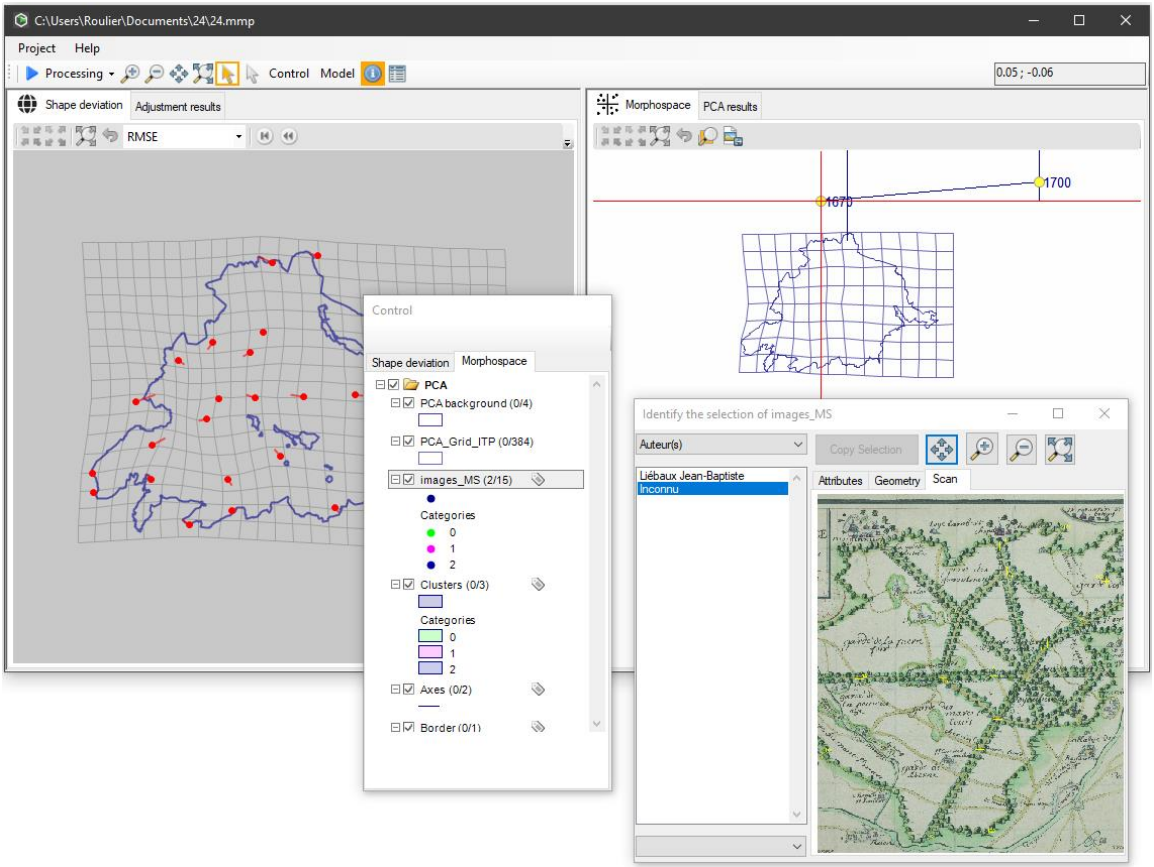
MapMorphy 1.1

Geometric morphometrics
for cartography

User Guide

https://mapmorphy.fr/



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1. General presentation

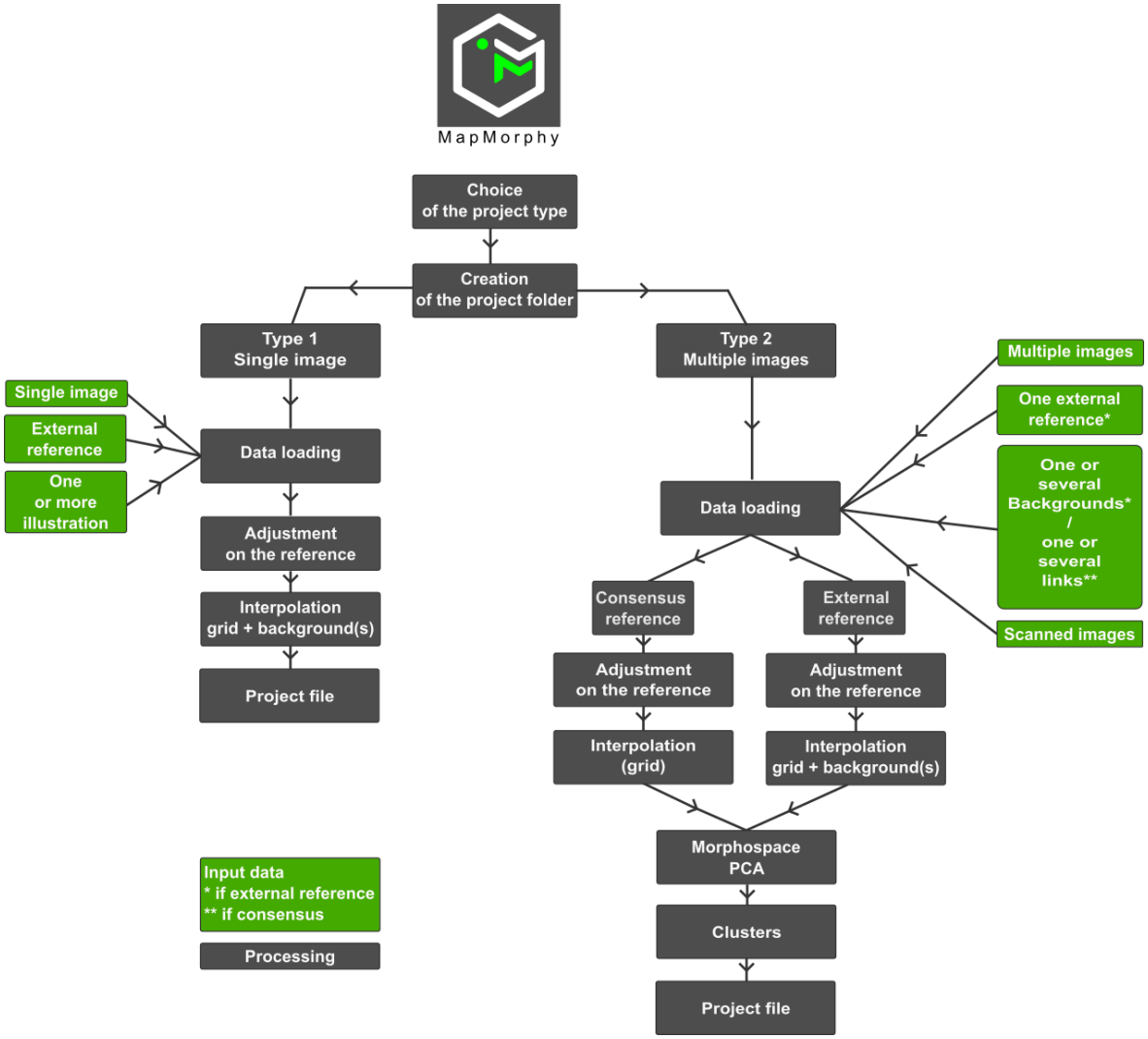
1.1. Introduction

MapMorphy is a free Windows software designed for morphometric analysis of 2D geographic data. The software offers the user an easy-to-use graphical interface for comparing the shape, for example, of several maps corresponding to cognitive representations of space or ancient maps.
MapMorphy is based on the principles of geometric morphometrics, a set of methods used since the 1980s, particularly on data of biological or archaeological origin. This methodology is combined with that of cartographic transformations of positions usually used in geography for spatial comparison.
The main objective of the software is to apply these methods to identify similarities/dissimilarities in shape between several maps or spatial structures and to produce shape variables.
The general principle is based on a statistical analysis of the Cartesian coordinates of homologous points, that is, points (landmarks, places) having the same identity on different maps or spatial structures. This will involve superimposing these points on their counterparts of a reference and then analyzing the residual differences.
Through the Shapefile format used, the software is clearly specialized in the comparison of base maps and spatial structures. It is, however, capable of analyzing the shape of any corpus of objects whose related shapes are quantifiable by a series of homologous points coded in this format. Software for converting the *.tps format, classically used in geometric morphometrics, into Shapefile format is available on the MapMorphy website. It is thus possible to compare the 2D shapes of non-geographic objects (leaves, insects, bones, etc.) produced for example by the tpsdig2 software. The Shapefile format is also used as output from the software. GIS software can thus layout and export in vector format all the data produced by MapMorphy.

It is important to clarify to the reader now several key terms used in this documentation.

- The term " configuration " is used to designate the set of points used to code an object before superimposition.
- The term " shape " is used to designate the structure of the configuration once neutralized by superposition of information on the position, orientation and size of the configuration.
- The term " form " is used to designate the structure of the configuration once neutralized by superposition only the information on the position and orientation of the configuration.
- The terms " image " and "image point" are used to designate the configuration(s) to be compared.
- The terms " reference " and "reference point" are used to designate the configuration of the source to which the image configuration(s) is (are) compared. This reference can correspond either to a specific external configuration available in a file (for example from a topographical map), or to an average called "consensus" calculated from several image configurations during superimposition.

MapMorphy offers two distinct processing processes depending on whether two or more structures are compared: type 1 projects (a single image) and type 2 projects (several images).



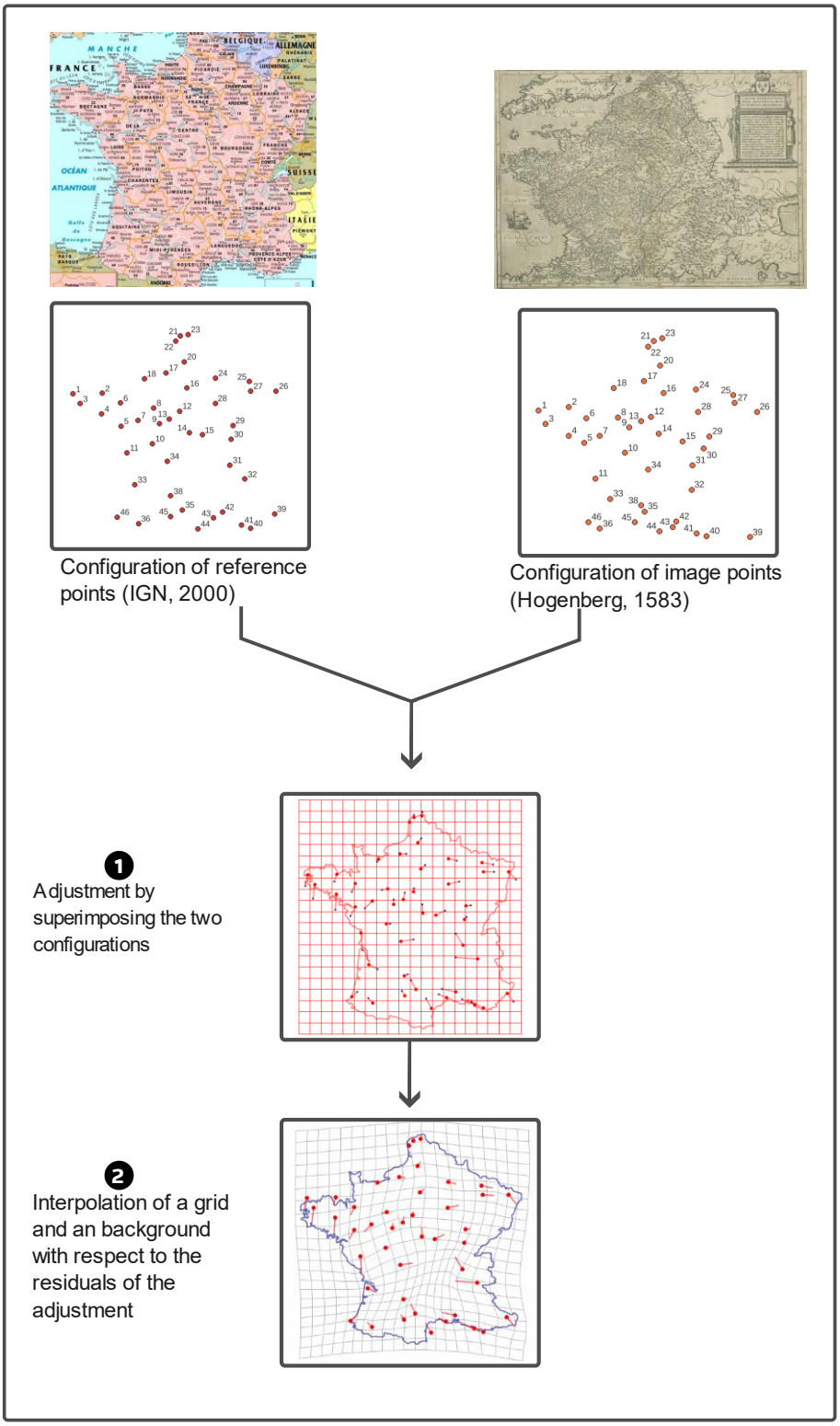
The two processing of MapMorphy

1.2 Overview of a type 1 project

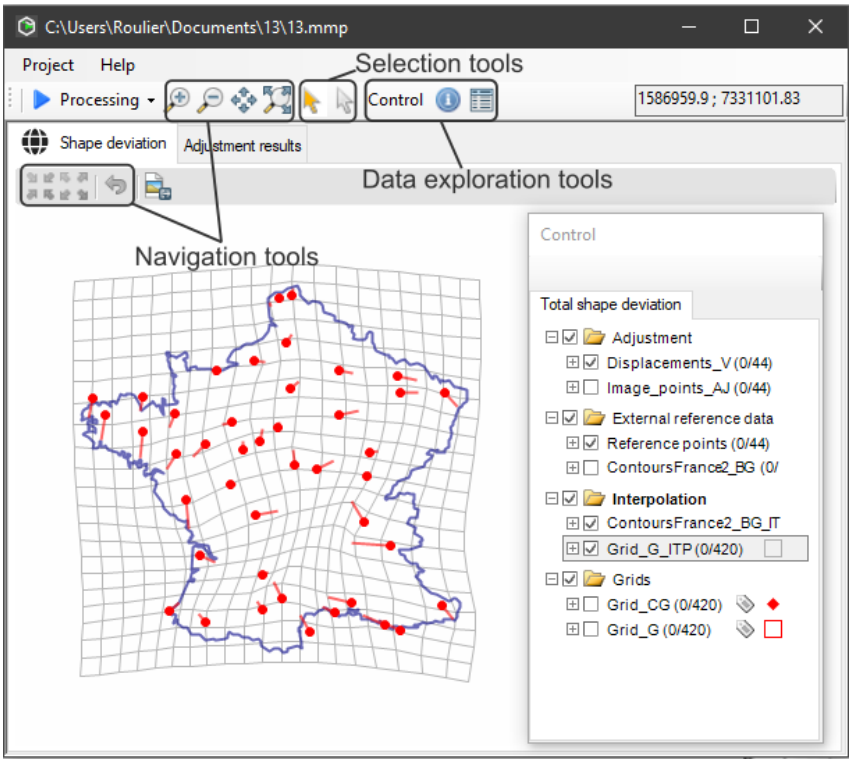
This type of project corresponds to the comparison of a single image configuration (positions in access time, positions evaluated in a cognitive space, positions on ancient maps, etc.) with a reference configuration contained in an external file. This type of project corresponds to a cartographic transformation of position. Two steps follow one another in this case to show the shape difference between the image and the reference.

