MAGNETIC-A: COMPLETE WEB-BASED TOOLBOX FOR PALEOMAGNETIC ANALYSES

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MAGNETIC-A

This manual introduces the user to the main functionalities of Magnetic-A, describing the calculations and plotting options. Figures are designed to be easily downloaded as vector pdf files and used with minimal manipulation. Help buttons (?) are present in different key locations of the pages: pop-up window will open with useful information and references.

1. Starting with Magnetic-A: Web version and local version

1.1. Web version

Magnetic-A is compiled using the R-Package Shiny, specifically designed to develop web-apps. The web version of Magnetic-A is deployed in the shinyapps server (https://www.shinyapps.io/). To access Magnetic-A, please navigate your browser to either:

- https://edoardodallanave.shinyapps.io/MagneticA/

or alternatively:

- https://edoardodallanave.shinyapps.io/MagneticA2/

1.2. Run Magnetic-A locally

If an extensive use of Magnetic-A is envisaged, it is advantageous to run Magnetic-A locally (faster bootstrap, no risk of losing connection). To do so, download and install both R and RStudio:

- R = https://www.r-project.org/
- RStudio = https://www.rstudio.com/products/rstudio/download/

Magnetic-A requires a series of packages that need to be installed only once. Most of the packages are stored in the CRAN, which makes it easy to proceed. Type the following commands in the RStudio console and press return after each:

- install.packages("plyr")
- install.packages("dplyr")
- install.packages("shiny")
- install.packages("shinyWidgets")
- install.packages("DT")
- install.packages("shinyhelper")
- install.packages("glue")
- install.packages("tidyverse")

The last (but essential!) package is called PmagDiR (Dallanave, 2024) and it is stored in GitHub. The easiest way to install it is to use a package called "devtools". Type the following commands:

- install.packages("devtools")
- library(devtools)
- install_github("edoardo-paleomag/PmagDiR")

Once all of these is done, you can run Magnetic-A locally by typing:

- shiny::runGitHub("Magnetic-A", "edoardo-paleomag")

Alternativley, you can run Magnetic-A offline after pulling the GitHub content in a folder of your local device and type:
:

- shiny::runApp("/Path_to_the _folder/Name_of_the_folder/")

The instructions are also available in https://github.com/edoardo-paleomag/Magnetic-A/blob/main/README.md.

2. Directions analysis

2.1. Vector end-points interpolation

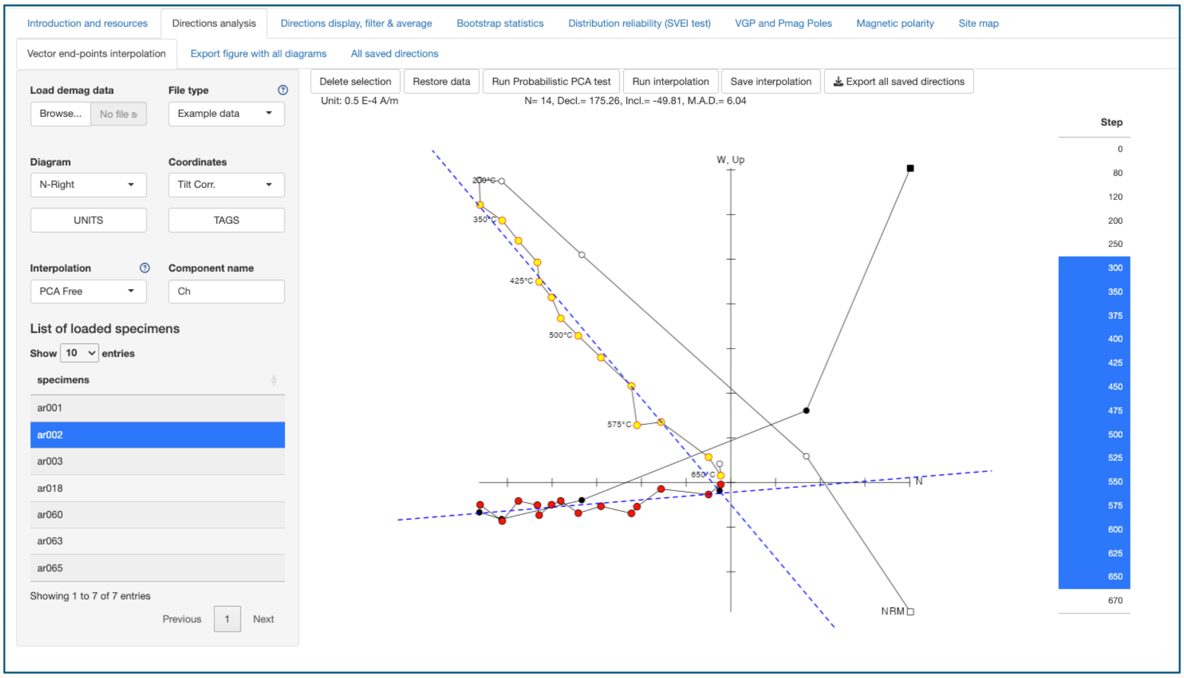

Figure 1.1. Vector end-points interpolation main window.

This page is designed to isolate paleomagnetic components of the NRM. VEPs can be selected by either dragging the mouse onto the diagram, or by selecting the demagnetization steps on the right-hand side of the screen. If you want to preserve the selection also after shifting to a different coordinate system or projection, then you are recommended to select the points by clicking on the list (dragged selection is otherwise lost). Selected VEPs are highlighted by different color: projection of VEPs onto the horizontal plane change from black to red, while projection onto the vertical plane change from white to yellow. The same applies for the equal area projection, but in this case black and white symbols correspond respectively to projection onto the lower and upper hemisphere of the diagram.

To operate the software:

Load demag data: click on it to upload the demagnetization data file from your device.

File type: different data formats are accepted. Please refer to the Appendix 1 of this manual to check examples of data files. The file format currently accepted are also described in the help pup-up window shown by clicking on the help button. By selecting "Example data" at the bottom of the list, some real examples of VEPs data from Dallanave et al. (2012) are available to familiarize with the functions. The list can be updated with new formats upon request.

Diagram: select the preferred projection between N-Right (north axis point to the right of the screen), N-Up (north axis points up), and equal area diagram.

Coordinates: select the preferred VEPs projection coordinates between Specimen (data are plotted in the sample coordinate system), Geographic (data are plotted with respect to the geographic reference system), and Tilt Corrected (Tilt Corr. – Data are plotted restoring the original horizontality of the strata). The data in the three different projections are taken from the demagnetization file uploaded, so pay attention to the file format (Appendix 1) to avoid any problem.

UNITS: this button opens a pop-up window where the user can define the demagnetization unit, NRM unit, volume and mass of the specimens if normalization is required. For some formats (e.g. LASA), the window is pre-compiled, but all values can be changed.

TAGS: this button opens a pop-up window with the labels spacing and position. It is advised to set all parameters as desired before exporting the figure (sub-page 1.3, see below) for publication purposes.

Interpolation: The selected VEPs can be interpolated using different methods. These are:

- PCA Free: PCA free from origin of the demagnetization axes.
- PCA Anch.: PCA anchored (*sensu* Kirschvink, 1980).
- PCA Or. Incl.: the origin of the demagnetization axes is included as VEP.
- PPCA Constr.: PCA constrained (sensu Heslop & Roberts, 2016).
- Fisher: VEPs are averaged by using standard spherical statistics (Fisher, 1953).
- G. Circle: VEPs are interpolated by a plane (Kirschvink, 1980) expressed as pole (*i.e.*, declination and inclination of the line perpendicular to the plane).

<u>*Component name*</u>: The name associated to each component saved (multiple NRM components can be saved during the same session!).

<u>*List of loaded specimens*</u>: interactive list of the specimens loaded; by selecting a specimen, all operation options are activated.

<u>*Delete selection*</u>: The selected VEPs will be removed from the figure.

<u>*Restore data*</u>: All VEPs will be restored and the current interpolation cancelled (this does not affect interpolation already saved).

<u>*Run Probabilistic PCA test*</u>: this button performs the Bayesian model selection introduced by Heslop & Roberts (2016) which provide the probability that the selected VEPs support the use of an anchored, unanchored, or constrained PCA solution. Please cite the original Heslop & Roberts (2016) paper if using this method (recommended).

<u>**READ CARFULLY:**</u> Generally speaking, the use of PCA anchored is generally **WARMLY DISCOURAGED** (unless justified by the probabilistic PCA test) as it results in **ARTIFICIALLY LOW MAD**! VEPs failing to trend linearly toward the origin of the demagnetization axes should be interpolated with Fisher (1953) mean.

<u>*Run interpolation*</u>: performs the VEPs interpolation. The interpolation line is plotted on the diagram as blue dotted line.

<u>*Save interpolation*</u>: save the interpolated components in the list of directions (interactive list in "All saved samples" page).

<u>*Export all saved directions*</u>: export all saved directions in your local device.

<u>**READ CARFULLY:**</u> Magnetic-A DOES NOT SAVE AUTOMATICALLY the interpolated directions in your personal device. It is WARMLY RECOMMENDED to download regularly the saved directions to avoid annoying loss of data.

2.2. Export figure with all diagrams

In this page a figure with all diagrams, units, and the interpolated component (if present) is shown. By clicking on <u>*Export figure*</u> the figure is downloaded as editable vector file (pdf) (Figure 1.3). The name of the exported file is the name of the selected sample.

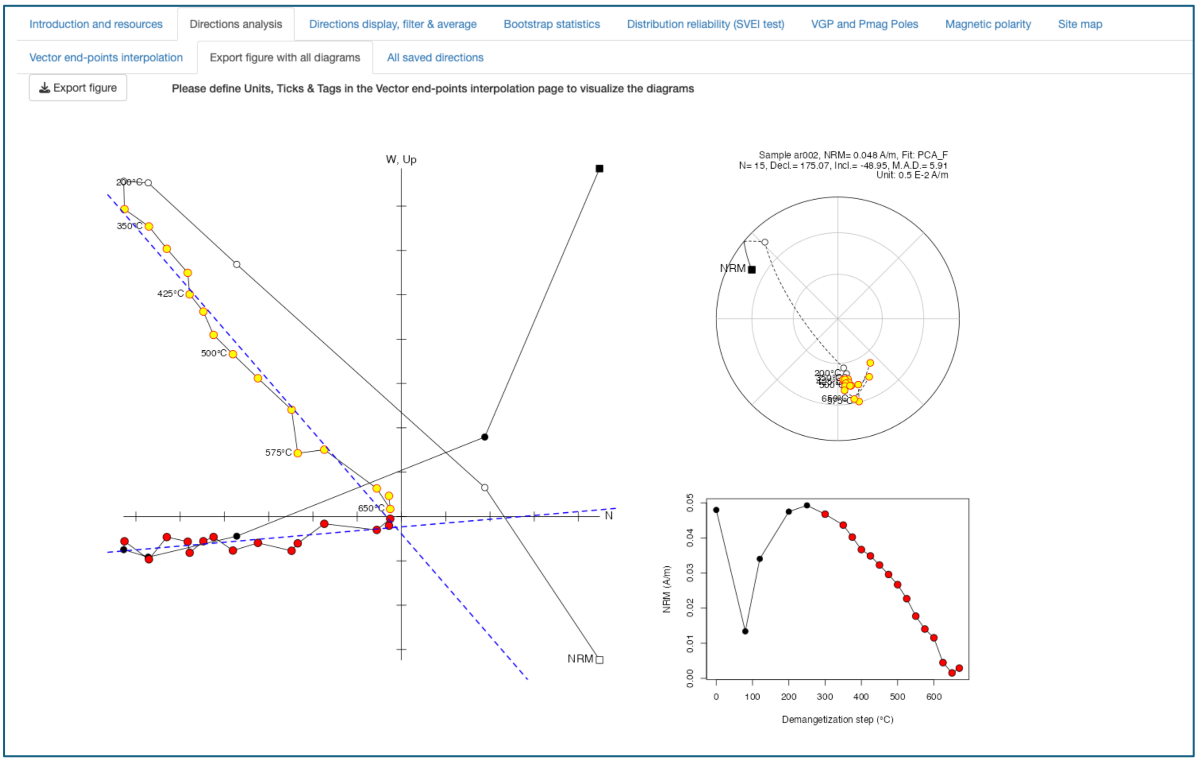

Figure 1.3: window showing all details of the sample selected in the "Vector end-points interpolation" panel, with the details of the interpolated direction (if present).

