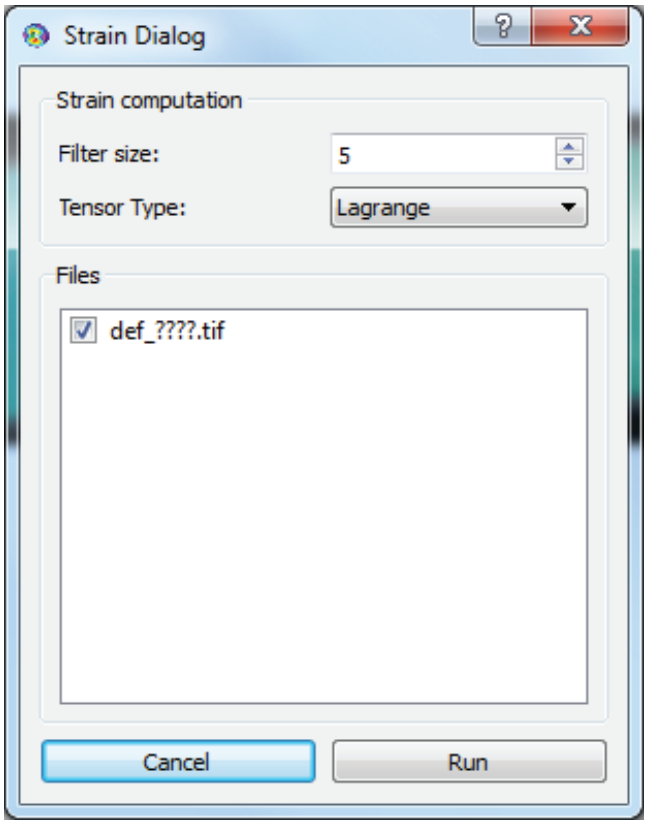
When ready, click **Run** and a status window will appear:



The process will iterate through each slice for each deformed data set. When complete, click Close. You can either view a volume plot, contour plot, or export the data using Data... Export Data from the main menu.

THE STRAIN DIALOG

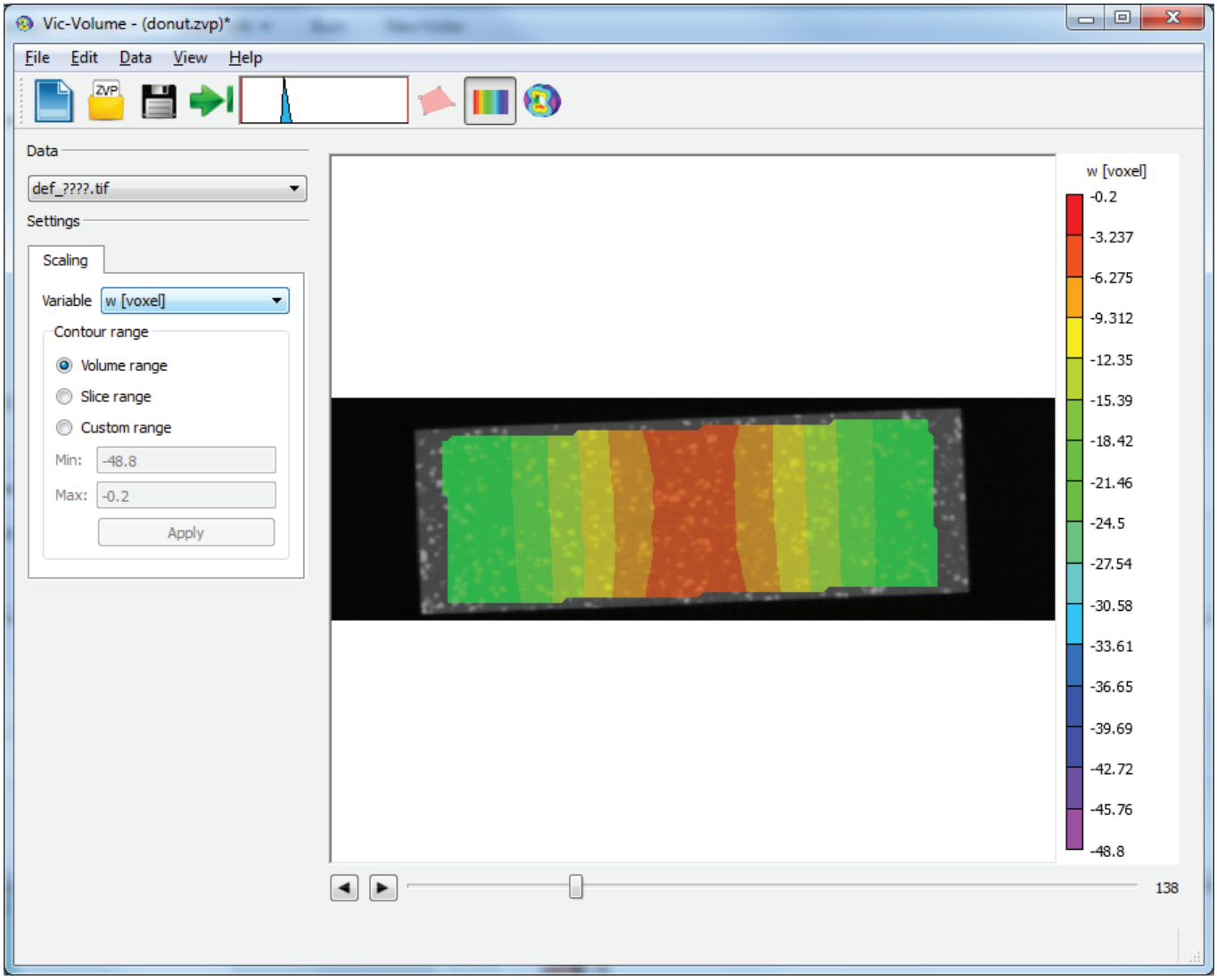
You can bring up the strain dialog by clicking Data... Calculate Strain from the main menu or pressing **Ctrl-U.**