- The first step calculates the total shape deviation by an adjusted superimposition of the image configuration on the reference configuration. This adjusted superimposition is carried out using the Waldo Tobler's bidimensional regression. This method simultaneously operates a translation, a rotation and a displacement of the points of the image configuration on their counterparts of the reference configuration so as to reduce according to the law of least squares the difference in shape between the two configurations. The residual differences (there are always some if the two configurations are not identical) determine the displacement vectors for each point of the reference configuration. The origin of the vectors corresponds to the point of the reference configuration and the end of the vectors to the adjusted homologous points. The length (norm) of these vectors illustrates the shape variation; Calculating the root-mean-square error (RMSE) provides information on the overall shape variation. MapMorphy then proposes to design a grid covering the reference space and representing a continuous space.

● The second step is a data interpolation making it possible to propagate on the grid and on backgrounds relating to the reference, all of the movements corresponding to the displacement vectors. MapMorphy uses multiquadric interpolation for this step. This type of project allows, for example, to compare an image configuration with that of a reference topographic map or to compare an average of image points (from several configurations) with this same topographic reference. The following example compares the map of France drawn by cartographer Frans Hogenberg in 1583 with a modern reference map.



The type 1 project



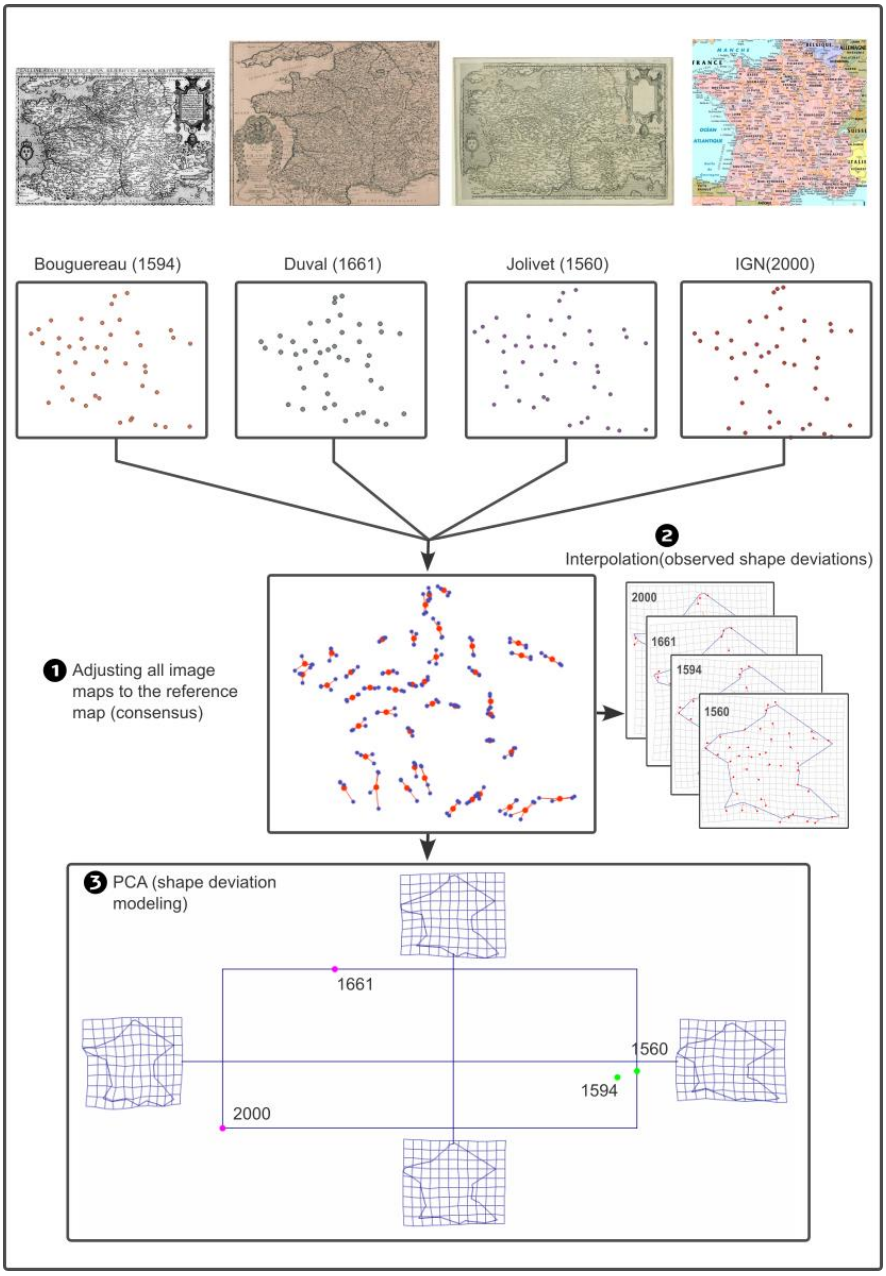
The interface of a type 1 project

1.3 Overview of a type 2 project

This time it involves comparing several image configurations to a reference configuration. The latter can correspond to a specific configuration external to the images such as a topographic reference map or to the consensus, that is to say the average of the adjusted image configurations. The treatment procedure consists of three stages.

- The first step consists of calculating the adjusted superimposition of each image configuration on the reference, preferably a consensus in order to optimize the modeling. In this case, a generalized version of bidimensional regression is applied. As in the type 1 project, it is at this stage proposed to create the grid representing a continuous space. The total shape deviation is therefore precomputed here for all image configurations.
- The second step is to interpolate the illustrative data associated to each image according to their total shape deviation calculated in the previous step. The displacement vectors of each adjusted image are used to calculate the deformations of the grid and, where applicable, those of the backgrounds. When the reference corresponds to a consensus, no background is available because the consensus is an average which does not correspond to any existing background. Links between the adjusted points, however, make it possible to provide a complementary visual context to the interpolated grid. This step makes it possible to pre-compute and visualize the cartographic position transformations, that is to say the total shape differences observed between each image and the reference.
- The third step corresponds to the calculation of a PCA constructed from the adjusted coordinates. These coordinates can be projected onto a tangent linear space more suitable for PCA analysis than the adjusted original coordinates located on a curved space. This PCA analysis makes it possible to produce a 2D modeling of the morphological space called “morphospace” where each point corresponds to a map or a spatial structure. It is created from the covariance matrix of the adjustment residuals between the images and the reference. PCA constitutes the key statistical processing of MapMorphy because it shows on the one hand, thanks to the distances between points, the similarities and dissimilarities of the shapes and on the other hand, thanks to the reconstruction of four models located on the margins of the graph, the main deformations compared to the reference. The PCA makes it possible to reconstruct,

thanks to its parameters, models because at any point in the PCA space there corresponds a difference in shape with the reference. Clusters can be calculated by K-means to identify close shapes on the PCA graph. The example below shows the comparison of the shapes of four maps of France, three of which are ancient and one recent map. The reference chosen here is the consensus.

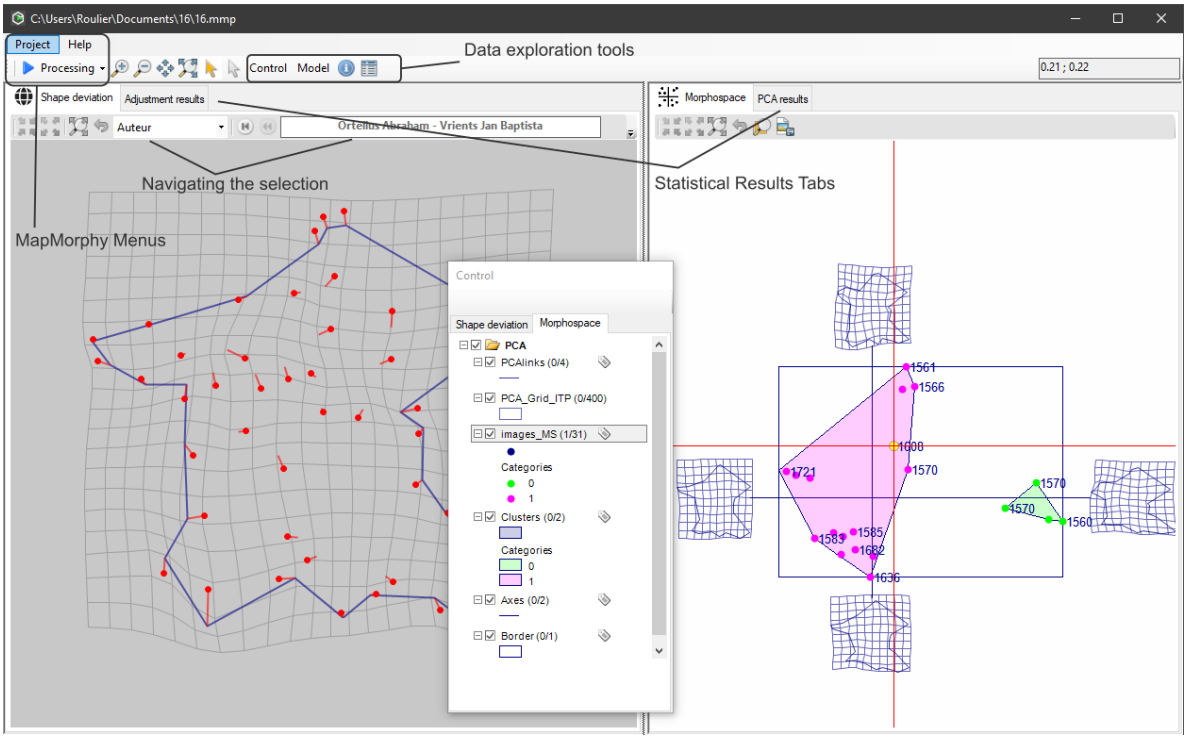


The type 2 project

The user interfaces for Type 1 and 2 projects are very similar. The type 1 project presents a single window showing the total shape deviation observed with the reference. The type 2 project presents two viewing windows, one to display the total shape deviation observed between a particular map and the reference, another to display the morphospace. In fact, the interface of a type 1 project is a simplification of the interface of a type 2 project and many tools are common. The visual codes for using the two user interfaces (cartographic navigation, layer control window, formatting, etc.) are those of GIS software. The two types of project are processed according to comparable sequences: data loading, adjustment, interpolation, calculation of a PCA then clusters (only for type 2).

In both cases, computer processing is automatically saved in a folder previously designated by the user. This folder contains all geographic files in Shapefiles format and statistical outputs in Text format. At the end of processing, a project in *.mmp format is automatically saved in the folder. The latter can be

moved or copied. The project file eliminates the need to reload the data and recalculate the adjustment and interpolation processing. It also makes it possible to relaunch the ACP for type 2 projects.
MapMorphy facilitates interaction with the cartographic dataset thanks to its exploration tools (attribute table, identification) and symbology. More detailed analyzes can be carried out by other software from the results produced and saved in the project file. For example, points in the morphospace can be easily linked to a geographical location in a GIS and the calculated parameters integrated into the Shapefile tables can be cross-referenced with other data.



Interface of a type 2 project

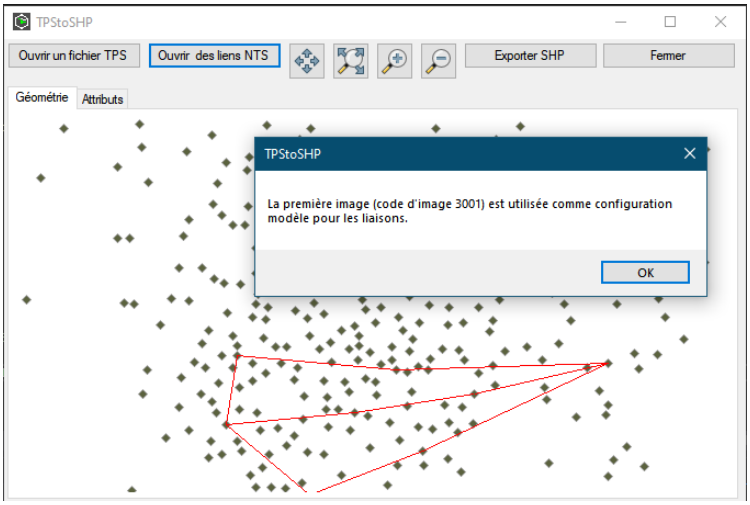
2. Prepare data sources

MapMorphy uses the Shapefile format for geographic data input (image points, reference points, backgrounds, links) and output from the software in the project folder. The Shapefile format can be easily produced by common GIS software.

The accepted data types are the point, the polyline and the polygon without M data and Z data. These entities must not be multi-part and for polygons must not contain holes.

The field name “ID” is a reserved name in Shapefile attributes.

The TPStoSHP application available for download from the MapMorphy website allows you to convert data originally in *.tps format for image points and *.nts for connections to Shapefile format. Note that only the keywords "VARIABLE", "LM", "ID" are considered for the moment in TPStoSHP.