2.3. All saved directions

In this sub-page you find an interactive list of all saved directions. All directions selected in the table will be displayed in the equal area diagram on the main panel (Figure 1.2). The table is interactive, so any parameter can be used to sort the list by clicking on the header. For example, clicking on the header of the last column will sort the directions by component name, allowing to select and display more easily components with the same name.

Import saved directions: upload a file as exported from the "*Vector end-points interpolation"* page. This allows to work on data previously isolated using Magnetic-A.

*Name of exported file***:** selected (highlighted in blue) directions can be exported as a new (.csv) file in your personal device, and the name of the exported file can be typed here.

Coordinates: in this diagram, directions can be displayed by using a geographic or a tilt corrected coordinate system frame.

Delete selection: Selected directions will disappear from the interactive list. If directions are from a loaded file, the original file stored in the personal device will stay unchanged.

Undo delete: restores last deleted directions.

Export selected directions: this will download in the local device the selected directions using the "*name of exported file*"; this option is useful to separate the NRM components in different files.

*Export figure***:** equal area diagram is downloaded locally as vector (editable pdf) file.

*Combine DI & GC***:** combines directions and great circle (or only great circle) by using the algorithm of McFadden & McElhinny (1988).

*Add GC dirs to list***:** the directions lying on the great circles (shown as triangles in figure) estimated by using McFadden & McElhinny (1988) are saved as directions and added to the interactive list, indicated by "*Dir*" in the "*Type*" column.

*Clear GC dirs from plot***:** the directions lying on the great circles (triangles) are deleted from the figure (not from the list if already saved).

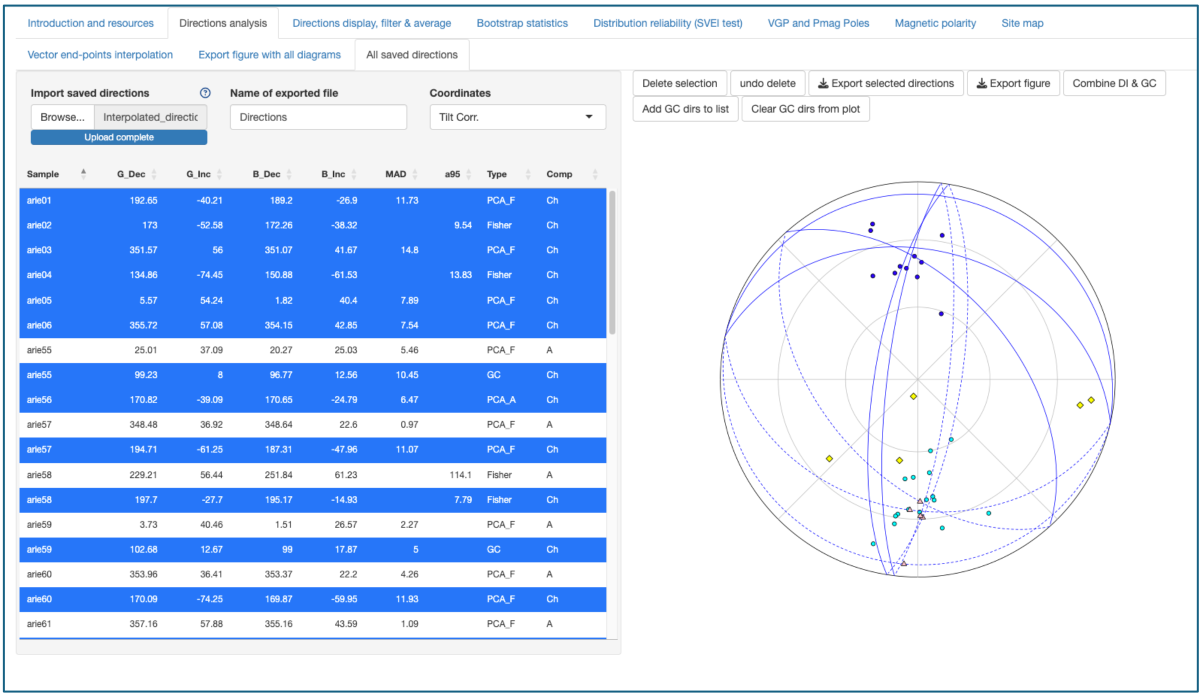

Figure 1.2. Window showing all saved interpolated directions and planes.

3. Directions display, filter & average

This page is designed to work on a set of interpolated directions. Directional data can be plotted with different style, and several statistical options to estimate the average directions are available (Figure 2.1). Directions can be either uploaded as a file or directly imported (internally) from the "*Directions analysis*" page.

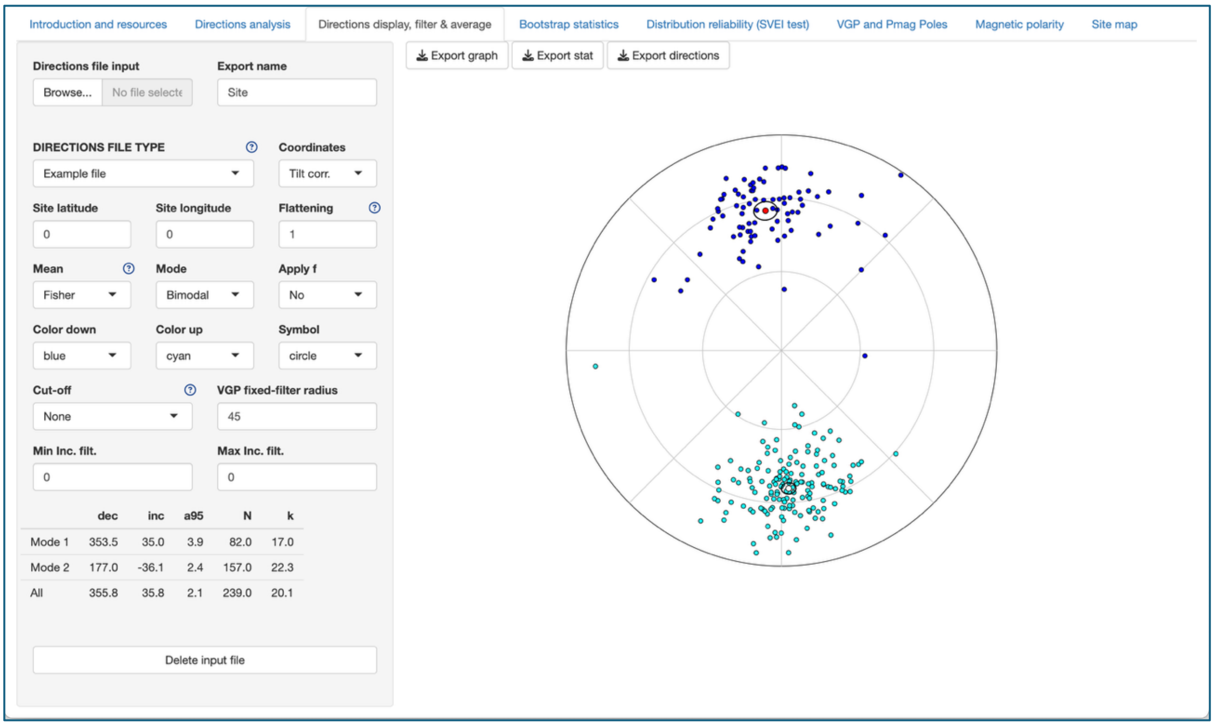

Figure 2.1. Directions display, filter and average window.

Directions file input: upload a directions file.

Export name: directions can be exported after processing, and the exported file will have the name typed here.

Directions file type: several (.csv) file formats are accepted (the details are listed within the helper pop-up window). **NOTE**: add a header to the data file, or it will skip the firs data point!

- Dec, Inc: two columns with declination and inclination, and optional third column with stratigraphic position.
- G_dec, G_inc, B_az, B_plunge: four columns in total, first two with declination and inclination in geographic coordinates, third and fourth with bedding (azimuth and dip of plunge; NO STRIKE); optional fifth column with stratigraphic position for magnetic polarity plot.
- G_dec, G_inc, B_dec, B_inc: four columns in total, first two with declination and inclination in geographic coordinates, third and fourth with declination and inclination in tilt corrected coordinates; optional fifth column with stratigraphic position for magnetic polarity plot.
- S_d, S_i, G_d, G_i, B_d, B_i: six columns in total, first two with declination and inclination in specimen coordinates, third and fourth with declination and inclination in geographic coordinates, fifth and sixth with declination and inclination in tilt corrected coordinates; optional seventh column with stratigraphic position.
- Magnetic-A: file as exported from the Directions analysis page.
- Internal file: all directions selected within the "All saved samples" sub-page.
- Example file: paleomagnetic ChRM directions from in geographic and tilt corrected coordinates, with associated stratigraphic position for magnetic polarity determination (see below), from Dallanave et al. (2012).

Coordinates: preferred reference frame (specimen, geographic, tilt corrected). Selection depends on the input file! Make sure to select the appropriate file type.

Site latitude, Site longitude: these are used in the next pages for the VGPs calculation and site map. Make sure to type in the proper coordinates if you want to use the "*VGP and Pmag Poles*" pages.

Flattening: a flattening factor ranging from 0 to 1 (applied to the directions by using tangent function of King, 1955) can be typed in and used to correct directions that are already known to be affected by paleomagnetic inclination shallowing.

Mean: the average direction and 95% confidence angles can be estimated by using different approaches.

- Fisher: calculate (Fisher, 1953) average and 95% cone of confidence (a95); if a distribution is bimodal, statistic is calculated automatically for the two modes, and for all directions flipped onto a common mode.
- Elliptic: calculate average direction and 95% ellipses defined by the two semi-angles of confidence (a95dec and a95inc) as described by Deenen et al. (2011). Bimodal distributions are treated as in Fisher.
- Inc. only (single mode and bimodal): specifically designed for directions from azimuthally unoriented deep-sea drilled cores, provides average inclination and 95% confidence calculated by using the maximum likelihood solution of Arason & Levi (2010). *Single mode* considers all data as a single distribution. *Bimodal* split the directions in up-pointing and down-pointing.
- Arithmetic (single mode and bimodal): similarly to Inc. only, it calculates the arithmetic means, useful when the maximum likelihood solution fails to provide an estimate (see Arason & Levi, 2010).

Mode: if directions are originally split in two clusters (e.g., normal and reversed polarity) or are generically divided in up-pointing and down-pointing, different options can be applied. Bimodal distributions are evaluated by using the same computational background of PmagDiR (Dallanave, 2024).

- Bimodal: directions are plotted in their original form.
- Mode 1: all directions are flipped toward Mode 1, which is considered the one with down-pointing average direction.
- Mode 2: all directions are flipped toward Mode 2, which is considered the one with up-pointing average direction.
- All down: all directions flipped as down-pointing
- All up: all directions flipped as up-pointing.

Apply f: if yes, it applies to the directions the flattening correction factor typed in the "*Flattening*" box.

Color down; color up; symbol: colors and symbols of choice can be used.

Cut-off: applies different types of cut-offs to the direction distribution. The cut-offs defined as "*dynamic*" include in the reiterative process the correction for inclination flattening by using the TK03.GAD-based method (Tauxe & Kent, 2004). Although this method is now superseded by the recent SVEI method (Tauxe et al., 2024), inclusion in the cut-off reiterative of the TK03.GAD method provide a less-strict cut-off result. Details on this concept are provided in Dallanave (2024).

READ CARFULLY: Be aware that for comparing the distribution with what expected from GGP model THG24 (Tauxe et al., 2024), it is recommended NOT TO APPLY ANY CUT-OFF. The explanation is provided in Tauxe et al. (2024).