Select the desired smoothing filter, and tensor type; click **Run** to proceed.

CONTOUR PLOTS

Once the data has been run, you can view a contour plot by clicking the button in the toolbar. A slice plot and navigator will fill the workspace.

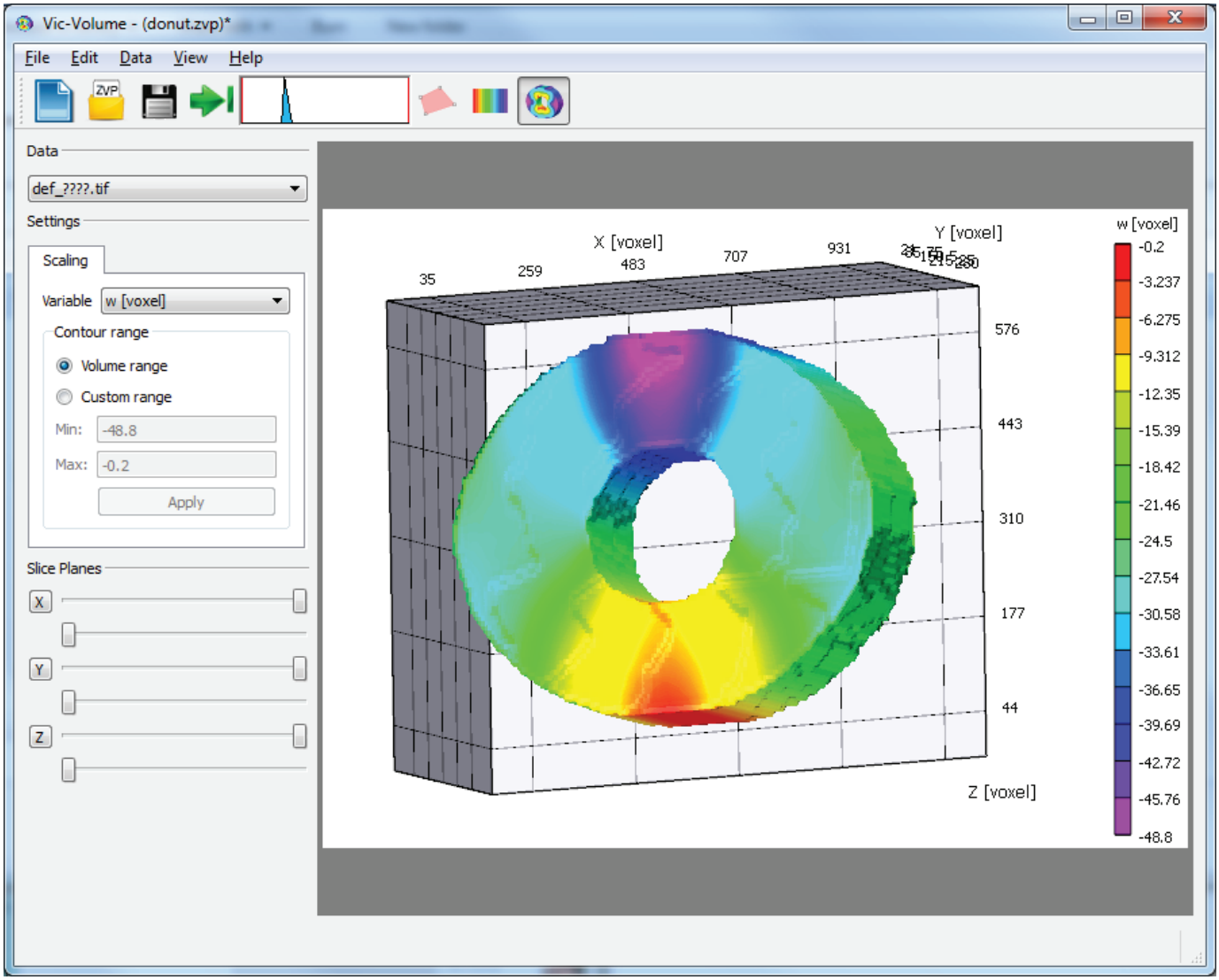


You can select the dataset using the pulldown at the top right. Choose a variable