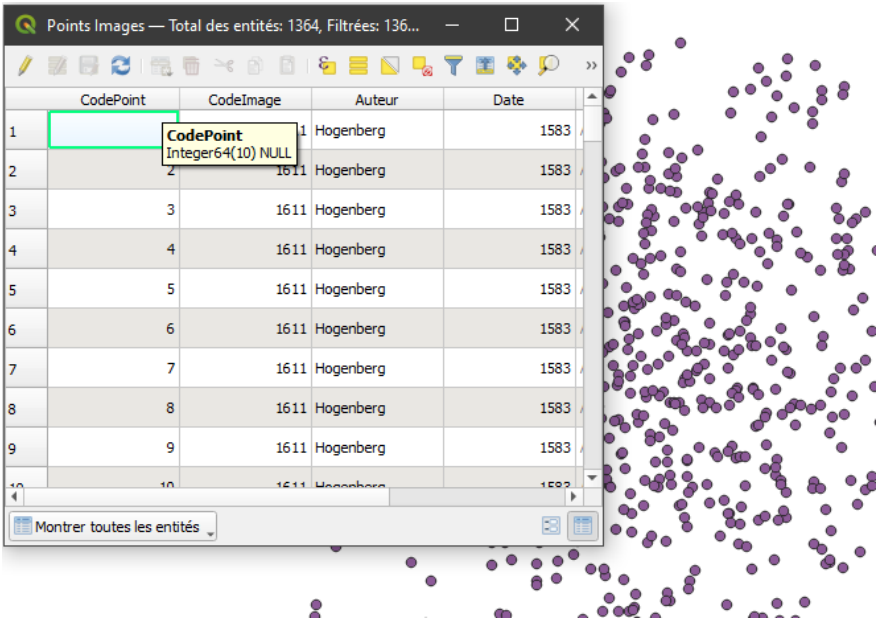


TPStoSHP interface

2.1. Image points

The main file in MapMorphy is the image point configurations file corresponding to perfectly identified specific locations. For the type 1 project, only one configuration of image points in Shapefile format is necessary. It is made up of at least three points. For type 2 projects, the file brings together several configurations of more than three points. The first field must be of integer numeric type and allows you to enter the points codes, the second field must also be of integer numeric type and allows you to enter the image code. Additional fields allow you to integrate various attributes for each image.

Point code	Image code	Field1	Field2	
1	1	val1	aaa	image 1
2	1	val1	aaa	
3	1	val1	aaa	
1	2	val2	bbb	image 2
2	2	val2	bbb	
3	2	val2	bbb	
1	3	val3	ccc	image 3
2	3	val3	ccc	
3	3	val3	ccc	



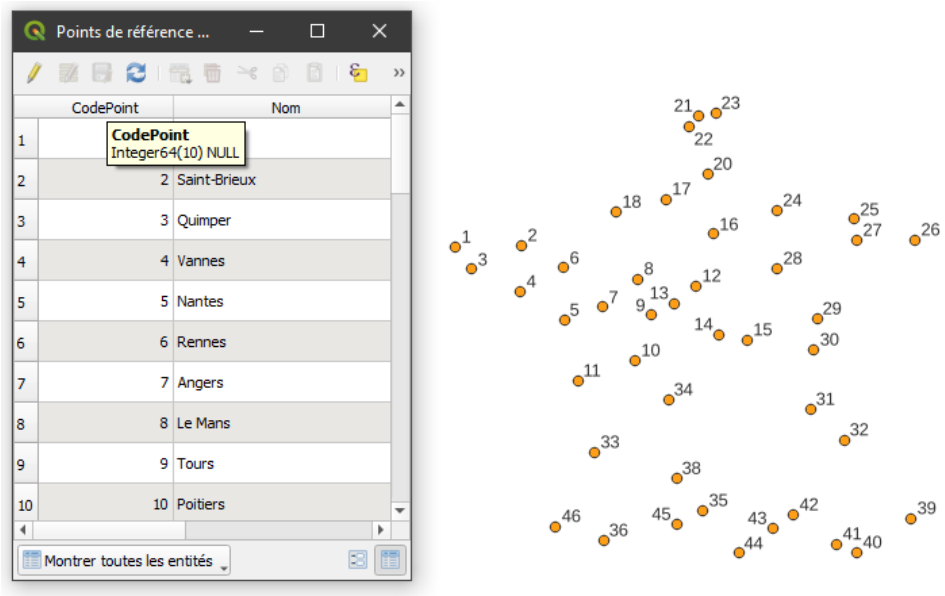
An image points file for a type 2 project (several images)

The coordinate system does not matter for the creation of the image points because they will be adjusted to a reference. Points of the same image must follow each other in the file. On the other hand, the order of creation of the points for the same image does not matter because MapMorphy reclassifies them in an identical order for each image. For the production of the image point configuration file in type 2 project, it is recommended to create an image point file per map and then gather the data using a data layer fusion function in GIS software.

2.2. Reference points

For type 1 and 2 projects, it is possible to compare the position of the image points to those of a reference, for example the points in Lambert coordinates of a topographic map. For type 1 projects, this reference is essential. For type 2 projects, it is possible but we most often prefer the average of the adjusted image points called consensus. Indeed, although the external reference is often acceptable, the produced morphospace will provide a better approximation of the curved space and more accurate modeling with the consensus as a reference.
The order of the fields in the reference points file does not matter here, but it will be necessary to provide an integer numeric type field to enter the point identification codes, similar to those of the image points. Additional fields can be added corresponding, for example, to toponymy (which can be displayed on the maps). The reference configuration is a single set of points. It is not necessary to copy the reference points of each image into the file for Type 2 projects.

Point code	Field1	Field2
1	val1	aaa
2	val2	bbb
3	val3	accc

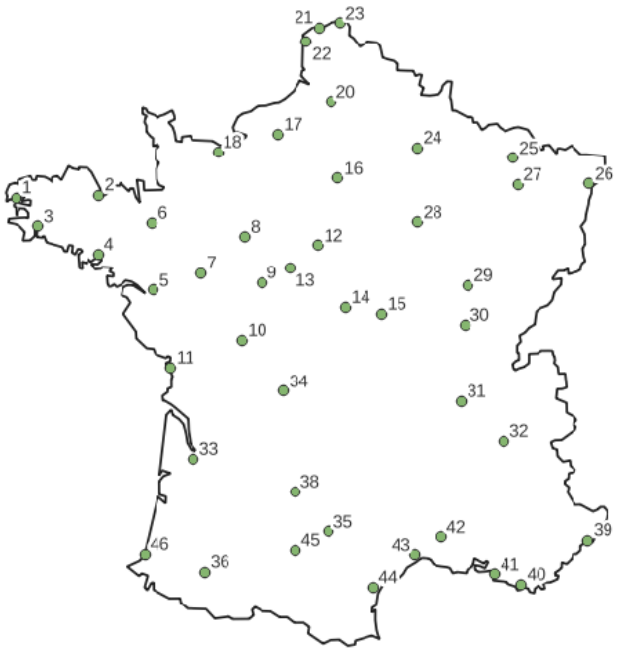


A reference points file

2.3. Backgrounds

The background files correspond to Shapefiles of points, polylines or polygons whose coordinates must be expressed in the same geographic reference as that of the external reference. These background files therefore overlap perfectly with the points of this reference and are mapped in the same coordinate system. They will be interpolated with the same parameters as the grid to provide a better appreciation of the shape difference between a configuration of image points and the configuration of reference

points. It is therefore important that these background files correspond to the overall extent of the reference points. It is possible to provide several background files to be interpolated. Multi-part features and surfaces with holes are not accepted, as are M and Z values. The processing speed of the MapMorphy Interpolation menu depends on the complexity and number of features constituting the background files.



A background for reference points

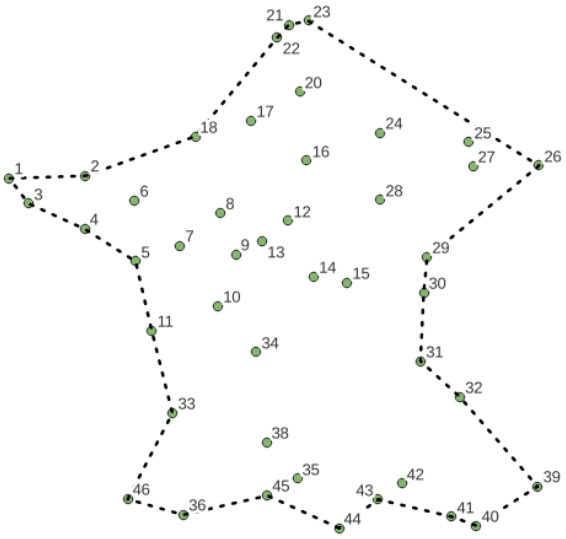
2.4. Links

For consensus-adjusted Type 2 projects, no background is available since the reference is calculated from an average of the adjusted image configurations. To allow a better appreciation of the shape deviations from the consensus, it is however possible to use the adjusted image points connected together according to a precise order, what we call here the "links". We proceed as follows from a single image:

1. The user adds a particular image configuration to a GIS project (by clearly identifying its image code because it will be requested when loading the data).
2. The user then creates a polyline Shapefile in the GIS project which will be associated with this image.
3. The user vectorizes the polylines to be connected in this Shapefile, taking care to capture the points of the polyline by the points of the image configuration.

From the same image configuration, it is possible to create several link Shapefiles.

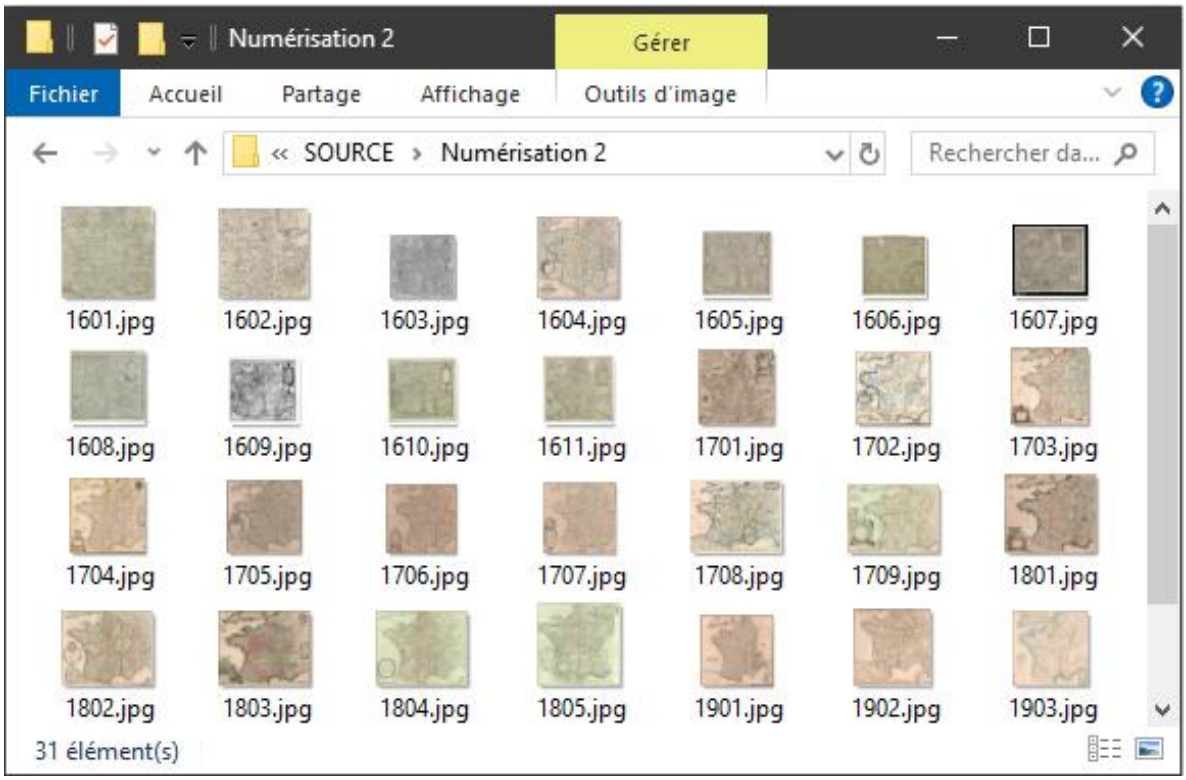
When processing the data, files in Text format will be created in the project folder with the name Link0, Link1, etc. These are files indicating to MapMorphy the sequences of points to connect for the display of each configuration.



Link file created in a GIS from one of the images

2.5. Scans

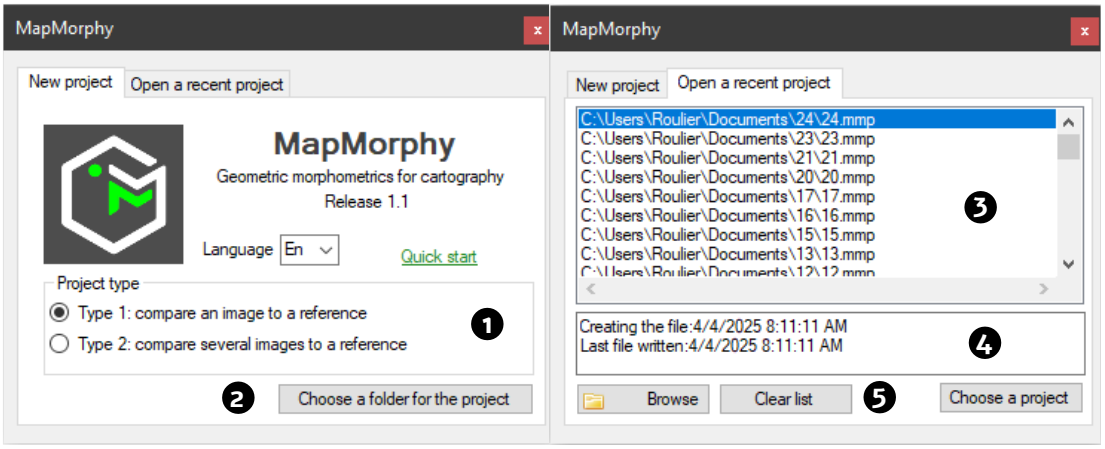
Optionally, it is possible to add to the folder of a type 2 project, a folder of scanned files in *.png or *.jpeg format (non-progressive). These scan files correspond to the source documents for creating image configurations. They can be displayed in the MapMorphy identification window. To speed up display, it is recommended not to exceed 500 KB for these files. The files must necessarily have the corresponding image code as their name.



Contents of an imported scans folder in the MapMorphy project

3. Starting the application

The start window allows you to choose between creating a new project or opening an existing project. Any MapMorphy project starts by creating the project folder. All data will be automatically imported and saved in this folder. A project file (*.mmp) is saved at the end of data processing. It allows you to reload the results without restarting the calculations.



The MapMorphy startup window

1. The *New project* tab allows you to choose the user interface language (French or English), quick start documentation and create a project of your choice, type 1 or 2.
2. Choose the folder for the future project. This must be empty and can be created directly from MapMorphy in the dialog box opened by clicking on the button.
3. The *Open a recent Project* tab shows the path of the last 50 saved projects in the user interface language. A " ? " indicates that the project is no longer accessible (because deleted or moved). Double click on a project line or click on the *Choose a project* button to open the selected project.
4. Information about the project selected in the list.
5. Browse the computer tree to select an older project. It is possible at this stage to empty the list.