- Vandamme: applied the cut-off proposed by Vandamme (1994).
- Fixed: applies a cut-off based on the VGP angular distance from the average paleomagnetic pole; the cut-off maximum angle is defined in the "*VGP filter-fixed radius*" box (default= 45°).
- Cut up-(down-) pointing: cuts all directions pointing either up or down.
- Cut fixed inc.: specifically designed for directions from azimuthally unoriented deep-sea drilled cores, it cuts all directions comprised within the angular interval defined in the "*Min inc. filt.*" and "*Max inc. filt.*" boxes (default values are both zero).

Export graph: download the equal area diagram as editable vector (pdf) file.

Export stat: download the table (.csv format) with the statistical parameters.

Export directions: download the directions as displayed in the equal area in a single file, declination and inclination in two columns (.csv format).

4. Bootstrap statistics

This page performs non-parametric statistical analysis of the distribution. The first page calculates the 95% confidence ellipses around the average direction(s), while the second page performs the bootstrap-based reversal test (Heslop et al., 2023).

READ CAREFULLY: Please cite Heslop et al. (2023) if using this page for publication (the link to the publication is embedded in the bottom left of the page).

4.1. Confidence ellipses

This sub-page works on the directions loaded in the "*Directions display, filter & average*" page. To perform the calculation of the non-parametric confidence ellipses, at least 10 directions (per mode, if distribution is bimodal) must be present. If not, a warning message will appear, and the simulation does not start (Figure 3.1).

Export name: name of the result file and graphic file to export.

Bootstrap n.: number of the simulated pseudosamples used to estimate the confidence ellipses. Default is 10.000 as suggested by Heslop et al. (2023).

Plot Dirs: add or remove the directions from the equal area (not the average and the ellipses).

Run Mode 1 and *Run Mode 2:* perform the test for the two modes (if present) separately.

Clear plot: remove all directions and confidence.

Export graph: downloads equal area diagram

Export ellipses: the confidence ellipsis is not defined by parameters but by a series of declination-inclination pairs. This command will generate and download a .csv file containing the average direction of the mode (or both modes if present) and the coordinate of the confidence ellipsis (for both modes if present).

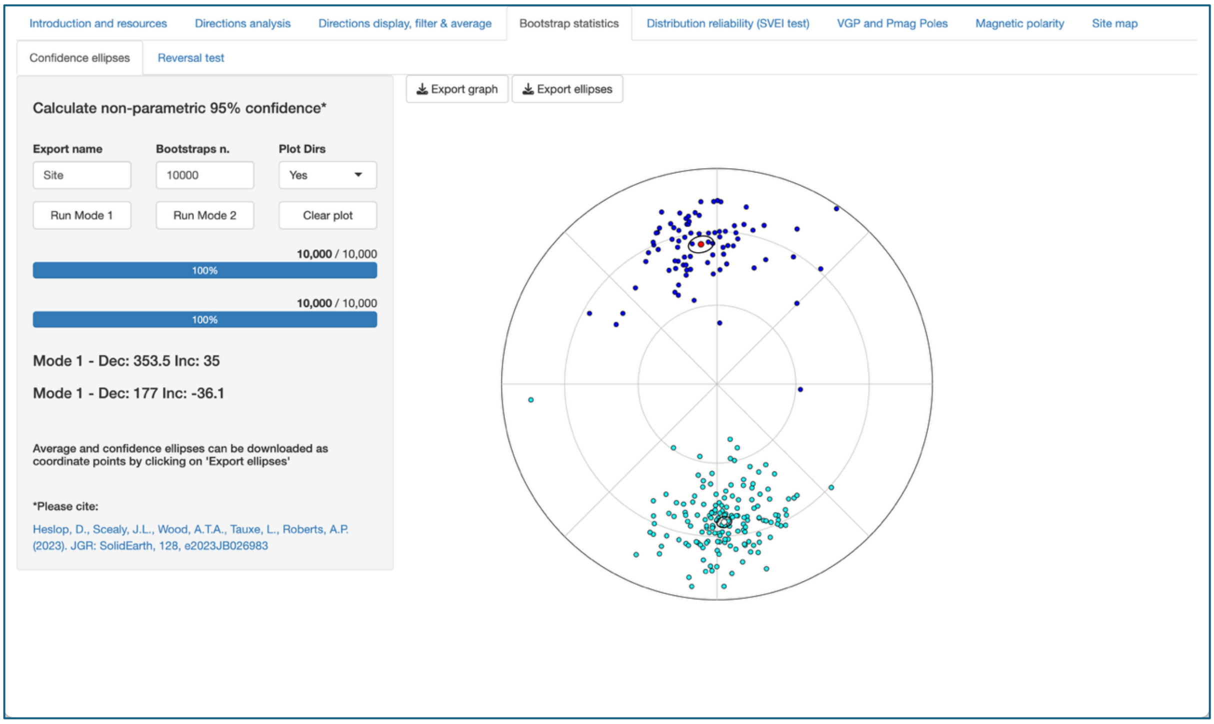

Figure 3.1. Confidence ellipses sub-page of the bootstrap statistics.

4.2. Reversal test

This sub-page performs the bootstrap test for common mean direction of Heslop et al. (2023), applied to the two distribution modes (see e.g. the classic textbooks of Butler, 1992 or Tauxe, 2010 for details on the field tests for paleomagnetic stability).

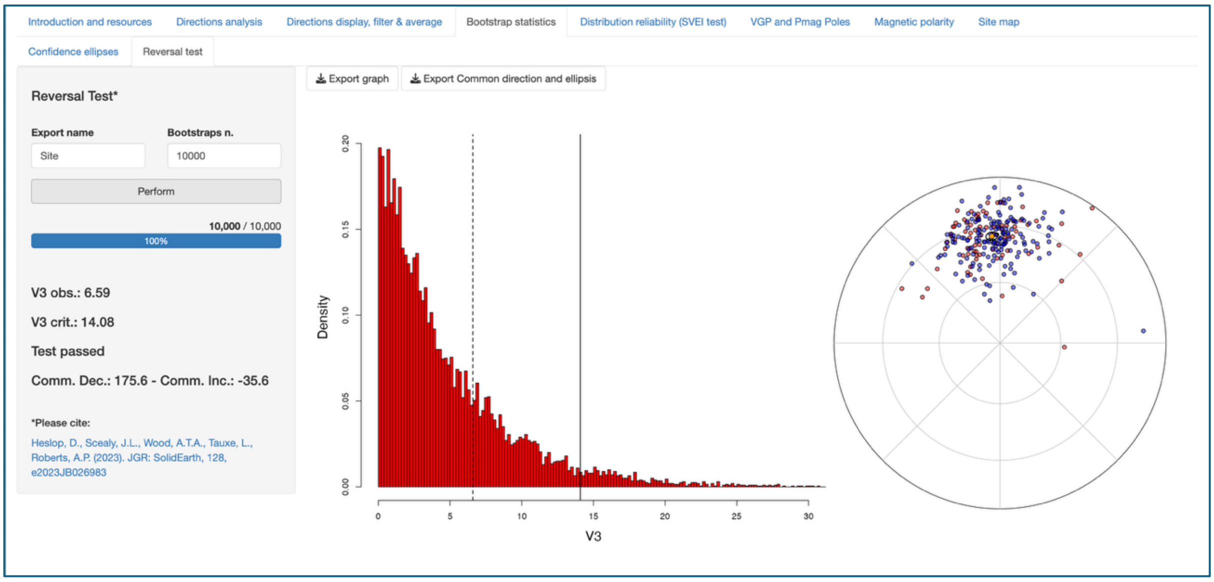

Figure 3.2. Bootstrap test for a common mean direction (aka reversal test) sub-page.

Export name: name of the result file and graphic file to export.

Bootstrap n.: number of the simulated pseudosamples used to calculate the estimate the confidence ellipses. Default is 10.000 as suggested by Heslop et al. (2023).

Perform: starts test.

Export graph: downloads figure with histogram containing the critical v_3 value, the observed value, and the result of the simulations (Heslop et al., 2023), together with the equal area diagram with both modes plotted on a common polarity.

Export Common direction and ellipsis: if the test is positive, a common direction and the relative 95% confidence ellipsis is generated and exported.

5. Distribution reliability (SVEI test)

This page performs the test for paleomagnetic directions distribution consistency with the THG24 GGP paleosecular variations model (Tauxe et al., 2024) (first sub-page), and the estimation of the inclination flattening for direction distribution derived by sedimentary rocks (second sup-page).

READ CAREFULLY: The original protocol is compiled in Python and published as Jupyter Notebook (Tauxe et al., 2024), and it has been translated into R (with minor modifications) to be applied within Magnetic-A. Please cite the original publication if using this method (the link to the publication is embedded in the bottom left of the page).

5.1. SVEI test

This sub-page compares a given directions distribution (loaded in the "*Direction display, filter & average*" page) with simulated distributions drawn from the THG24 paleosecular variations model (Tauxe et al., 2024) for the same sampling site latitude. The empirical declination and inclination from the distribution are compared with the expected cumulative distribution functions using the Anderson-Darling "goodness-of-fit" test (Anderson & Darling, 1952; please refer to Tauxe et al., 2024 for details on the method). Similarly to the Elongation-Inclination method of Tauxe & Kent (2004), the elongation (E) of the distribution and its orientation, expressed as declination of elongation (E Decl.) are compared to the ones expected from simulated distributions (Tauxe et al., 2024). In the case of Figure 4.1, the directions declination do not fit the expected declination, and the declination of elongation is outside the confidence boundaries defined by the simulated distribution: the test is not passed. For consistency with Tauxe et al. (2024), this example is based on the paleomagnetic directions of Gilder et al. (2001) filtered for MAD≤10, also available at https://www2.earthref.org/MagIC/20098.

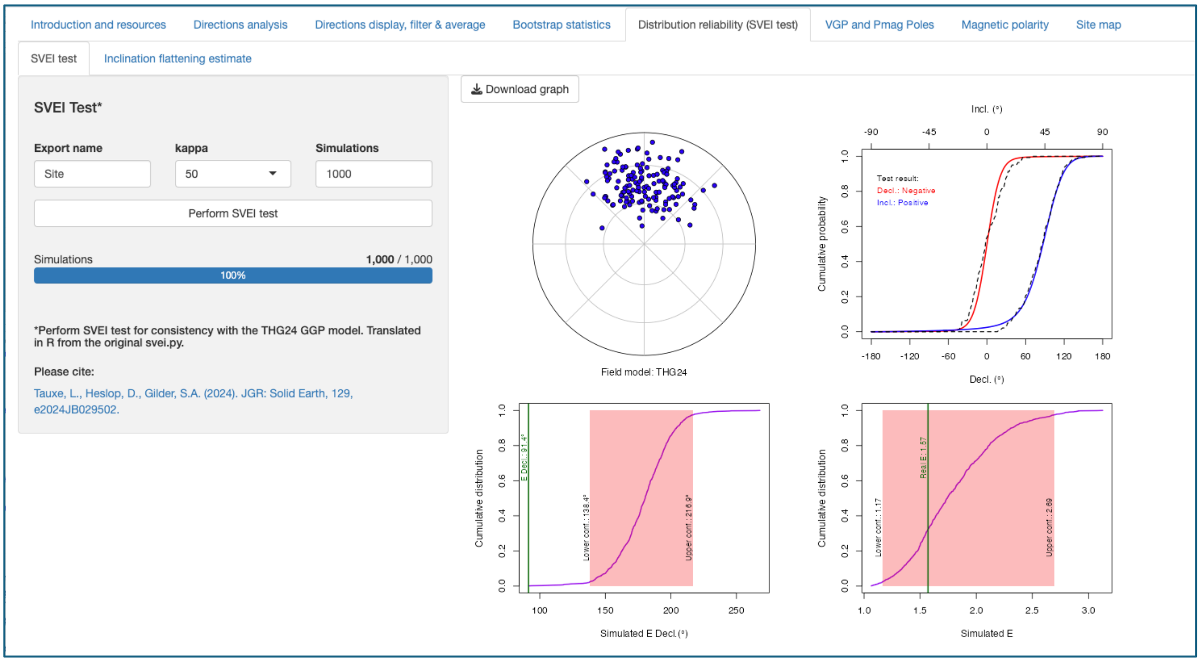

Figure 4.1. SVEI test for consistency with the THG24 GGP model.