to display, and use the **Contour range** controls to adjust the levels.

The current slice can be selected with the buttons or slide bar at the bottom of the display.

VOLUME PLOTS

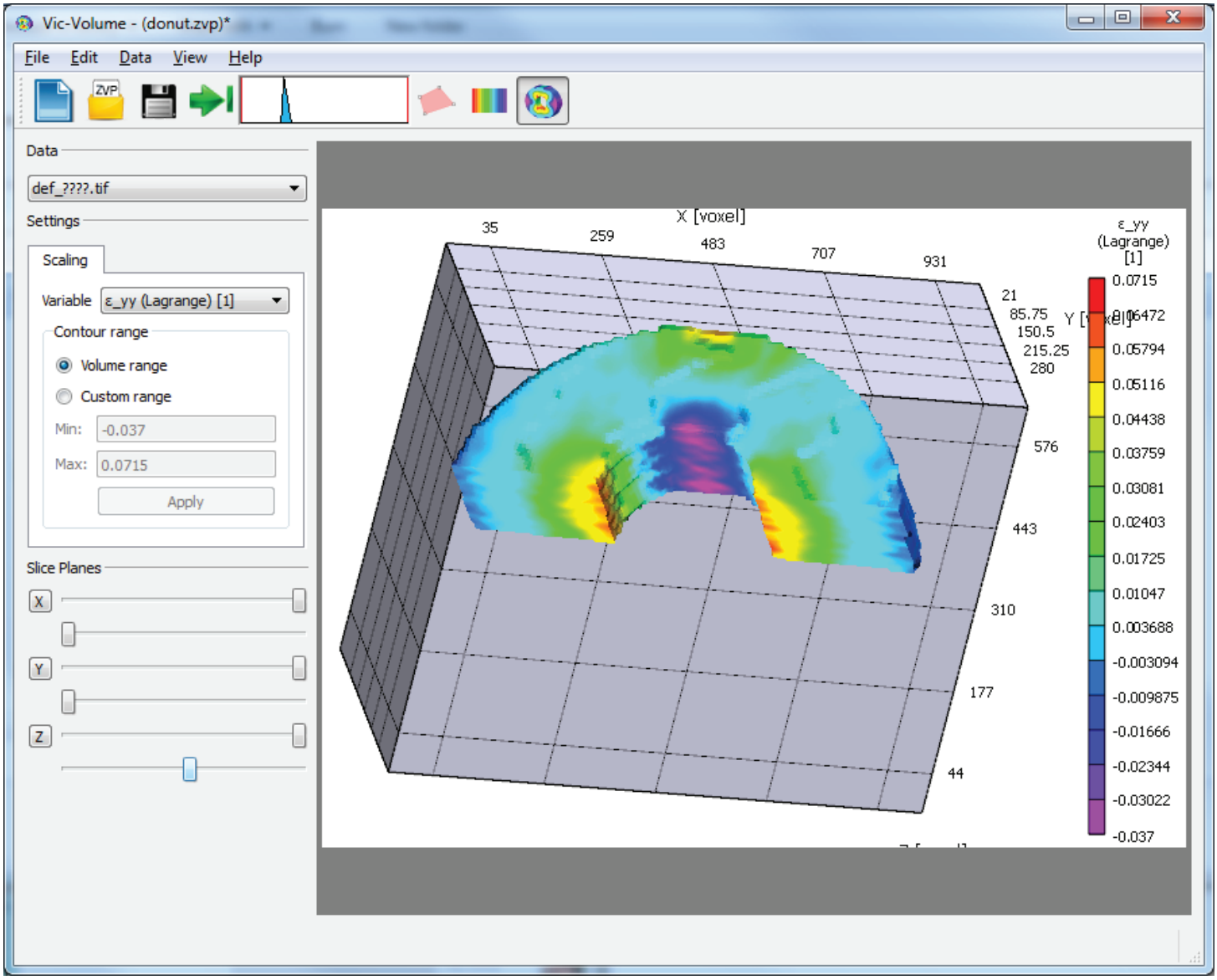
Once the data has been run, you can view a volume plot by clicking the button in the toolbar. A 3D plot and controls will fill the workspace.