Type 1 projects create the following folders in the project folder upon startup:

- Interpolated data
- Grids
- Background
- Images
- Adjusted images
- References
- Displacement vectors

Type 2 projects add the following folders to the project folder:

- PCA
- Axes
- Border

PCA Background

PCA links

PCA test

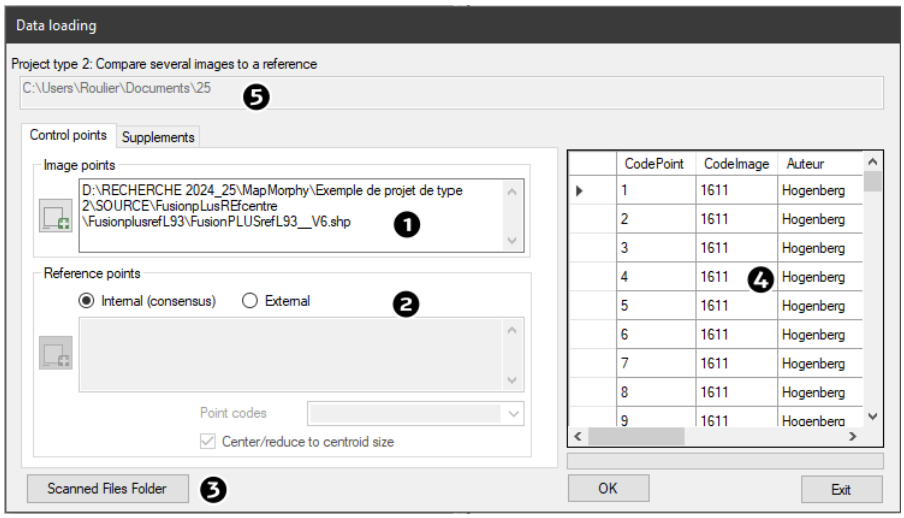
Scans

Depending on the options, not all of these folders are necessarily used. A folder can contain several Shapefiles (*Grids* or *PCA* folder for example). Additional files in Text format such as the results of the adjustment, those of the PCA, the description of the links are placed in the project folder. The *mmp project file is saved in relative paths in the project folder at the end of processing. The project folder can thus be moved to another address and opened on another computer with MapMorphy.
It is strongly recommended not to delete or modify the data produced by MapMorphy and saved in the project folder. However, it is possible to add other files such as a GIS project file using the data in the folder.

4. Loading data

The loading window launches immediately after choosing the project folder. It adapts its interface to the type of project chosen, type 1 or type 2.
The *Control points* tab allows you to choose the image and reference point files necessary for the adjustment step.
The *Supplements* tab allows you to choose additional background or link elements.

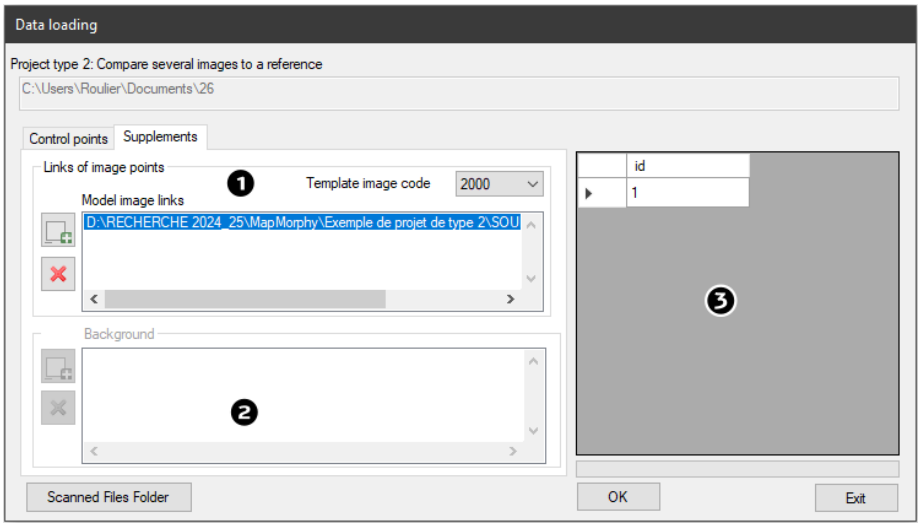
The *Control points* tab:



The Control points tab of the loading window (type 2 project)

1. Choose the image data Shapefile (a file containing a single image for a type 1 project or several images for a type 2 project).
2. Choose the reference type. For a type 1 project, this is an external file. A type 2 project allows you to choose the consensus calculated automatically from image points or an external file. Consensus is the default choice. If applicable, indicate the field containing the point codes of the external file. Coordinates in the external file can be zero-centered and scaled to unit centroid size, allowing them to be projected onto the tangent space and to visualize models from the PCA.
3. For type 2 projects, it is possible to import into the project folder, a folder containing the different scans corresponding to the image codes and visible in the identification window.
4. Clicking in the file paths brings up their attribute table.
5. Project path.

The *Supplements* tab:



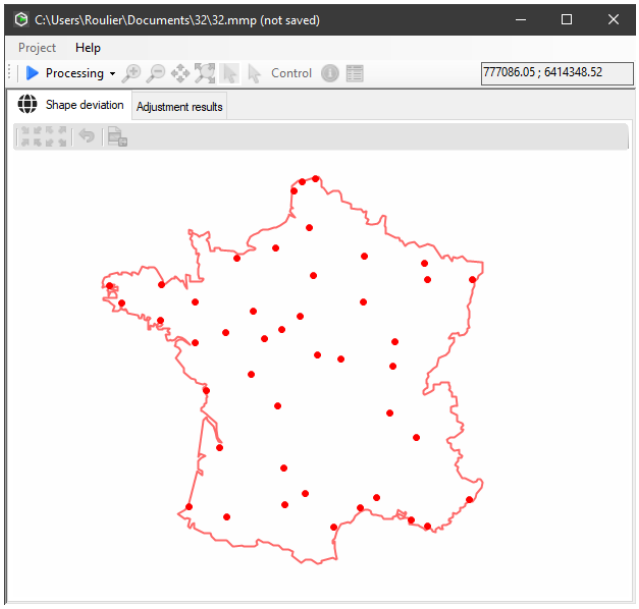
The Supplements tab of the Data loading window (type 2 project)

The *Supplements* tab allows you to provide illustrations to better appreciate shape differences by adding a graphic context to the grid. An alert message is displayed if no data of this type is entered in this tab. Only the distorted grid will then be displayed.

1. If the consensus has been chosen as a reference in type 2 project, it is possible to choose one or more link files between adjusted points. It is then necessary to indicate in the list to which image code these link(s) refer. No background is then available.
2. If an external file has been chosen as a reference (project type 1 or 2), it is possible to choose one or more background files coded in the same coordinate system as the reference points of the external file. No link is available in this case.
3. Consultation of attribute tables. The contents of the table appear when clicking on the path of a Shapefile.

5. Data processing in a type 1 project

In a type 1 project comparing only two bidimensional datasets, the interface consists of a single cartographic window. This appears once the data has been loaded. Reference data is displayed in red color.

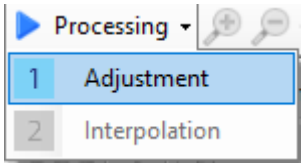


The Shape deviation window before data processing (type 1 project)

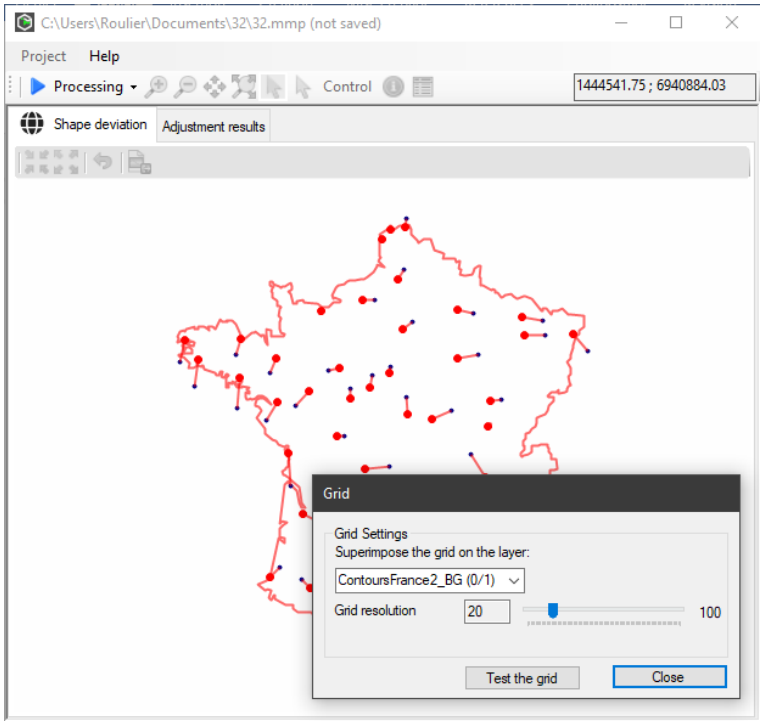
The user must successively launch two operations from the *Processing* menu before being able to explore the cartographic transformation and format it:

1. Adjusting the image points to the reference points (and setting the grid).
2. Interpolation of the grid and backgrounds.

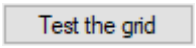
5.1. Adjustment

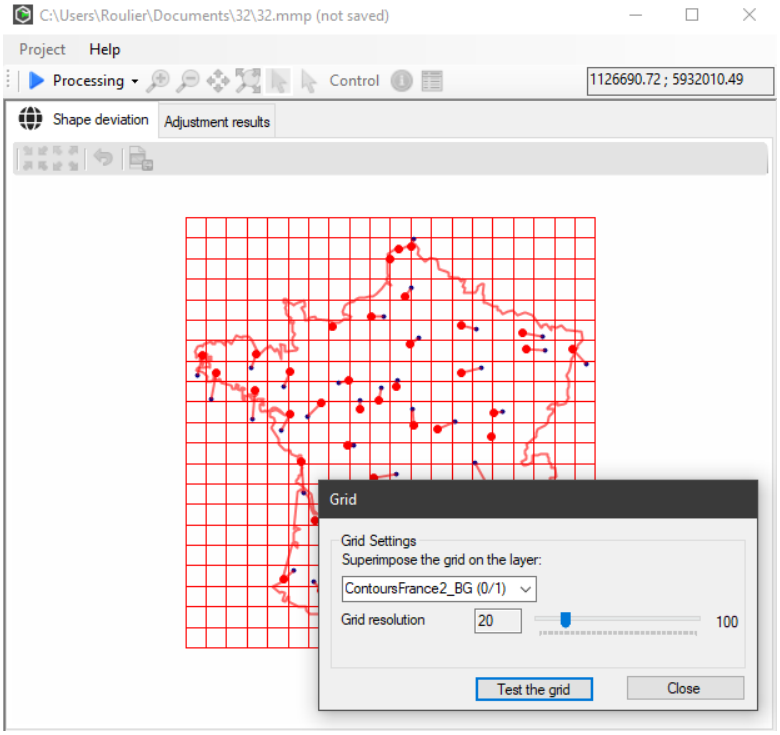


After launching the *Adjustment* menu, MapMorphy adds the adjusted points in blue color and the displacement vectors in red color to the map in the Shape deviation tab. The grid settings then appear in a dialog box. They allow you to choose the reference layer for the extent of the grid (by default the largest extent) as well as its resolution corresponding to the average number of rows and columns. A value of 20 in resolution is chosen by default because it corresponds to the good compromise between the precision of the graphic representation and the calculation time.



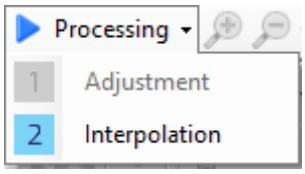
Step 1: Adjustment…

Click on  to display a grid.

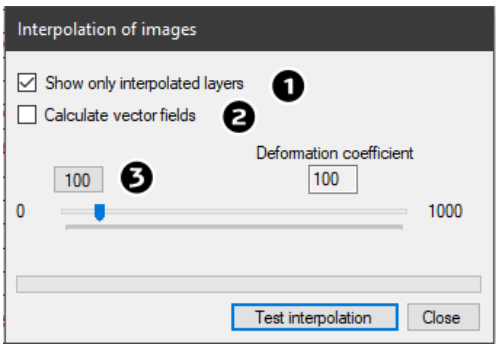


... then creating the grid

5.2. Interpolation



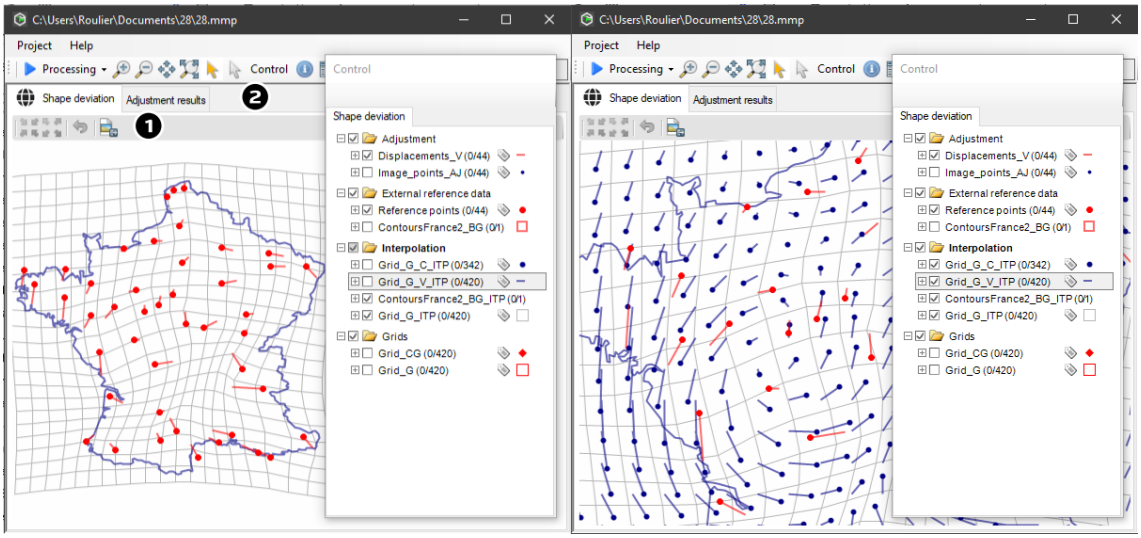
The second processing results in a deformation of the background layers and the grid according to the calculated differences between the reference points and the adjusted points.