Export name: name of the graphic file to export.

Kappa: assumed uncertainty. First run the test with kappa=infinite (no site scatter assumed), then 100 and 50 if test fails. For sedimentary records originally sampled for magnetostratigraphy, 50 is preferred (Tauxe et al., 2024). Please cite th

Simulations: number of the simulated dataset drawn from the THG24 model.

5.2. Inclination flattening estimate

This sub-page gradually "unflattens" the paleomagnetic directions following the tangent function of King (1955):

$$\tan I_o = \frac{\tan I_f}{f}$$

Where I_o is the original (unflattened) inclination, I_f = is the flattened direction, and f = flattening factor ranging from 0 to 1. After each unflattening step, it applies the SVEI test for consistency with the THG24 paleosecular variations model. Please refer to Tauxe et al. (2024) for details on the routine.

Export name: name of the graphic file to export.

Simulations: number of the simulated dataset drawn from the THG24 model.

Initial f, Target f, and *Increment:* the series of unflattening *f* values can be compiled by using three intervals (see below for the fast and slow routines)

Check f list: opens a pop-up window with all *f* values that will be applied.

Perform flattening test: starts the test.

5.2.1. Suggested routine for the inclination flattening test

Following what suggested by (Tauxe et al., 2024), before starting the unflattening procedure on data from sedimentary rocks, it should be tested if the data (when bimodal) pass the reversal test (sub-page 3.1), and that they are not already consistent with the THG24 model (sub-page 4.2). After that, an initial inspection of the data can be applied setting *f* values ranging from 1 to 0.3 with 0.05 increments (red rectangle in Figure 4.2; analogous of the Quick= True option in the original Jupyter notebook of Tauxe et al. (2024)). The pink areas in all diagrams bracket the range of *f* where the data show consistency with the THG24 model.

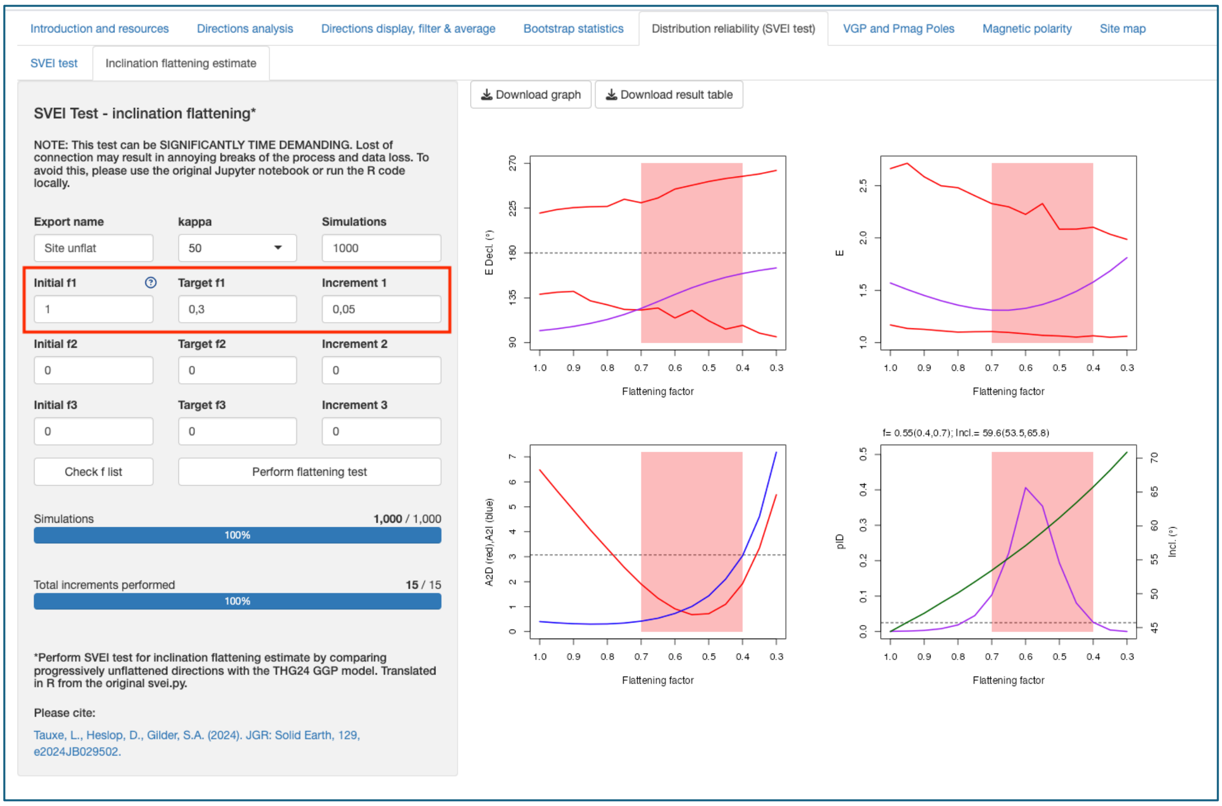

Figure 4.2. Preliminary (explorative) paleomagnetic inclination flattening detection.

If the test shows promising results, the series of "*f*" increments can be adjusted to refine the results and maximize the reliability of the confidence boundaries. In the following example, after inspection of the results of Figure 4.2, *f* increments are reduced to 0.01 from *f*= 0.75 to *f*= 0.35, and left as 0.05 between 1 and 0.75, and between 0.35 and 0.3 (red rectangle in Figure 4.3). This is similar (not identical!) to the Quick=False option in the original Jupyter notebook of Tauxe et al. (2024).

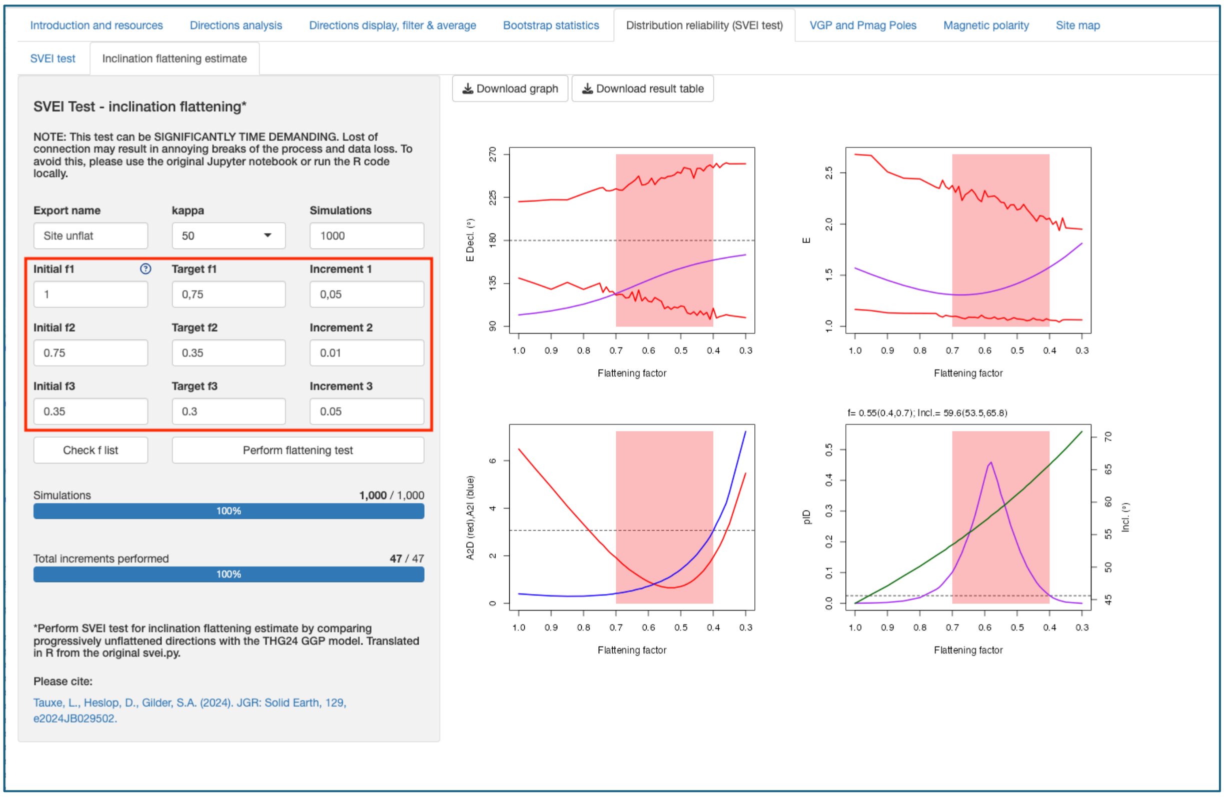

Figure 4.3. Detailed inclination flattening calculation process.

The estimated best *f* value, indicated atop the right-down panel (pID) can be typed in within the "*flattening*" box of the "*Directions display, filter, & average*" panel (Figure 4.4) to work on the unflattened directions. This allows, for example, to calculate the VGPs by using the unflattened directions.

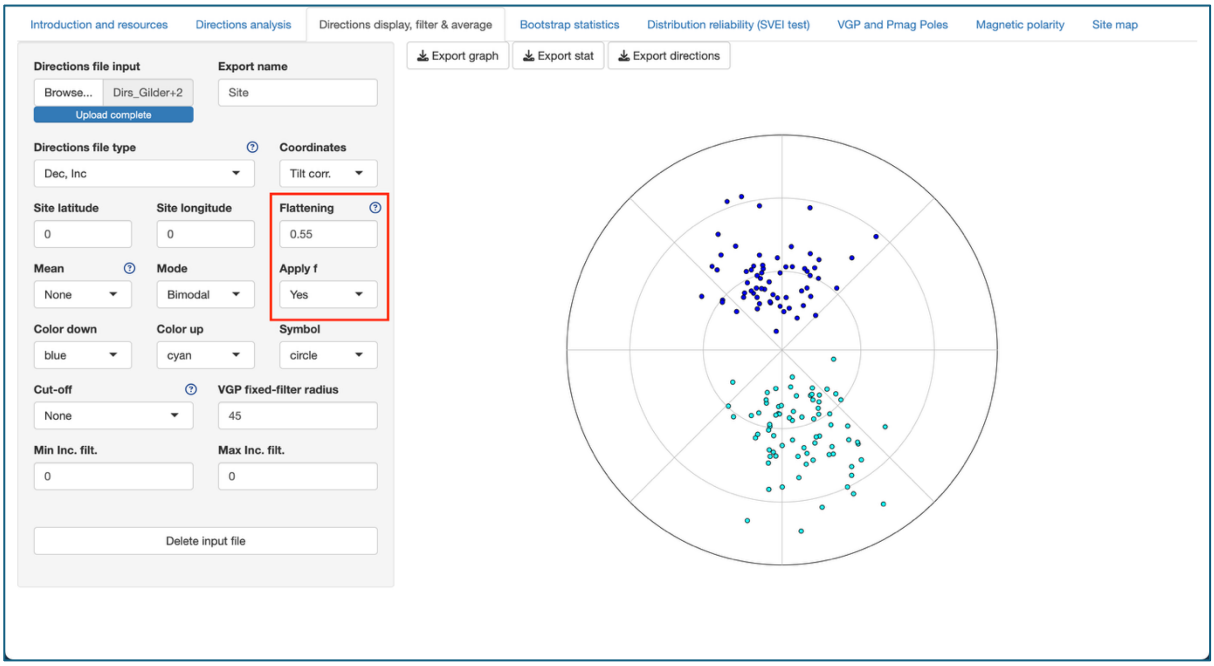

Figure 4.4. The f value is applied to the original dataset.

6. VGP and Pmag Poles

This page consists of seven sub-pages that allows different operations on VGPs, paleomagnetic poles, and the average of them.