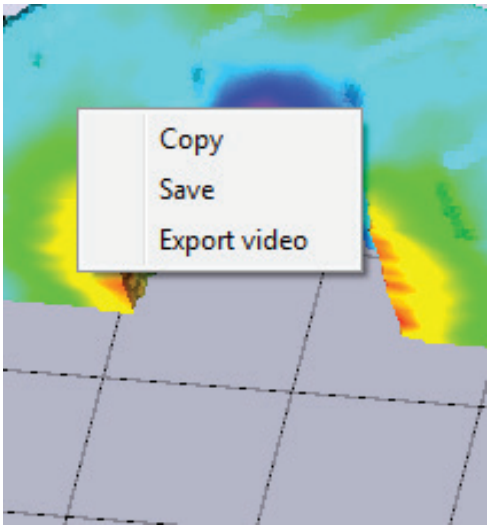
You can select the dataset using the pulldown at the top right. Choose a variable to display, and use the **Contour range** controls to adjust the levels. Select **Volume range** to make the range match the values present in the data set.

To view inside the object, you can use the **Slice Planes** controls to adjust the start and end range in each axis:

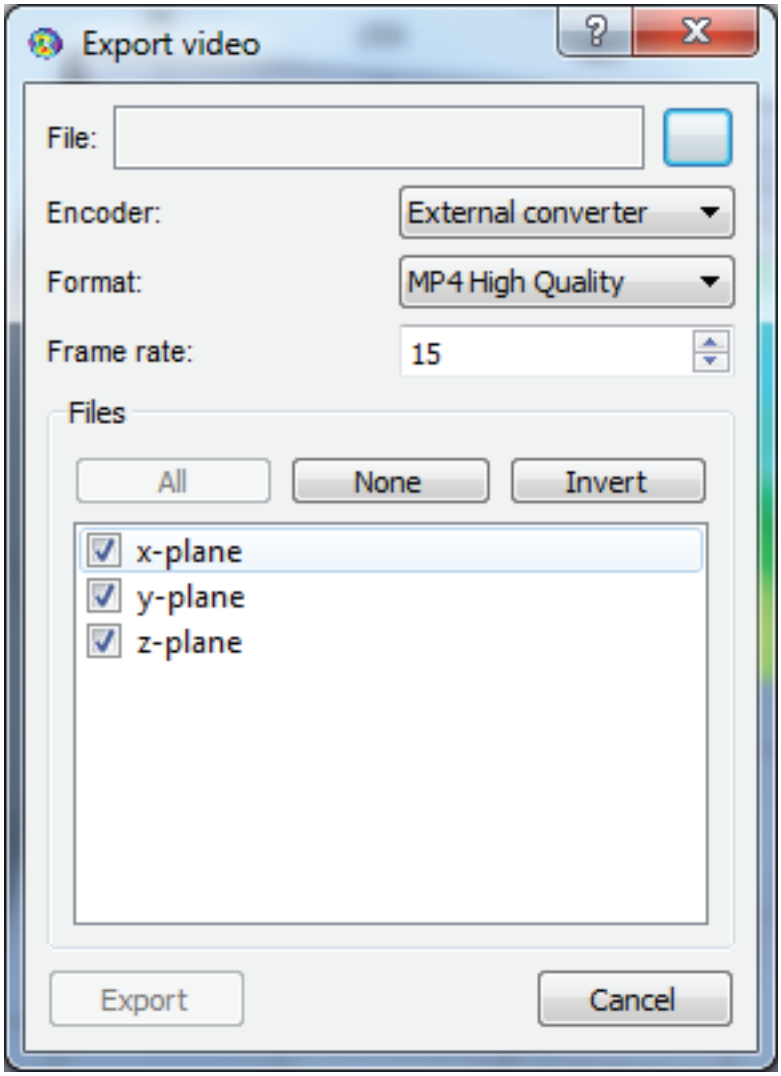
To run the displacement analysis, select the *Run Correlation* entry from the *Data* menu, or press the button on the tool bar.