Step 2: Interpolation

1. Indicate whether the software displays all the layers in the *Shape deviation* tab after the interpolation calculation. Layers not displayed will, however, be available through the *Control* window.
2. Indicate whether the software should calculate the vector field. In this case the interpolation is applied to the centroids of the grid cells, which slows down the processing proportionally to the resolution of the grid. The corresponding displacement vectors are also calculated and saved in the project file. A stress index centered on the value of 1 is then calculated by the finite element method for each centroid. This index expresses the compression and expansion forces at each of the nodes of the grid.
3. Test the deformation level. A value greater than 100 amplifies the deformation, while a value lower than 100 reduces it. This setting allows you to better visually appreciate small variations or reduce large variations. However, changing this setting only affects the data display and not the stress

calculations and subsequent PCA calculations that use the value of 100. The following window then appears:



The Shape deviation tab and its vector field after adjustment

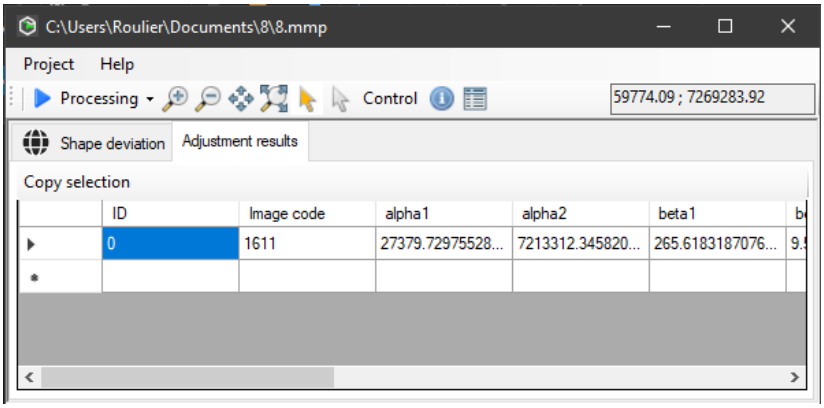
1. MapMorphy then adds to the *Shape deviation* tab the grid and the background(s) deformed according to the differences observed between the points of the reference configuration and their counterparts in the adjusted image configuration (and optionally of the vector field).

Tools acting on the visualization of this window are available  : Constant zoom in/out, previous view, export of the map window in pixel format (*.jpeg, *.gif, *.png, *.tiff, *.bmp). It is possible to add a title to the upper part of the image when saving it.

2. The *Adjustment Results* tab presents the main calculations of the bidimensional regression on a row of data.

- ID: image identification code automatically assigned by MapMorphy
- Image Code: Image code assigned by the user in the original file.
- alpha1: alpha parameter of the transformation
- alpha2: alpha parameter of the transformation
- beta1: beta parameter of the transformation
- beta2: beta parameter of the transformation
- scale: Transformation scale
- theta: angle of transformation
- deltax: displacement on the x axis
- deltay: displacement on the y axis
- rsquare: index indicating the quality of the fit. The maximum value of rsquare is 1. The closer rsquare is to 1, the better the fit. Two sets of identical points produce a rsquare index equal to 1.
- DI: distortion index. Complementary value of rsquare. The higher the value, the greater the difference. Two similar shapes have a DI index equal to 0.
- RMSE: average value of deviations after adjustment expressed in the unit of the reference map.

These results are automatically saved in the project folder in a Text file. A selection can be copied from the *Adjustment results* tab. Shapefile layers can be loaded into a GIS to be formatted and presented in a layout.

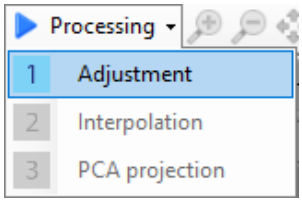


Cartographic transformation parameters

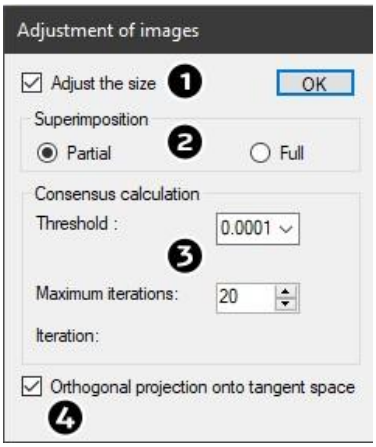
6. Data processing in a type 2 project

The example presented shows the compared shapes of 31 maps of France produced between the 16th century and the 20th century. The implementation of the first two stages of data processing (adjustment and interpolation) is very close to that of a type 1 project. Consensus is chosen as a reference in this example.

6.1. Adjustment



The *Adjustment* menu will calculate the adjustment of all images to the reference as well as all the displacement vectors. Several adjustment options are available here:

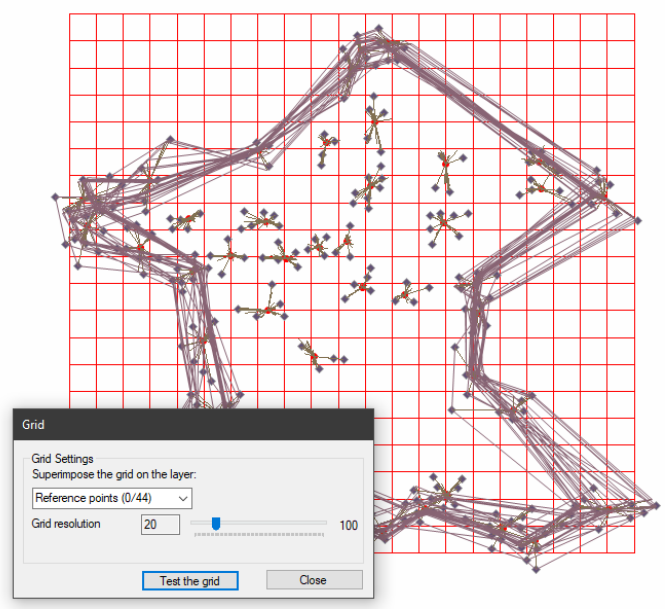


1. Adjust the size: taking size into account in the adjustment (default option). If this box is unchecked, the adjustment does not modify the scale of the objects but only their position and orientation. The PCA will then integrate the size into its analysis and correspond to a form space instead of a shape space.
2. Type of adjustment. Partial adjustment initializes processing by applying the three superimposition operations (translation, scaling, and rotation) on a single image. The iterative process then applies only one rotation to calculate the adjusted images and consensus. Full adjustment applies all three superimposition operations in its iterative process to calculate the adjusted images and consensus.
3. At this stage, it is possible to set the number of iterations and the stopping threshold for the search for consensus.

4. Orthogonal projection: projection of the fitted coordinates onto a linear multidimensional space (default option).

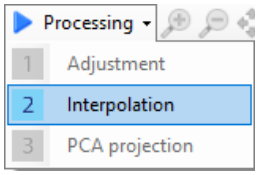
Depending on the case, not all of these options are available.

MapMorphy then offers the same options for creating the grid as for a type 1 project.

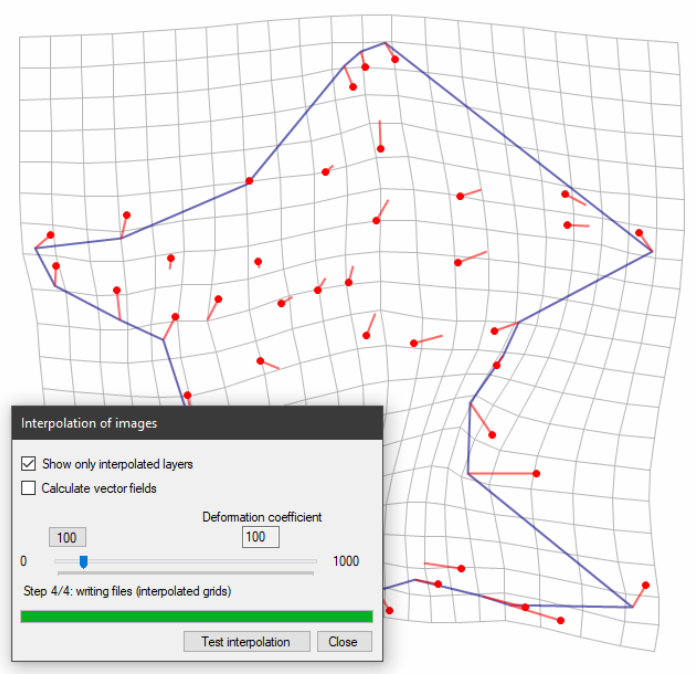


The grid in the Shape deviation window for a Type 2 project

6.2. Interpolation

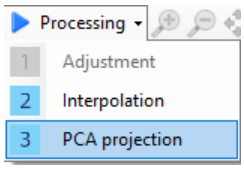


The implementation of the interpolation is strictly identical to that of a type 1 project. All the image maps are then interpolated with the reference map (consensus or external).

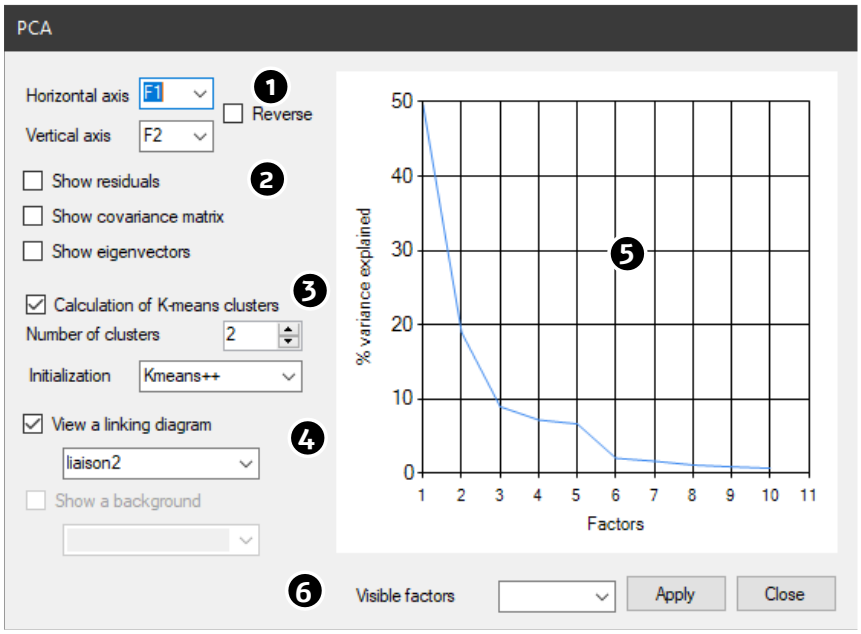


Calculation of interpolated data for a type 2 project

6.3. Mapping of morphospace



PCA is the central data processing in MapMorphy because it places each map in a morphological space and produces new variables through the scores of these maps on the axes.

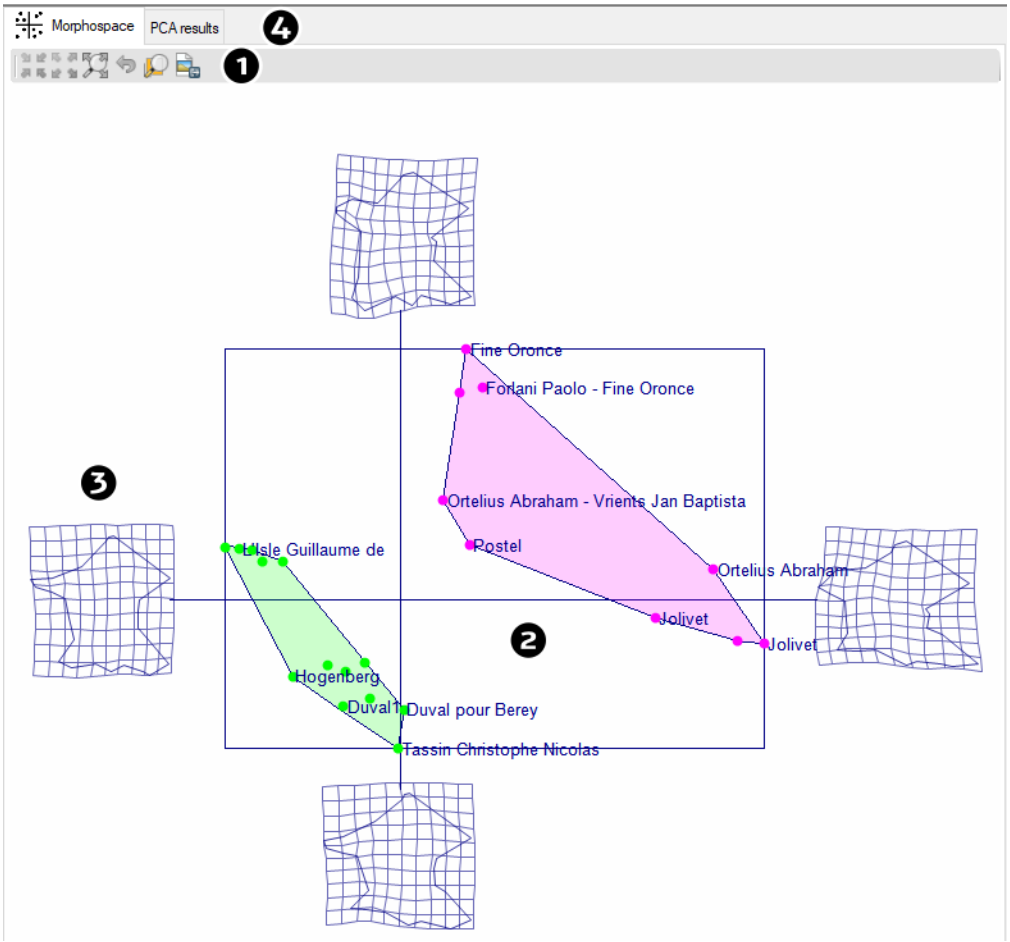


The ACP window for building the morphospace

1. Choose the factors associated with the two axes of the PCA graph. It is possible to reverse the sign of the eigenvectors at this stage, which modifies the presentation but does not change the interpretation of the graph.
2. Indicate whether you wish to display in the PCA results tab, the residuals, the covariance matrix and the eigenvectors.
3. Indicate whether you wish to calculate clusters by K-means; if necessary, choose the number of clusters and the initialization method (by default the Kmeans++ method).
4. When several linkage or background files have been loaded, indicate which one will be used for display on the four standard models of the morphological space map.
5. Presentation of the percentage of variance explained by the factors.
6. Number of factors displayed for the presentation of the percentages of explained variance (by default the first 10 are displayed).