6.1. VGPs plot and average

Here, the paleomagnetic directions loaded in the "*Directions display, filter, & average*" are automatically converted into VGPs and plotted on a stereographic projection. The projection is automatically centered on the average position of the VGPs (i.e., paleomagnetic pole), but the center can be changed arbitrarily, as well as other plotting details like grid and coastline. The 95% confidence angle can be estimated by either Fisher (1953; A95) statistic or by bootstrap statistic (B95; see Dallanave, 2024 for details). VGPs and average can be uploaded in the so-called "*List of loaded VGPs*", which allows to operate on the data throughout the next pages (Figure 5.1).

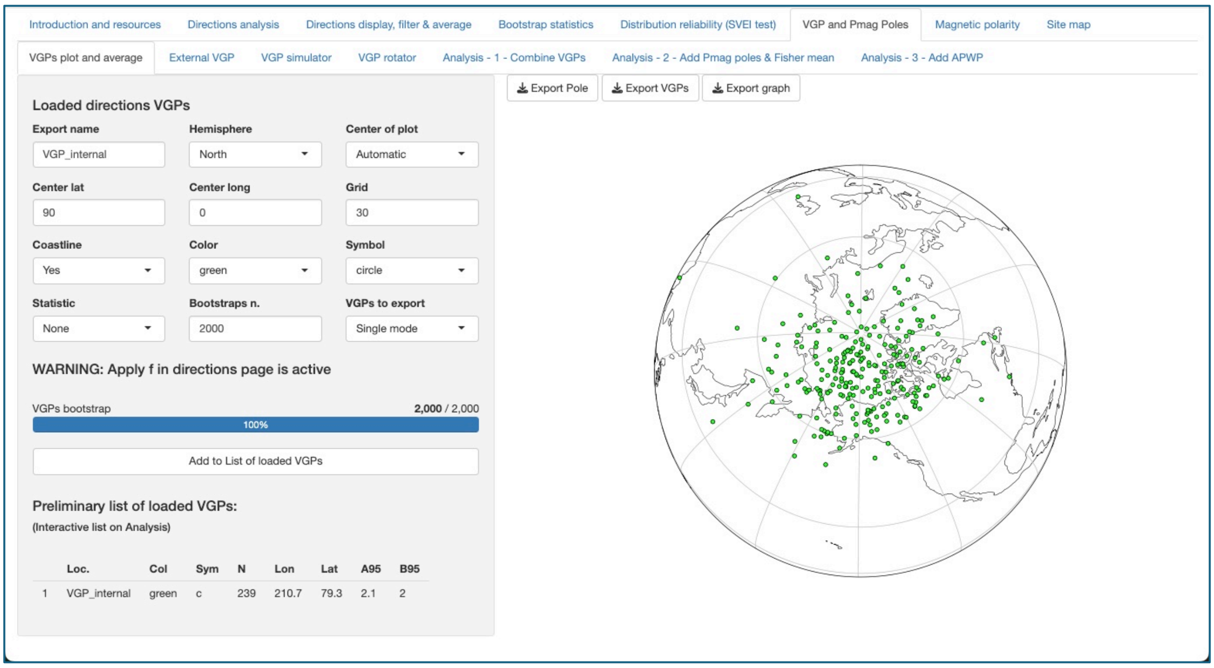

Figure 5.1. VGPs plot and average sub-page.

Export name: name of the downloadable files (buttons in main window).

Hemisphere: VGPs can be plotted either on the northern or the southern hemisphere.

Center of plot: either "*Automatic*" or "*Manual*"; if manual is selected, latitude and longitude can be typed in the Center lat and Center long boxes, respectively.

Grid: defines angular distance between parallel and meridians.

Plot coastline: select "*No*" to remove coastlines from the graph.

Color and symbol: define the color and the symbol of the loaded VGPs. These will be kept in the next pages.

Statistic: plot the average and the 95% confidence of choice together with the VGPs.

Bootstrap n.: number of VGPs pseudosamples used for the B95 confidence angle (default is 2000).

VGPs to export: it defines the exportable VGPs file form. Three options are available: (1) "*Single mode"* = even with bimodal distribution, the VGPs are flipped on a common polarity; (2) "*Bimodal"* = if the distribution of paleomagnetic directions is bimodal, it keeps the VGPs in the original position; (3) "*Rotated*" = VGPs are bimodal but rotated to place the average paleomagnetic pole coinciding with the geographic north pole; this is used to determine (e.g.) the magnetic polarity stratigraphy.

Add to List of loaded VGPs: it loads the current VGPs onto the *List of loaded VGPs*, automatically calculating A95 and B95. Here the list of loaded VGPs is only visualized; the interactive list is shown (when necessary) in the next pages.

Export Pole: downloads the paleomagnetic pole longitude and latitude associate with either the A95 or the B95 (depending on what is selected in the "*Statistic*" button) as csv file.

Export VGPs: downloads the VGPs as csv file in the format selected in the "*VGPs to export"* box.

Export graph: downloads the figure as vector editable file (pdf).

6.2. External VGPs

In this sub-page the user can load VGPs longitude and latitude files and upload them into the List of loaded VGPs (Figure 5.2).

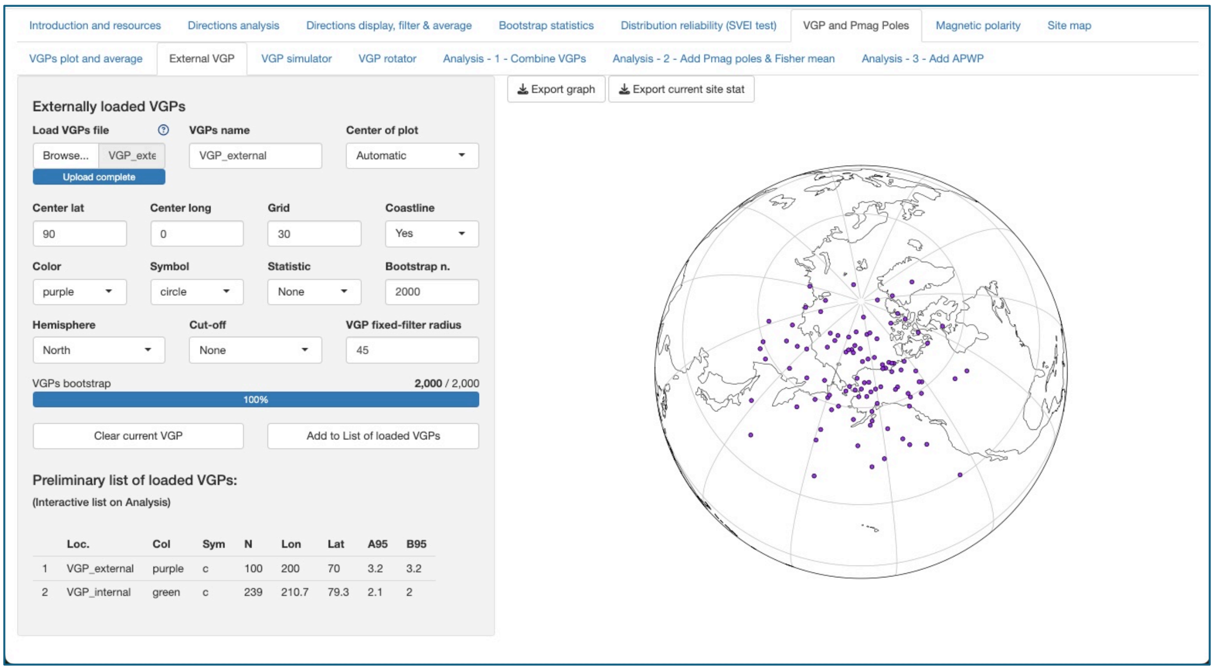

Figure 5.2. External VGPs sub-page.

Commands are same as page 5.1, except that Magnetic-A offers the possibility to apply a *cut-off*, either based on a given distance from the average pole (*VGP fixed-filter radius* window) or based on the method suggested by Vandamme (1994). Note that the dynamic cut-off is not possible as its calculation is performed by working on the paleomagnetic directions rather than on the VGPs.

Clear current VGP: delete loaded VGPs

Export current site stat: downloads the average paleomagnetic pole and 95% confidence angle of the loaded VGPs.

6.3. VGP simulator

This page is designed to simulate a Fisher (1953) distribution of VGPs from known longitude, latitude, number of VGPs and kappa precision parameter. The rationale behind using simulated VGPs rather than paleomagnetic pole when averaging multiple paleomagnetic poles is explained in (Vaes et al., 2023). The simulated VGPs can be uploaded in the *List of loaded VGPs* and processed as a real set of VGPs.

Longitude, Latitude: longitude and latitude of the simulated VGPs center.

N, K: number of VGPs and Fisher (1953) precision parameter of the know paleomagnetic pole.

K tolerance: the precision parameter of the simulated VGPs might differ from the one typed in the box. Here, the maximum difference between the selected and the real simulated kappa can be typed in. The script reiterates the simulation until the difference is lower than the tolerance.

The rest of the commands are like in sub-page 5.1

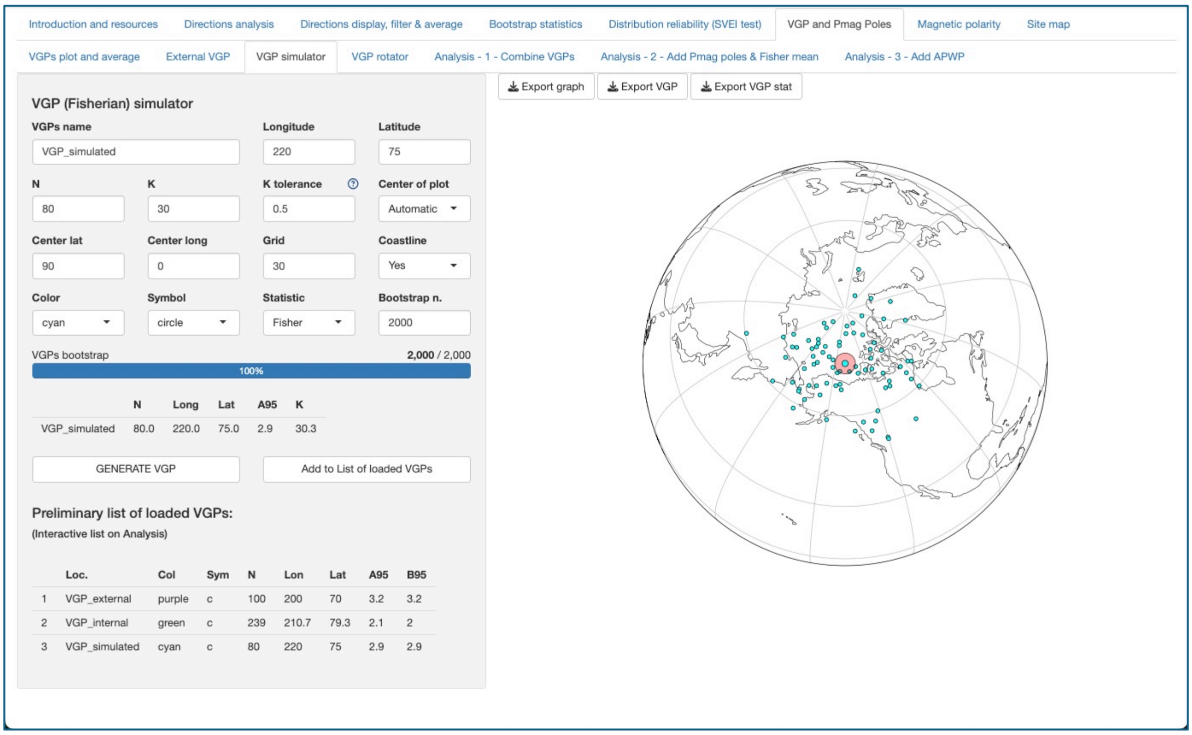

Figure 5.3. Simulated VGPs sub-page.

6.4. VGP rotator

This page rotates a selected VGPs distribution, together with the associated Fisher average and the bootstrapped pseudosamples used to determine the B95, by applying the rotational parameters typed in by the user. The rotated data are saved as separate (new) VGPs set. In the example of Figure 5.4, the rotation is visualized by showing the rotated bootstrapped pseudosamples rather than the VGPs, but the same rotation is applied to all the parameters associated to the original VGPs set. It works only on one dataset at the time.