Right-click in the plot for a context menu:



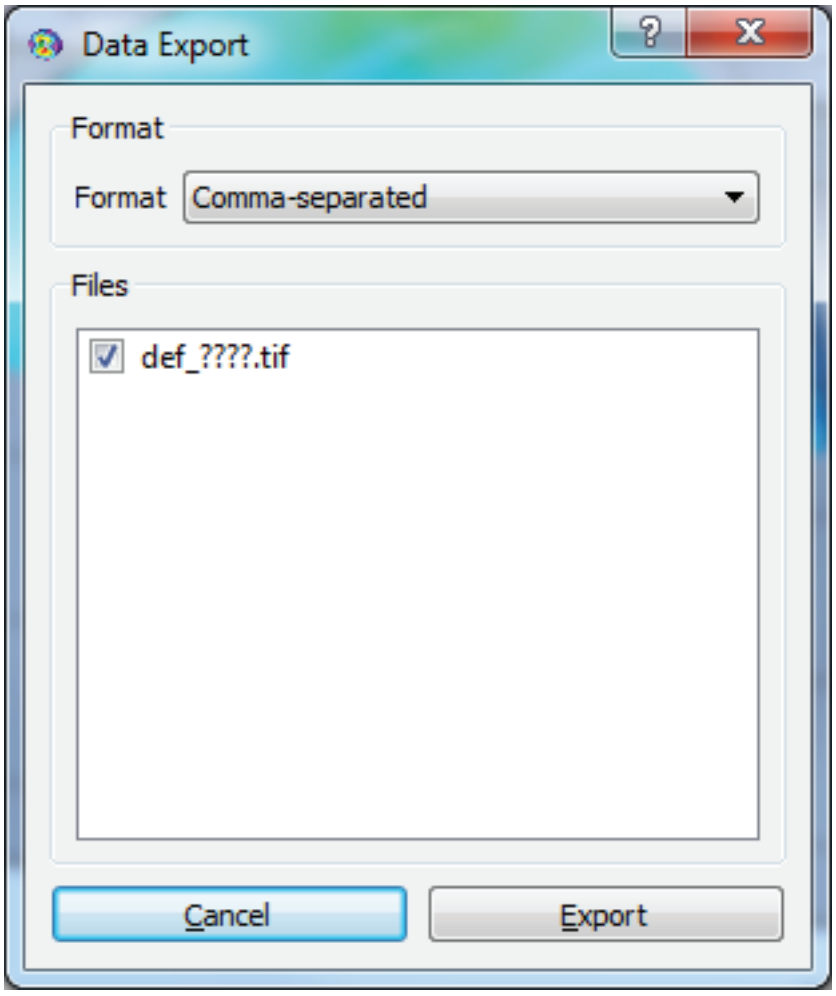
You can copy the current plot to the clipboard or save as a static image. To export a video, click Export video:



You can choose a filename, format, and frame rate. Choose whether to animate through some or all of the X-plane, Y-plane, and Z-plane. The video will consist of slices proceeding through the object in each selected plane, one after the other.

EXPORTING DATA

You can bring up the data export dialog by clicking Data... Export data from the main menu or pressing **Ctrl-E.**



You can choose the appropriate file format and select the files for export; click **Export** to complete.