The adjustment results of the *Shape deviation* tab, present one line of data per image using the parameters of the type 1 project. When the reference is the consensus, these data correspond to the different stages of the recursive adjustment of the different images to this consensus. The results of each iteration are presented (usually three or four iterations are enough to calculate a consensus).

MapMorphy now adds a PCA window to the Shape deviation window. It consists of the *Morphospace* tab and the *PCA results* tab:



Calculation of the PCA and visualization of the morphospace

1. The *Morphospace* tab displays the individual PCA results calculated with the chosen parameters. The PCA graph can be considered as a continuous space and explored as such with the navigation tools offered. At each point in this space there corresponds a shape (or a form) difference with the reference configuration (external file or consensus) located at the origin of the PCA graph. This shape difference is calculated by the PCA model and can be displayed in the *Model* window.
2. Each of the plots displayed in the PCA graph corresponds to a specific configuration of the image file. The colors of these points correspond to the clusters associating the configurations by proximity on the 2D graph (by default two clusters are calculated). Convex hulls polygons delimit these clusters.
3. The four grids placed at the ends of the two axes correspond to the four models corresponding to the intersection of the border and the axes.
4. The *PCA results* tab presents the main results of the PCA, namely:

- General parameters (processing date, reference type, adjustment type, number of iterations in case of consensus calculation, size adjustment, orthogonal projection, grid resolution, PCA factors displayed, number of clusters, initialization method, project path, number of points per image, number of images).
- X and Y coordinates of the reference configuration (consensus or external).
- Table of residues (if requested).
- Covariance matrix (if requested).
- Tables of eigenvalues with the percentage of explained variance and the accumulation of these percentages.
- Table of eigenvectors (if requested).
- Table of PCA scores of images.

At this stage, it is possible to restart a new interpolation and/or a new PCA via the *Processing* menu.

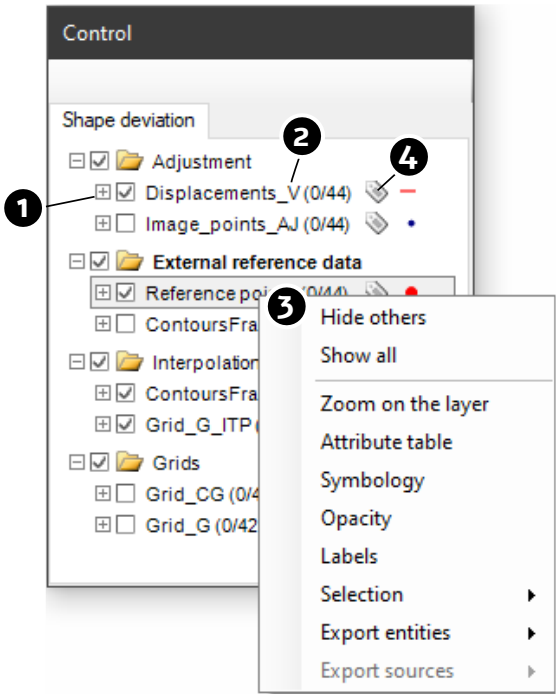
These results are automatically saved in the project folder in a text file. A selection of data from this tab can be copied to a spreadsheet for example.

7. The *Control* window

7.1. Presentation

Control Click the button to show/hide the *Control* window.

This essential window lists and manages the layers of the two map windows. Type 1 projects only display a *Shape deviation* tab. Those of type 2 add a *Morphospace* tab. By clicking in the maps, you automatically switch to the corresponding tab (and vice versa).



The Control window of a type 1 project

1. Click on the ⊞ to view the symbology assigned to the layer and on the check box for showing/hiding the layer. The number of features selected out of the total number of features in the layer is shown in parentheses.
2. Drag the layer vertically to change the display order.
3. Right-click on a layer to display the layer's context menu functions. Double-clicking on a layer opens the symbology window.
4. Click on the thumbnail of a selected layer to display its file address.

7.2. The layers of the *Shape deviation* tab

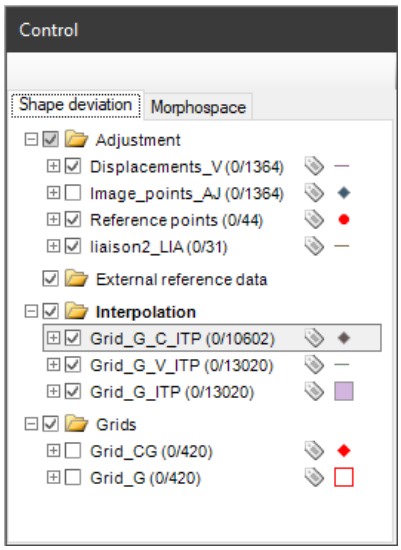
This tab refers to the Shapefiles displayed on the shape deviation map. Depending on the options chosen, we will find:

- Reference_points.shp: the points in the consensus file or the external reference (*References* folder in the project folder).
- Image_points_AJ.shp: the points adjusted by bidimensional regression at the end of the process (*Adjusted Images* folder in the project folder).

- Displacements_V.shp: the displacement vectors of the adjusted points (*Displacement vectors* folder in the project folder).
- ***_BG.shp: The background files. They include the name of the imported files and are all followed by "_BG" (*Background* folder in the project folder).
- ***_LIA.shp: the link files take the name of the imported files and are all followed by "_LIA" (*Links* folder in the project folder).
- Grid_G_C_ITP.shp: the interpolated centroids of the grid for the vector field (*Interpolated data* folder in the project folder).
- Grid_G_V_ITP.shp: the displacement vectors of the centroids of the interpolated grid for the vector field (*Interpolated Data* folder in the project folder).
- ***_BG_ITP.shp: interpolated background files have the name of the imported files and are all followed by "_BG_ITP" (*Interpolated data* folder in the project folder).
- Grid_G.shp: the original grid (*Grids* folder in the project folder).
- Grid_CG.shp: the centroids of the original grid (*Grids* folder in the project folder).
- Grid_G_ITP.shp: the interpolated grids (*Interpolated data* folder in the project folder).

These layers are organized into four folders in the *Control* window:

- Adjustment
- External reference data
- Interpolation
- Grids



The Shape deviation tab of the Control window (Type 2 project)

Unloaded layers in the *Shape deviation* tab:

- Original_images.shp: the image points in their original coordinates (*Images* folder in the project folder).
- Image_points.shp: centered and reduced image points before consensus search (*Images* folder in the project folder).
- Projected_image_points_AJ.shp: the image points adjusted at the end of the adjustment process then projected onto a tangent space (*Adjusted Images* folder in the project folder).

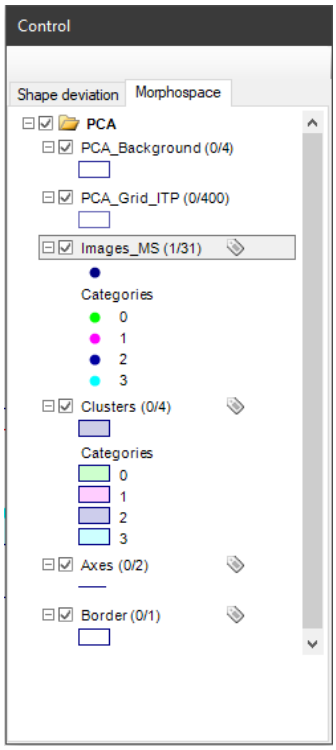
7.3. The layers of the *Morphospace* tab

This tab refers to the Shapefiles displayed on the Morphospace map of a type 2 project. Depending on the options chosen, we will find:

- PCA_links.shp: the links displayed on the four models (*PCA links* folder in the project folder).

- PCA_background.shp: the background displayed on the four models (*PCA background* folder in the project folder).
- PCA_Grid_ITP.shp: the interpolated grids corresponding to the four models appearing on the PCA graph (*Grids* folder in the project folder).
- Images_MS.shp: the different configuration represented by a plot in the morphospace (*PCA* folder in the project folder).
- Clusters.shp: the convex hulls corresponding to the clusters (*PCA* folder in the project folder).
- Axes.shp: the axes of the PCA (*Axes* folder in the project folder).
- Border.shp: the border of the PCA (*Border* folder in the project folder).

All these layers are presented in the *PCA* folder of the *Morphospace* tab.



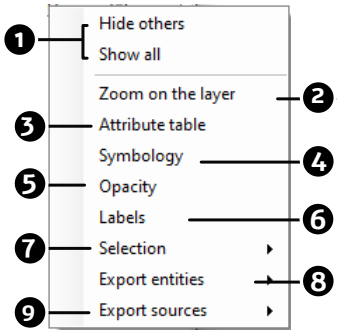
The Morphospace tab (type 2 project)

Unloaded Layers in the *Morphospace* tab:

- PCA_Grid_G.shp: the original grids of the four models (*Grids* folder in the project folder).
- Regression test for PCA (*PCA test* folder in the project folder).

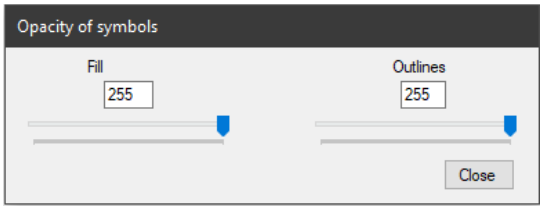
7.4. The context menu of the *Control* window

Right click on a layer in the *Control* window:

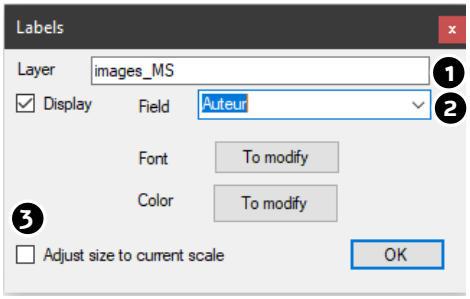


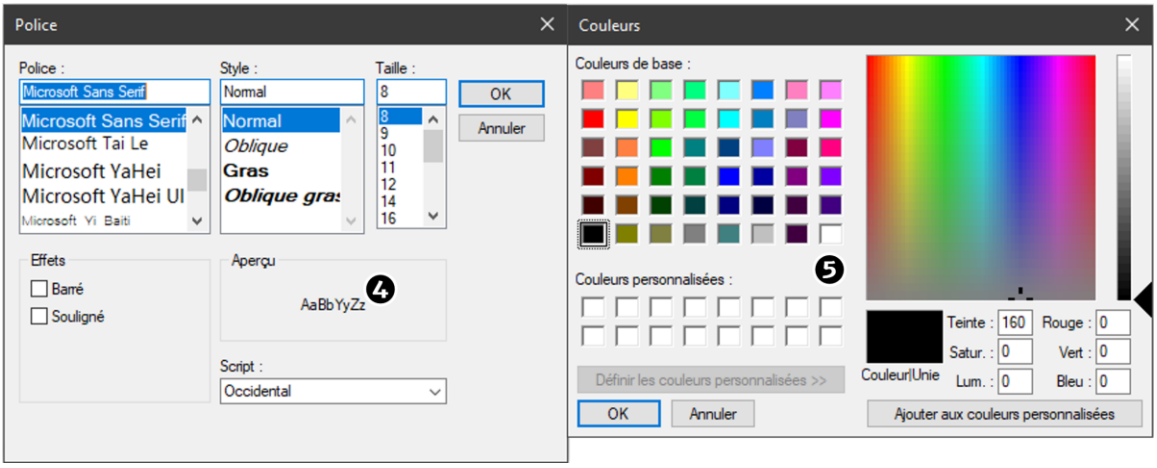
1. Show only the selected layer or show all layers.

2. Zoom on the extent of the layer.
3. Opening the attribute table.
4. Opening the layer symbology.
5. Adjusting the opacity of the selected layer.



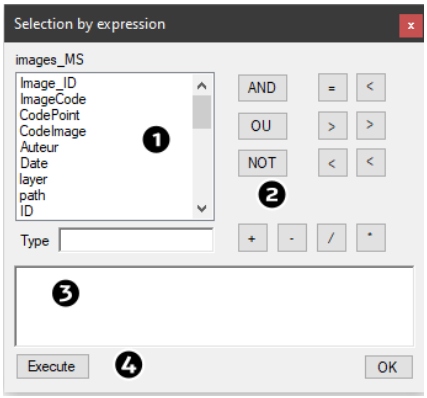
6. Label settings.





1. Labeled layer.
2. Choose the field to display.
3. Adjust to current scale. The option varies the size of the label depending on the viewing scale.
4. Setting the label font.
5. Setting the color of label text.

7. Selection of layer features: All, Undo, Invert, Selection by expression:



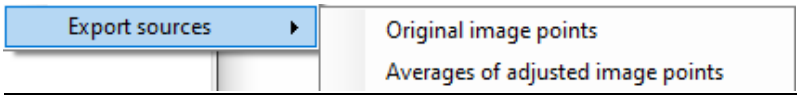
Selection by expression. The function automatically opens the attribute table of the layer concerned.

1. Double click to select the field (the type of field used is indicated).
2. Use a comparison, logical or mathematic operator to complete the expression. These operators can be used on numeric values or string values.
3. The search expression fits here. Character strings included in the expression must be enclosed in double quotes.
4. Run expression (replaces previous selection).

8. Export entities.

This menu exports all the features in the layer or only the selected features in Shapefile format.

9. Export sources. This menu is only available for features in the *Images_MS* layer, i.e. the maps or spatial structures represented on the PCA graph. It is possible to export the configurations of the original points corresponding to the selected features in the Morphospace map. It is also possible to export the average of the adjusted points corresponding to the selected features in the Morphospace map. This average can then be used in a type 1 project, once compared with a reference layer.



8. Exploration tools

8.1. Selection/deselection of features

 The selection is mainly used to designate the plot of the Images_MS layer.