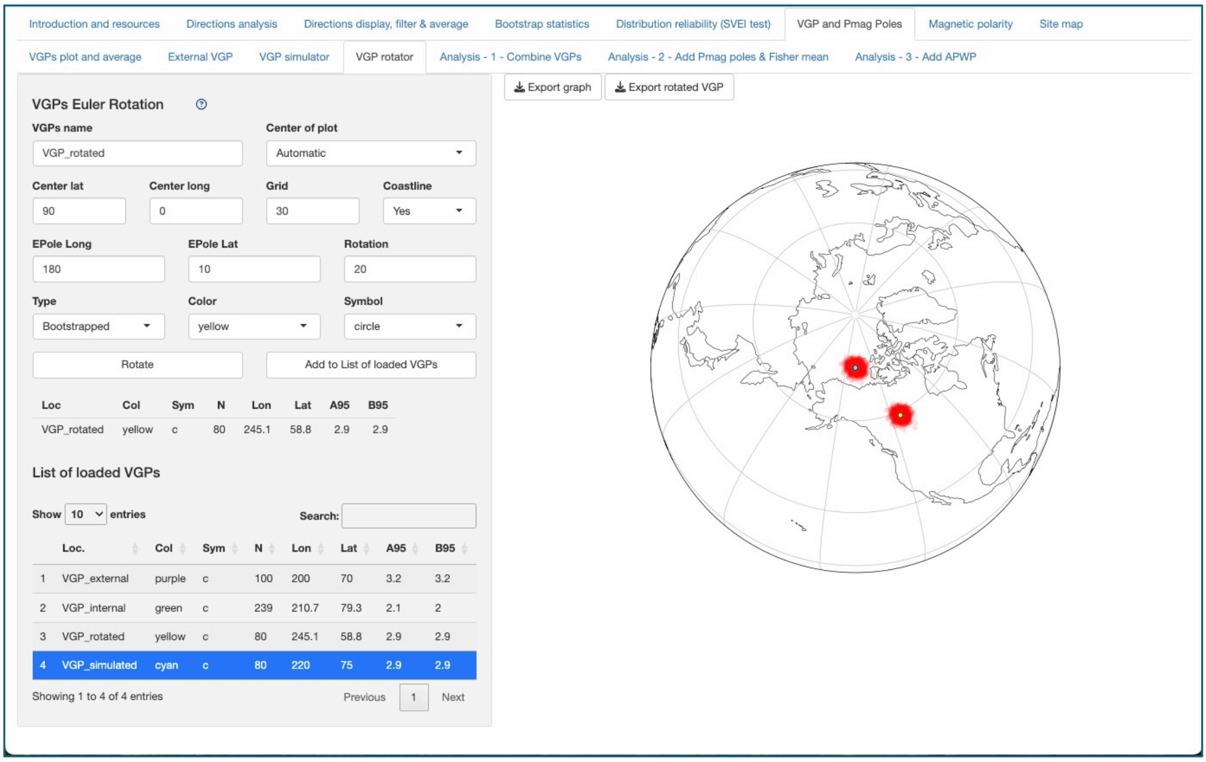

Figure 5.4. VGPs rotation sub-page.

VGPs name: name of the rotate VGPs set that will be uploaded to the List of loaded VGPs.

Center of plot to *Coastline:* as in previous pages.

EPole Long, EPole Lat: coordinates of the Euler (rotation) pole coordinates.

Rotation: applied finite rotation (positive clockwise)

Type: data display on plot can VGPs, Fisher average, or bootstrapped pseudosamples mean (all data are rotated independently of what is visualized).

Color and *Symbol:* color and symbol of the rotated VGPs.

Rotate: performs rotation.

Add to List of loaded VGPs: upload the rotated poles to the List of loaded VGPs.

Export graph and *rotated VGPs:* these buttons respectively download the plot as vector (pdf) file and the list of rotated VGPs as csv file.

READ CAREFULLY: the next three sub-pages (analysis 1, 2, and 3) are designed to perform different calculations but they share the same figure, visualized in all three pages, that can be updated with different elements in the three sup-pages.

6.5. Analysis – 1 – Combine VGPs

This sub-page is designed to merge different VGPs file into one. This operation allows to calculate a "weighted" mean of different sets of VGPs, rather than simply averaging the paleomagnetic poles determined from the VGPs themselves. A similar (although with a more complex algorithm) is at the base of the GAPWP of Vaes et al. (Vaes et al., 2023). If preferred, the "classic" Fisher average of the paleomagnetic poles can be calculated in the next sub-page.

NOTE: the plotting details that are selected in this sub-page (details about the stereographic projection like grid and coastline) are also used in the next two analysis sub-pages.

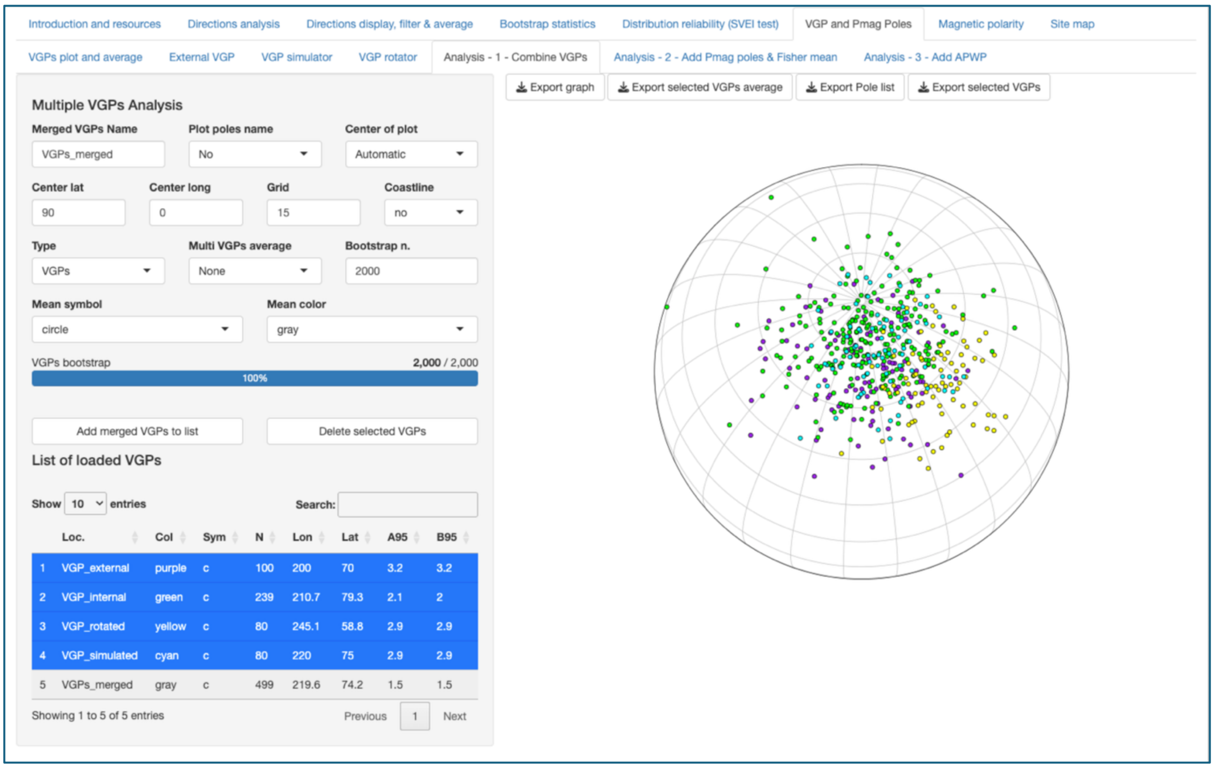

Figure 5.5. Example of merged VGPs.

Merged VGPs Name: this name will be used for the newly generated, merged set of VGPs.

Plot poles name: if "*yes*", it plots also the name of the VGPs sets onto the stereographic projection. Useful mostly if the sets are plotted as average pole with either A95 or B95.

Center of plot to *Coastline:* as in previous pages.

Type: choose between VGPs, Fisher average, average and bootstrapped pseudosamples mean.

Multi VGPs average: this function calculates and displays the average of all selected VGPs (either Fisher or bootstrapped) without saving the merged VGPs in the List of loaded VGPs.

Bootstrap n.: number of bootstrapped pseudosamples.

Mean symbol and *color*: symbol and color of the Multi VGPs average and of the merged VGPs, if uploaded to the List of loaded VGPs.

Add merged VGPs to list: the VGPs selected in the list, highlighted in blue (Figure 5.5), are merged to generate a new set of VGPs that is uploaded in the *List of loaded VGPs*, with the name typed in the *Merged VGPs Name* box.

Delete selected VGPs: the VGPs selected in the list, highlighted in blue (Figure 5.5), are permanently deleted from the list.

6.6. Analysis – 2 – Add Pmag Poles & Fisher mean

This sub-page is designed to add known paleomagnetic poles, defined only by longitude, latitude, and A95. The poles are added to a separate *List of external poles*. The poles are not listed with the Internal and external poles list (*List of loaded VGPs*) of the *Analysis – 1* sub-page because VGPs, bootstrapped pseudosamples means, and derived B95 are unknown. In this sub-page, the poles selected in both the *List of external poles* and *List of loaded VGPs* of the *Analysis – 1* sub-page can be averaged by Fisher mean. Poles can also be rotated by applying Euler parameters and save as new paleomagnetic poles.

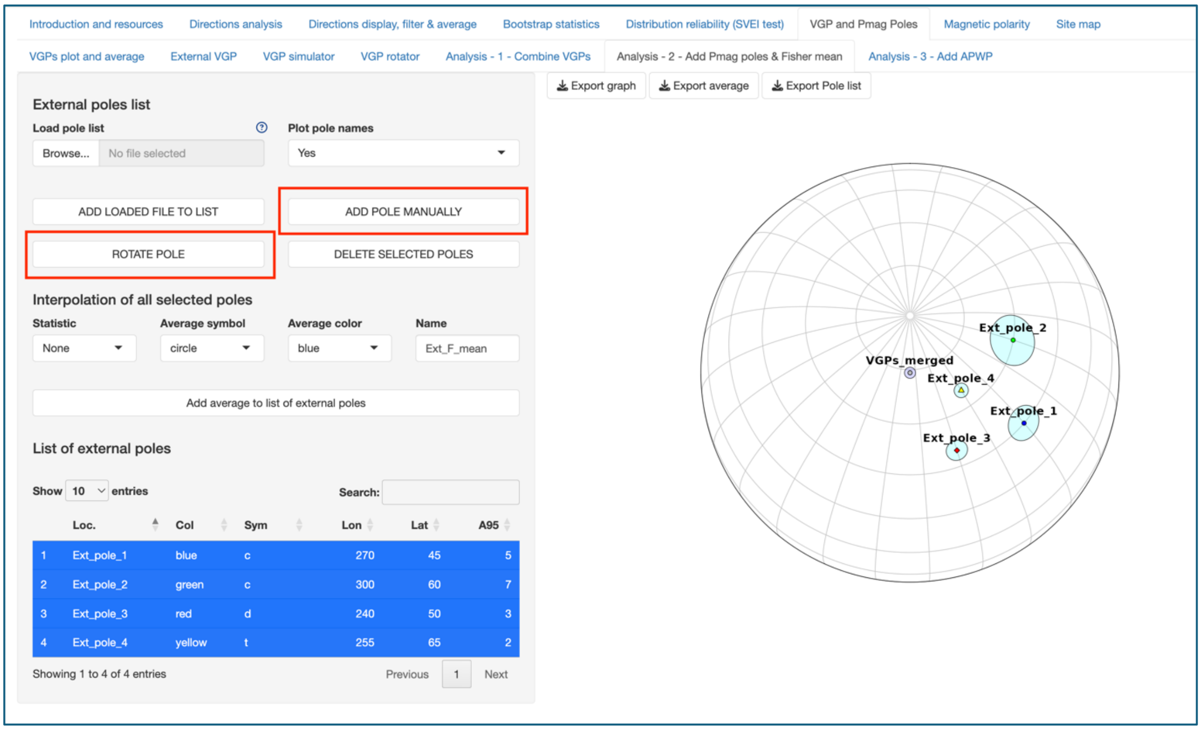

Figure 5.6.1. Analysis – 2 – Add paleomagnetic poles and Fisher mean sub-page. Highlighted the action buttons the open the data entry pop-up window (Figures 5.6.2 and 5.6.3)

Load pole list: a paleomagnetic pole list can be uploaded from your personal device, in the same form of the list exported by this page.

Plot pole names: as in previous pages.

ADD LOADED FILE TO LIST: upload the pole list file to the *List of external poles.*

ADD POLE MANUALLY: opens the data entry window of Figure 5.6.2.

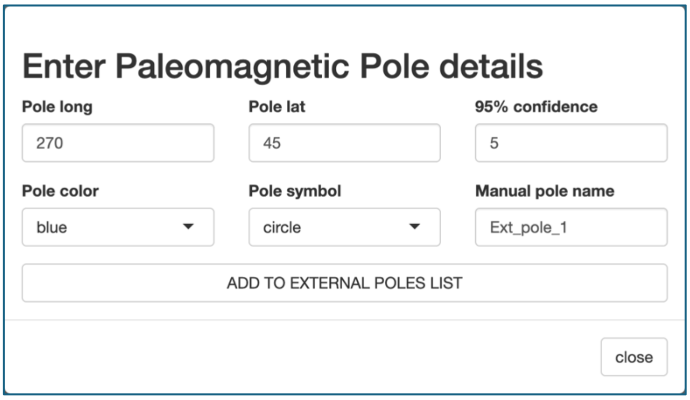

Figure 5.6.2. Paleomagnetic pole entry window

ROTATE POLE: opens the data entry window of Figure 5.6.3.

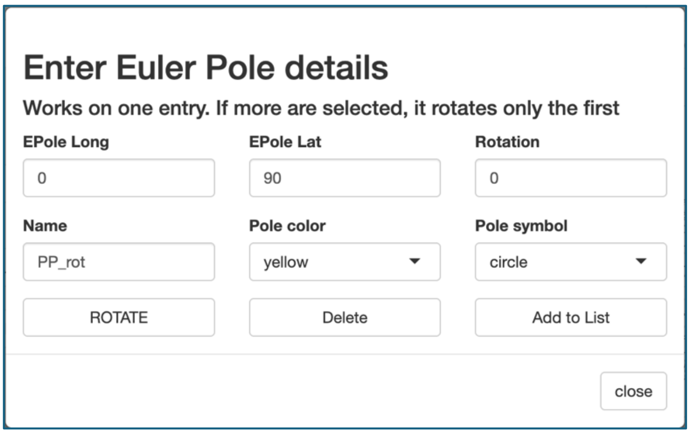

Figure 5.6.3. Euler parameter entry window

DELETE SELECTED POLES: poles selected from the interactive list are deleted permanently.

Statistic: all poles selected in the *List of external poles* (this sub-page) and in the *List of loaded VGPs* (*Analysis – 1 – combine VGPs* sub-page) can be interpolated by Fisher mean or by a great circle (expressed by the coordinate of the great circle pole).

Average symbol, *color*, and *name*: symbol, color, and name of the average paleomagnetic pole.

Add average to list of external pole: the average paleomagnetic pole can be added to the list and treated as an independent paleomagnetic pole.

Export graph and *average*: download the editable figure and the calculated average, respectively.

Export pole list: the *List of external poles* can be downloaded and, if required, it can be successively uploaded in Magnetic-A (*Load pole list* and *ADD LOADED FILE TO LIST*).

6.7. Analysis – 3 – Add APWP

In this sub-page any of the paleomagnetic poles or VGPs selected in both the previous *Analysis* sub-pages can be compared with an APWP. If needed, the APWP can be plotted on its own, with no paleomagnetic pole or VGP on the graph. Magnetic-A has two GAPWP internally loaded (Torsvik et al., 2012; Vaes et al., 2023; respectively called T2012 and V2023) in all the different reference frames compiled by the authors in the original publication. A custom APWP can be compiled and uploaded (see Appendix 2). In the example of Figure 5.7, all paleomagnetic poles of Figure 5.6.1 are first averaged by Fisher mean and uploaded to the *External pole list* with the name of *All_poles_mean*, then compared with the T2012 APWP from 20 to 250 Ma in Australian coordinates.

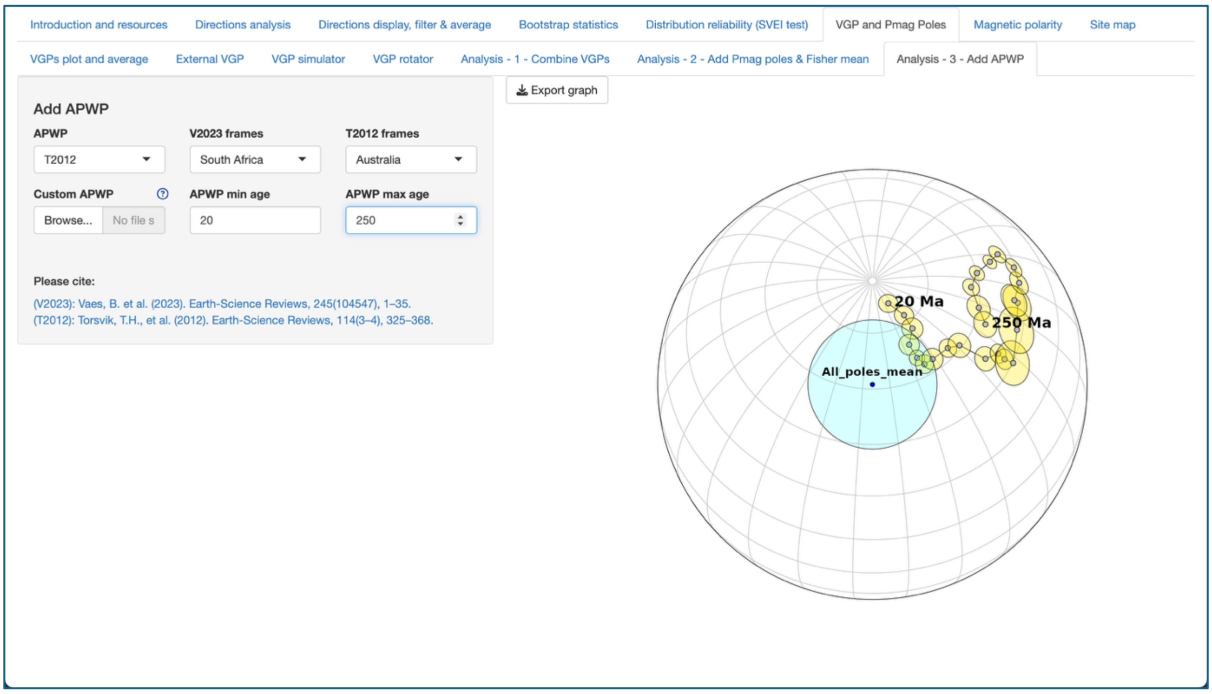

Figure 5.7. Add APWP sub-page.

7. Magnetic polarity

This page is designed to compile a classic magnetic polarity stratigraphy plot. To generate this plot, this page uses the paleomagnetic declination and inclination data uploaded in the *Directions display, filter & average* page, so please refer to Chapter 2 of this guide to verify the data format. In case of paleomagnetic directions isolated with Magnetic-A, the position of the specimens is missing from the directions file. In this case, a file with the sample position can be uploaded here.

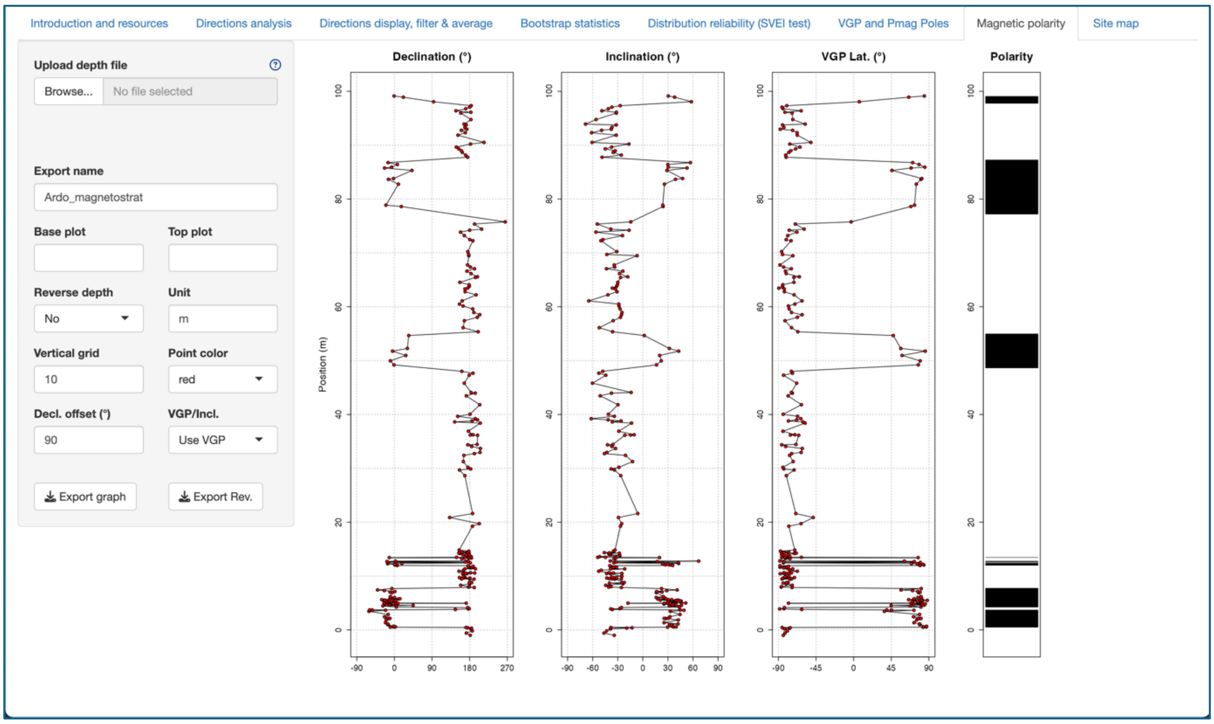

Figure 6.1. Magnetic polarity stratigraphy page

<u>*Upload depth file*</u>: samples depth file. To date, two formats are accepted (see also online help):

- A simple two columns csv file with sample code and depth. Be aware that the depth is assigned by checking the sample name, so THE SAMPLE NAME MUST BE THE SAME in both this file and the demagnetization data file.
- Spinner or ex-spinner file downloaded from LIMS (https://web.iodp.tamu.edu/LORE/), in case of discrete specimen data generated on the JOIDES Resolution. This file is must be the same uploaded in the Vector end-points interpolation window.

The file type does not need to be selected, the script recognizes the file depending on the number of columns.

Export name: name of the downloaded graph or reversals file.

Base and Top plot: a specific stratigraphic interval can be selected for plotting by typing in the stratigraphic base and top. By leaving the cells empty, the script will use the entire stratigraphic interval of the data.

Reverse depth: the position of the samples will be trated as top-to-down depth (e.g., samples from deep-sea drilled cores).

Unit: depth unit that will appear in the graph.

Vertical grid: defines the spacing of the horizontal dotted line in the graph.

Point color: defines the color of the data points.

Decl. offset (°): defines the horizontal offset in the declination plot. In case of paleomagentic directions organize in two modes pointing quasi-north-and-south like the ones of the example (Figure 6.1), the declination plot would result in annoying left-and-right swings between 0° and 360° degree. Setting an offset of 90° avoid this graphical problem.