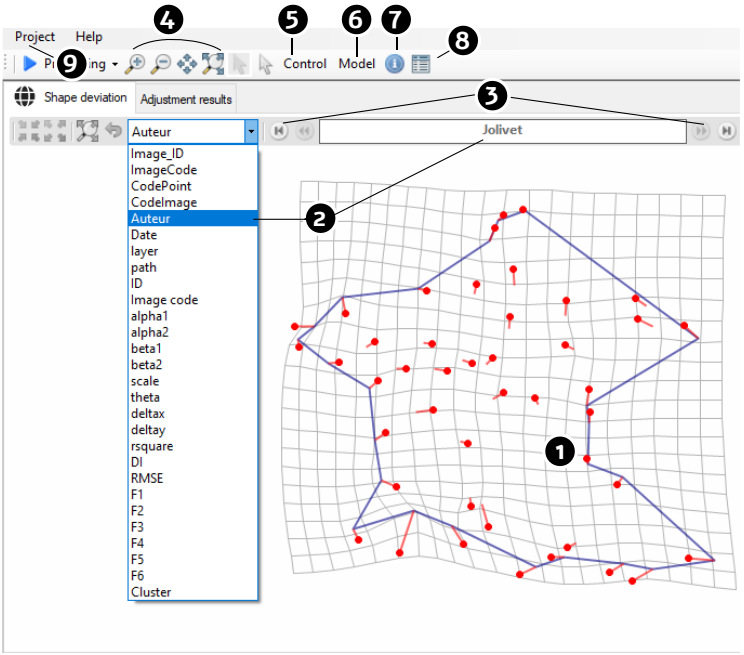
- To make a selection in the *Shape deviation* and *Morphospace* maps, first select in the *Control* window the layer in which you wish to make the selection. In a type 2 project, only a selection in the Morphospace map is possible. The selection in the maps uses the Selection tool and is carried out by click(s) and/or by selection zone(s) (click-drag) in the Shape deviation map or in the Morphospace map. A red preselection frame designates objects under the pointer for easy selection. A red selection cross indicates the current selection in the relevant window. The *Shift* key allows you to accumulate selections and deselect from an existing selection.
- It is also possible to select/deselect in the Attribute table by clicking on the row header and using the *Ctrl* and *Shift* keys.
- Selection is also possible in the *Identification* dialog box.
- A feature selected in the *Morphospace* map can visualize its shape model in the *Model* dialog.

The selections of these four environments are interdependent.

 Deselection of selected entities**.**

8.2. The *Shape deviation* map

The *Shape deviation* map shows the total shape difference between a map and the reference (project type 1) or that of one of the maps selected in the *Morphospace* map (*Images_MS* layer) with the reference (project type 2).



The Shape deviation map (type 2 project)

1. The *Shape deviation* map displays the superposition of the visible layers listed and managed by the *Shape deviation* tab of the Control window (display, order, formatting, etc.).

 The navigation tools specific to the map window are identical in type 1 and type 2 projects.

2. It is possible to choose a field from the *Images_MS* layer to display the value of the selected map above its shape (type 2 project).

3. Navigation buttons (previous, next, first and last of the selection) among the maps selected in the *Morphospace* window. The choice is displayed in the Shape deviation window, the *Morphospace* window, the Identification dialog, that of the attribute table and that of the model.

4.  Zoom and move. These tools can be used on both map windows.

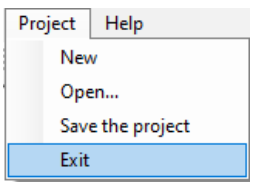
5. Control Opens the layers *Control* window. This window allows you to manage the different layers displayed. Click the button to show/hide the Control window.

6. Model Opens the *Model* dialog. This dialog box shows the shape deviation calculated according to the modeling obtained from the factors chosen for the PCA. Click the button to show/hide the *Model* dialog.

7.  Opens the *Identification* dialog. This dialog box allows you to consult the attributes of the selected entities on an information sheet. This window requires a first preselection to be activated.

8.  Opens the Attribute table of the selected layer in the *Control* window. This dialog box allows you to consult the attributes of the entities of the selected layer on a tabular view.

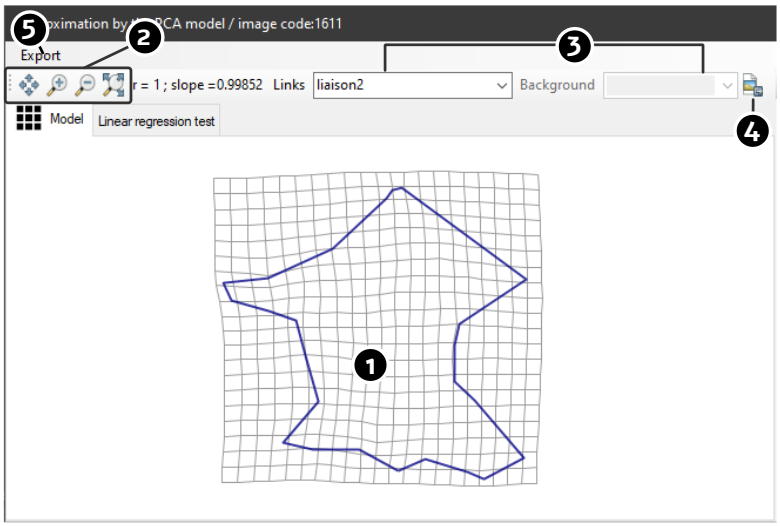
9. Project Project menu. This menu allows you to create and open a new project, resave the project in the project folder under the name project.mmp and exit MapMorphy.



8.3. The *Approximation by the PCA model* window

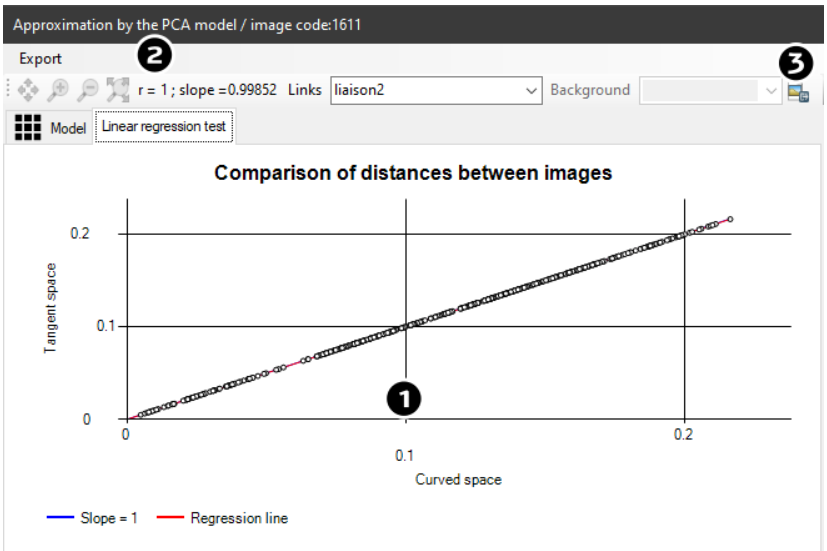
Model

The *Model* tab of this dialog box presents the model calculated from the PCA results, the coordinates of the point clicked in the Morphospace window and those of the reference configuration (consensus or external reference). A model can be calculated for any point in morphospace. To do this, simply click with the *Selection* tool in the *Morphospace* tab. This model only considers the two factors chosen in the PCA dialog. This is therefore a partial view of the shape deviation from the reference. This model can be compared to the full representation of the deviation from the reference in the *Shape deviation* window.



The Model tab

1. Display of the model calculated from the PCA.
2. Navigation tools (moves, zooms).
3. Choice of link or background to display, as appropriate. Only one link or background is available for display in the model. The symbology of these elements follows that of the *Shape deviation* window; However, you must select the link or background again to update the formatting if it has been modified in the *Shape deviation* window.
4. Export of the model in Bitmap format (*.png, *.jpeg, GIF, tiff, *.bmp formats).
5. The *Export* menu allows you to save in Shapefile format, the grid, link and background of the displayed model.



The Linear regression Test tab

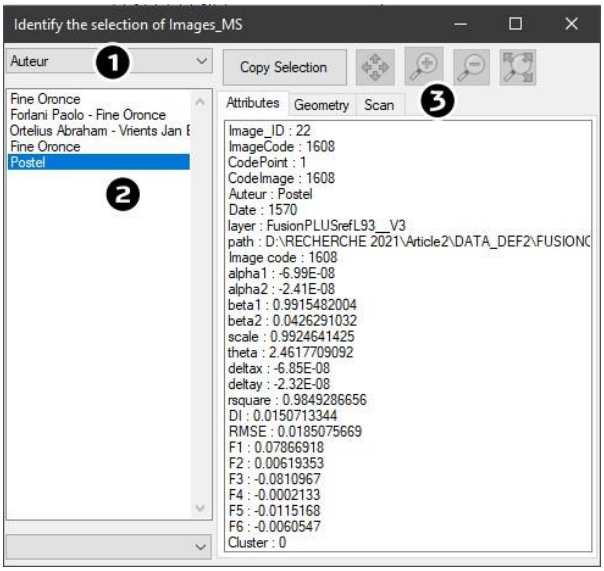
The *Linear regression test* tab of the *Approximation by the PCA model* dialog allows you to compare the distances between each pair of points of the configurations in the curved shape space (which is displayed in the Shape deviation map) and in the tangent space, used for PCA modeling. A good correspondence between these two types of distance results in a model faithful to the fit in curved space and a good alignment between pairs of points on the regression line, as is the case in the example.

1. The linear regression graph. The ideal slope of 1 line in blue color and the regression line in red color are shown. Ideally, the red line hides the blue line.
2. The adjustment parameters. A correlation value r and a slope equal to 1 correspond to the ideal situation.
3. Exporting a pixel image of the regression graph.

8.4. The *Identification* dialog box

The *Identification* dialog presents all the attributes of one of the selected features.

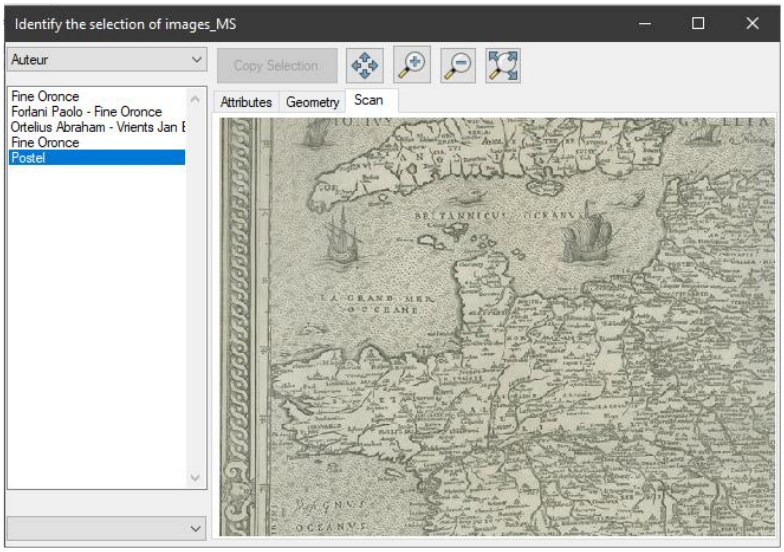
- When the identification dialog box is closed, select a layer in the *Control* window, then one or more entities before launching the identification tool.



The Identification dialog

1. Choose the layer display field. The field values of the selected features then appear below, in the list on the left.
2. Clicking on an entity in the list on the left causes the rest of the entity's attributes to be displayed in the *Attributes* tab and a red targeting cross on the Morphospace map.
3. The *Geometry* tab allows you to visualize the basic geometric parameters of the feature (X and Y coordinates, length and area depending on the Shapefile type). It is possible to select then copy the selected lines in this window.

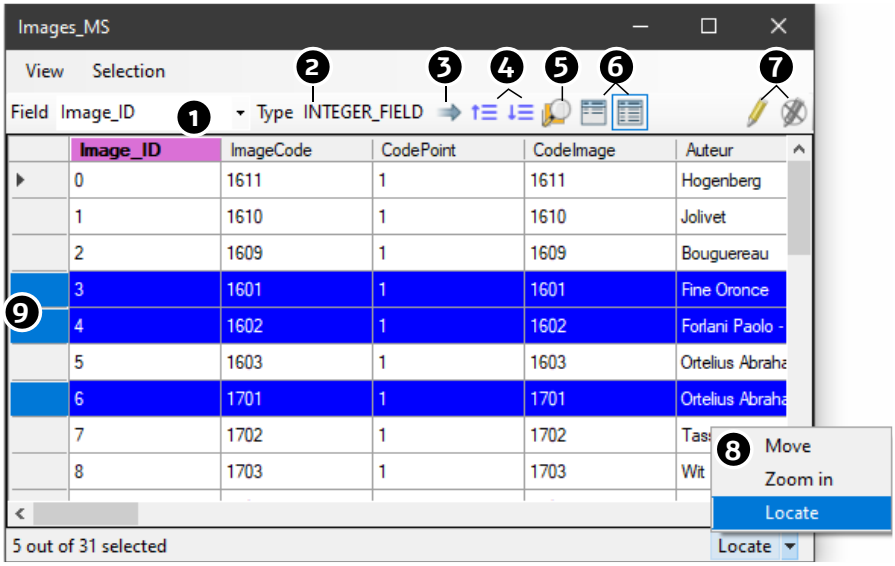
For type 2 projects, if a scan folder has been imported, the scan corresponding to the configuration of the *Images_MS* layer is displayed in the *Scan* tab. Navigation tools are then available to zoom and move within the scan.



The Scan tab (type 2 project)

8.5. The Attribute table

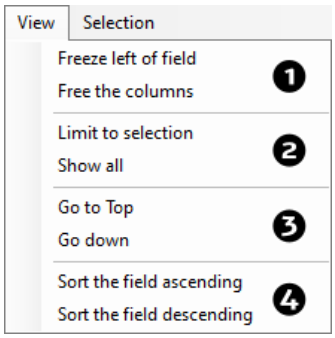
The Attribute table window displays the list of all attributes of all features in the layer selected in the *Control* window.



The Attribute table of a layer

1. Choice of the reference field. This field is used for certain operations in the attribute table (sort, freeze or focus on the field).
2. Indication of the type of the reference field.
3. Move to the reference field (moving the fields laterally).
4. Ascending and descending sorting of the reference field.
5. Zoom in the map on the selection.
6. *Limit to Selection* and *See All* views in the table. In *Limit to selection* mode and by clicking in the row header it is possible to point to the features on the *Morphospace* map.
7. Open and close the edit mode to change and save values in the table.
8. Pointing mode on the map: move, zoom in, locate (usable in *Limit to selection* view mode).
9. Selection in the table by clicking or dragging on the header (*Shift* and *Control* keys allowed). The selection is reflected in the other windows.

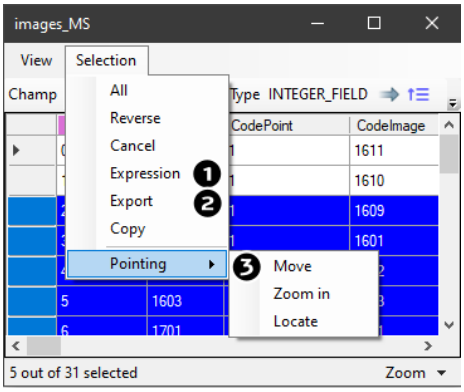
The *View* menu:



The View menu

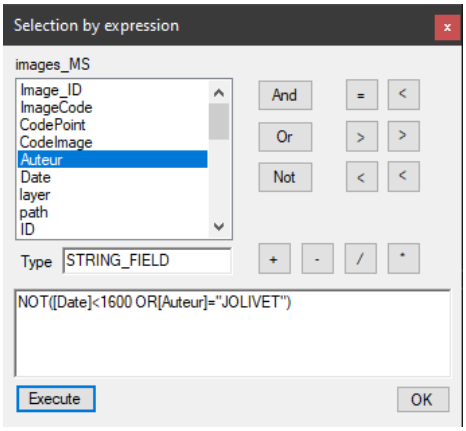
1. When using the horizontal window scrollbar, MapMorphy blocks fields to the left of the reference field or frees (allows scrolling) of these fields.
2. View only selected entities or all entities.
3. Moves the pointer up or down the table.
4. Sorts data by reference field.

The *Selection* menu:



The Selection menu

1. Allows selection automatically using a command:
   - Comparison operators and logical operators can be applied to numeric or string type fields.
   - Character strings must be enclosed in double quotes.



The expression editor

2. Export the table selection to Shapefile format.
3. Pointing mode on the Morphospace map when selecting an entity through the table in *Limit to selection* view mode.

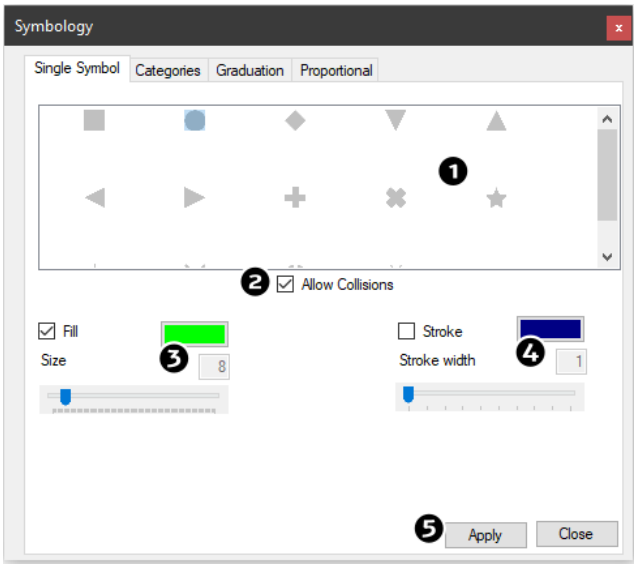
9. Symbology

➢ The symbology windows are opened by double-clicking on a layer or by the layer's context menu. It is mainly useful for a representation of point configurations of the *Morphospace* map.

➢ Symbology is not saved in project files. These save a standardized formatting of data layers.

9.1. Point symbology using a single symbol

The same symbol is applied to all point features.

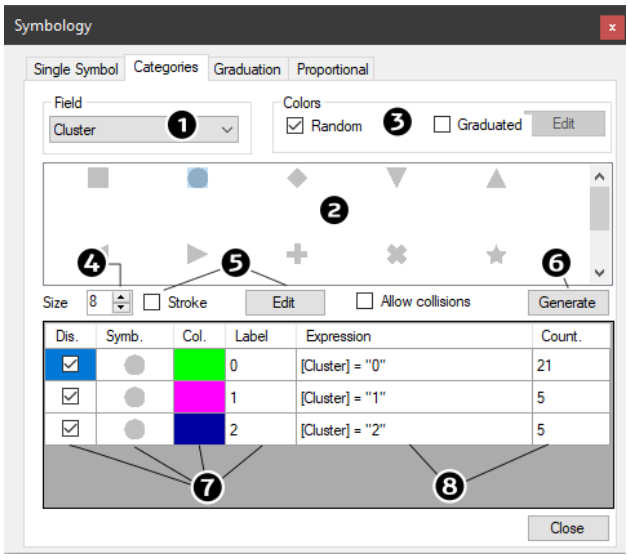


The Single symbol tab

1. Choose the type of symbol.
2. *Allow collisions* allows all features to be shown even if they overlap at the viewing scale.
3. Setting the fill: color and size of the symbol by moving the trackbar cursor.
4. Setting the stroke: color and width of the line by moving the trackbar slider.
5. Apply changes to symbol choice and value entry.

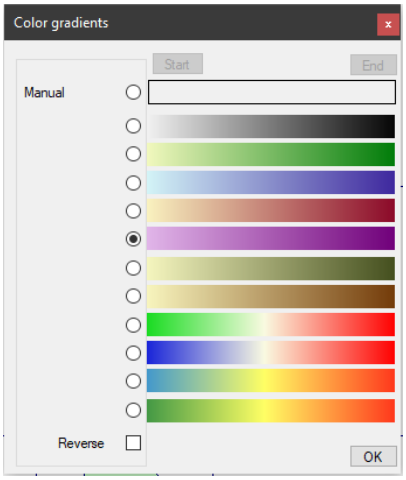
9.2. Point symbology using categories

The *Categories* tab settings create a different marker symbol per category.



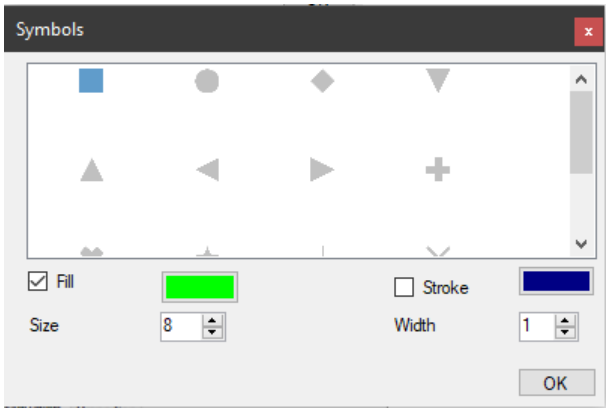
The categories tab

1. Choose the field to map here.
2. Choose the symbol used for all categories.
3. Colors can be random (change with map generation) or graduated. In this second case, an interface is available by clicking on the *Edit* button allowing you to choose or create a gradient.



The Gradients Dialog

4. Symbol size.
5. Display and configuration of contours (width and color).
6. Generate the map.
7. Once the map is generated, it is possible to modify some parameters for each category such as visualization, symbol type or label by clicking in the category parameter. Example for symbols:

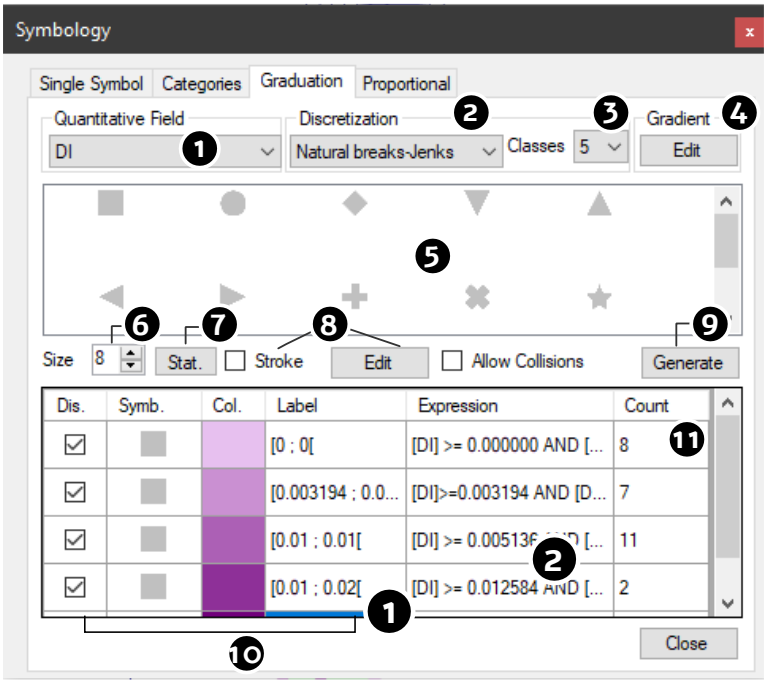


The Symbols Dialog

8. Indication of the expression used and the number of entities concerned by the category.

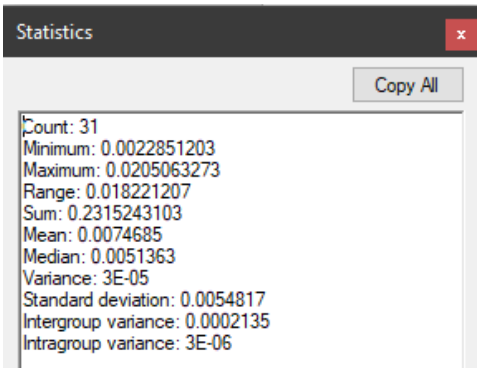
9.3. Point symbology using a graduation

The *Graduation* tab allows you to discretize a quantitative variable and assign a particular color to each class (choropleth mapping). This menu is to be reserved for relative quantitative data.



The "Graduation" tab

1. Choose the field to represent. Only quantitative fields are available.
2. Choose the discretization method. The following methods are available: quantiles, equal amplitudes, centered on mean and 1 standard deviation of amplitude, centered on mean and ½ standard deviation of amplitude, centered on 0 and 1 standard deviation of amplitude, centered on 0 and ½ standard deviation of amplitude, Jenks method, arithmetic progression and manual discretization.
3. Indicate the number of classes (12 at most).
4. Choose or create a color gradient.
5. Choose the symbol colored by the color gradient.
6. Indicate the size of the symbol.
7. Display of the basic statistical indicators of the variable. Copying values is possible using the *Copy all* button.

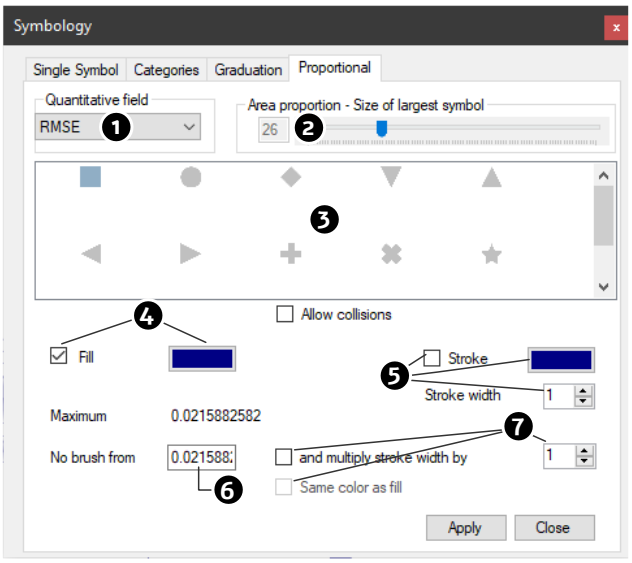


Variable statistics

8. Setting the strokes.
9. Generate the map.
10. After generating the map, certain properties can be modified for each class such as the visualization, color and label of the class (the shape of the symbol can no longer be modified).
11. The counting column allows you to quickly identify empty classes, not represented.

9.4. Point symbology using proportional symbols

The *Proportional* tab varies the area of a point symbol depending on the quantity mapped. This mapping should be reserved for absolute quantitative data.

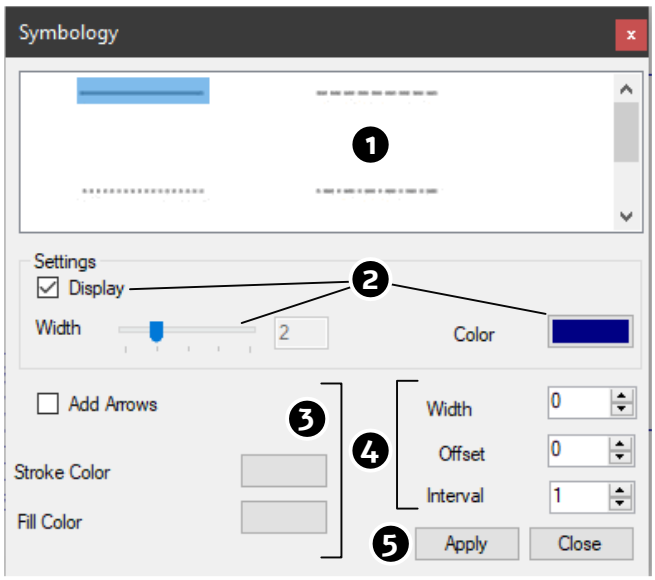


The "Proportion" tab

1. Choose the field to map. Only numeric fields appear in the list.
2. Indicate the largest size of the symbols. The areas of the other symbols will be calculated according to this data.
3. Choose the type of symbol to vary in proportion.
4. Configure the filling (display and color).
5. Configure strokes: display, colors and width.
6. It is possible to hollow out the symbols from the defined value...
7. ...and in this case increase the width of the outline and modify its color.

9.5. Symbology of linear features

Linear features are only represented by a single symbology, with no qualitative or quantitative attribute data attached to them by software processing.



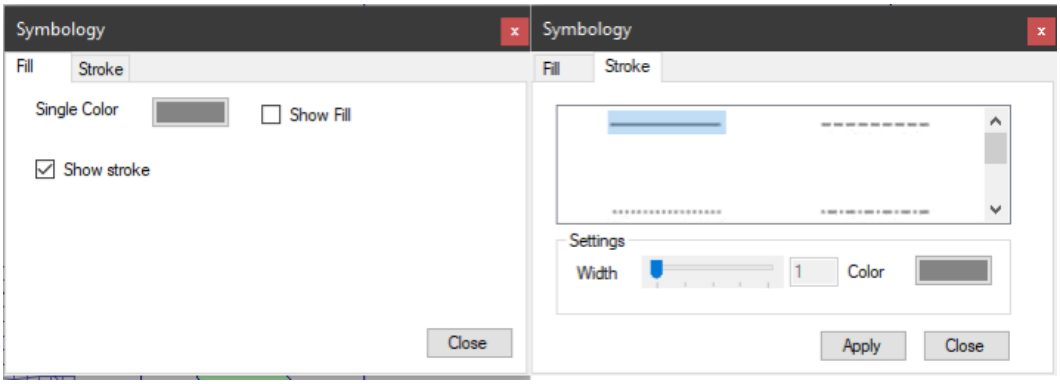
The line symbology window

1. Choose the type of line (solid or dotted).
2. Stroke settings: Display, width and color.
3. It is possible to add colored arrows to the oriented line (for example for displacement vectors).

For these arrows, it is possible to adjust the width, offset and interval between arrows.

9.6. Symbology of area features

Thematic mapping of surfaces only offers mapping by single symbol, no qualitative data being added by the treatments.
Two tabs are available: *Fill* and *Stroke*:



The area symbology dialog