VGP/Incl.: the magnetic polarity stratigraphy is determined by using three possible strategy:

- Use VGP: when paleomagnetic directions are defined by both declination and inclination.
- Use Inc (N.Hem): uses only inclination data, assuming down-pointing inclination as normal.
- Use Inc (S.Hem): uses only inclination data, assuming up-pointing inclination as normal.

Export graph: download the vector graphic file in your device.

Export rev.: download a csv file with top and bottom of the normal polarity zones, defined by the arithmetic mean of the position of two consecutive samples with different polarity.

8. Site map

Magnetic-A includes also a very simple tool for plotting localities in a present-day geographic sketch, which might be useful for publication purposes. While it automatically plots the working site with the coordinates typed in the Directions display, filter & average page, a file with several localities name, coordinates, and symbol features can be uploaded (Appendix 3).

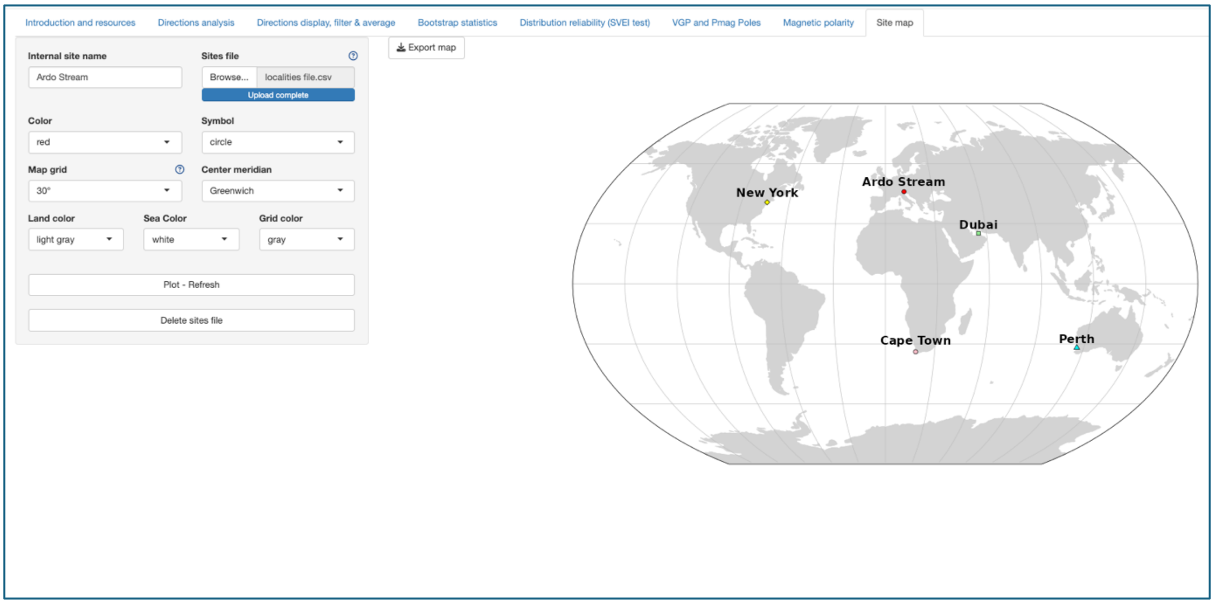

Figure 7.1. Site map page.

Internal site name: name of the site/localities which coordinates are typed in the *Directions display, filter & average* page (Chapter 2 of this manual).

Site file: a list of sites can be uploaded here, csv format, with five columns that include site name, longitude, latitude, symbol, color (see also online helper and Appendix 3).

Color and *symbol*: color and symbol of the internal site.

Map grid: angular distance between parallels and meridians.

Central meridian: the map can be centered either on Greenwich or 180°E meridian (useful for Pacific and peri-Pacific sites).

Land, Sea, Grid color: define the color of respectively land, sea and grid lines.

Plot – Refresh: plot or update map if anything has been changed.

Delete sites file: ignore the uploaded site file when plotting.

Glossary

A^2D and A^2I = Anderson-Darling test on declination and inclination (respectively) as a function of the flattening factor "*f*". In both cases, a value higher than 3.07 rejects the hypothesis that the considered directions distribution is drawn from the THG24 GGP model (please refer to Tauxe et al., 2024 for computational details).

A95= 95% confidence angle around the paleomagnetic pole estimated by using Fisher (1953) statistic.

APWP= Apparent polar wander path.

B95= 95% confidence angle around the paleomagnetic pole estimated by using bootstrap resampling. The routine that performs this calculation is described in Dallanave (2024).

ChRM= Characteristic remanent magnetization.

csv= comma separated values.

GAPWP= global synthetic apparent polar wander path.

GGP= Giant Gaussian Process.

NRM= natural remanent magnetization.

MAD= maximum angular deviation.

pID= combined *p*-values calculated from A^2D and A^2I. A value lower than 0.025 indicates that the distribution of directions is not drawn from the THG24 GGP model (please refer to Tauxe et al., 2024 for computational details).

PCA= principal component analysis.

T2012= GAPWP of Torsvik et al., (2012).

THG24= Tauxe-Heslop-Gilder (2024) field model.

TK03.GAD= Tauxe and Kent (2004) field model.

V2023= GAPWP of (Vaes et al., 2023).

VEPs= Vector end-points.

VGPs= virtual geomagnetic poles.

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Appendix 1: Demagnetization data file accepted formats

NOTE: JR6A expanded data can be retrieved under **Magnetism** in the following link: https://web.iodp.tamu.edu/LORE/

Magnetic-A.csv

```
sample,step,Sx,Sy,Sz,Gx,Gy,Gz,Bx,By,Bz
ar001,0,-0.00361,-0.01776,0.08674,0.06726,-0.00541,0.05743,0.07922,-0.00749,0.03898
ar001,80,-0.01496,-0.01582,0.04329,0.0044,-0.02745,0.0397,0.01375,-0.02909,0.03624
ar001,120,0.00811,-0.03025,-0.02536,-0.0314,-0.01094,-0.02277,-0.03605,-0.01013,-0.0149
ar001,200,0.01698,-0.03436,-0.04519,-0.04069,-0.0071,-0.04248,-0.04983,-0.0055,-0.03157
ar001,250,0.01511,-0.03578,-0.05307,-0.04665,-0.00285,-0.04626,-0.05653,-0.00118,-0.03357
ar001,300,0.01864,-0.03566,-0.05301,-0.04499,-0.00457,-0.04883,-0.05556,-0.00272,-0.03654
ar001,320,0.0249,-0.0313,-0.04975,-0.03725,-0.00637,-0.05144,-0.0487,-0.00435,-0.04103
ar001,350,0.01324,-0.03522,-0.04885,-0.04492,-0.00393,-0.04205,-0.05383,-0.00235,-0.02999
ar001,375,0.01688,-0.02799,-0.05272,-0.04009,0.00147,-0.04731,-0.05039,0.00326,-0.03602
ar001,400,0.01744,-0.02792,-0.05127,-0.039,0.00048,-0.04681,-0.04918,0.00223,-0.0359
ar001,425,0.01644,-0.02824,-0.03867,-0.03311,-0.0062,-0.0378,-0.04136,-0.00471,-0.02882
ar001,450,0.01519,-0.02489,-0.03601,-0.02985,-0.00473,-0.03513,-0.03753,-0.00335,-0.02698
ar001,475,0.01221,-0.02571,-0.04095,-0.03443,-0.00126,-0.03605,-0.04215,7e-05,-0.02665
ar001,500,0.01064,-0.02079,-0.03022,-0.02598,-0.00291,-0.02784,-0.03198,-0.00184,-0.0208
ar001,525,0.00836,-0.01786,-0.03602,-0.02791,0.00333,-0.02993,-0.03434,0.00446,-0.02206
ar001,550,0.00876,-0.01773,-0.02357,-0.02116,-0.00354,-0.02206,-0.0259,-0.00268,-0.0164
ar001,575,0.00535,-0.01784,-0.01889,-0.02034,-0.00458,-0.01641,-0.02373,-0.00397,-0.01117
ar001,600,0.00115,-0.01113,-0.01818,-0.01701,0.0017,-0.01279,-0.01959,0.00216,-0.0082
ar001,625,0.00491,-0.00549,-0.00893,-0.0064,-0.00124,-0.00956,-0.00854,-0.00087,-0.00776
ar001,650,0.00172,-0.0041,0.00294,-0.00065,-0.00525,0.00063,-0.00051,-0.00528,0.00055
```

Figure A1.1. Magnetic-A data file format for demagnetization data.

ardo1_LASA.txt

```
******************************** 22 July      2009 AzFile = ********************
LAT:  0.00  LON:   0.00 REC:2131 SAM: 115
!
!   ID      TREAT  IC CD    J     CDECL CINCL  GDECL GINCL  BDECL BINCL  SUSC  V/M
!J units 1e-4 emu (equivalent to 1e-2 A/m assuming 10 cc volume)
!_________________________________________________________________________________
ar001         0.0  Gh  0 0.08861 258.5  78.2  355.4  40.4  354.6  26.1 -99.0  0.0
ar001        80.0  Gh  0 0.04846 226.6  63.3  279.1  55.0  295.3  48.4 -99.0  0.0
ar001       120.0  Gh  0 0.04030 285.0 -39.0  199.2 -34.4  195.7 -21.7 -99.0  0.0
ar001       200.0  Gh  0 0.05925 296.3 -49.7  189.9 -45.8  186.3 -32.2 -99.0  0.0
ar001       250.0  Gh  0 0.06576 292.9 -53.8  183.5 -44.7  181.2 -30.7 -99.0  0.0
ar001       300.0  Gh  0 0.06655 297.6 -52.8  185.8 -47.2  182.8 -33.3 -99.0  0.0
ar001       320.0  Gh  0 0.06383 308.5 -51.2  189.7 -53.7  185.1 -40.0 -99.0  0.0
ar001       350.0  Gh  0 0.06166 290.6 -52.4  185.0 -43.0  182.5 -29.1 -99.0  0.0
ar001       375.0  Gh  0 0.06203 301.1 -58.2  177.9 -49.7  176.3 -35.5 -99.0  0.0
ar001       400.0  Gh  0 0.06093 302.0 -57.3  179.3 -50.2  177.4 -36.1 -99.0  0.0
ar001       425.0  Gh  0 0.05063 300.2 -49.8  190.6 -48.3  186.5 -34.7 -99.0  0.0
ar001       450.0  Gh  0 0.04634 301.4 -51.0  189.0 -49.3  185.1 -35.6 -99.0  0.0
ar001       475.0  Gh  0 0.04987 295.4 -55.2  182.1 -46.3  179.9 -32.3 -99.0  0.0
ar001       500.0  Gh  1 0.03819 297.1 -52.3  186.4 -46.8  183.3 -33.0 -99.0  0.0
ar001       525.0  Gh  0 0.04106 295.1 -61.3  173.2 -46.8  172.6 -32.5 -99.0  0.0
ar001       550.0  Gh  1 0.03077 296.3 -50.0  189.5 -45.8  185.9 -32.2 -99.0  0.0
ar001       575.0  Gh  1 0.02653 286.7 -45.4  192.7 -38.2  189.5 -24.9 -99.0  0.0
ar001       600.0  Gh  1 0.02135 275.9 -58.4  174.3 -36.8  173.7 -22.6 -99.0  0.0
ar001       625.0  Gh  1 0.01157 311.8 -50.5  191.0 -55.7  185.8 -42.1 -99.0  0.0
ar001       650.0  Gh  5 0.00533 292.8  33.5  262.9   6.8  264.5   5.9 -99.0  0.0
```

Figure A1.2. LASA data file format for demagnetization data.

```
COR_example_file.COR
 Name        Field (mT) Squid_x      Squid_y      Squid_z (emu)
U1507B001    0.0     -1.19518E-4  -5.55012E-5  -1.09887E-4
U1507B001    5.0     -1.13729E-4  -6.24101E-5  -1.07915E-4
U1507B001   10.0     -1.02764E-4  -6.26037E-5  -9.84553E-5
U1507B001   15.0     -9.09908E-5  -5.77228E-5  -8.78316E-5
U1507B001   20.0     -7.97847E-5  -5.17261E-5  -7.77476E-5
U1507B001   25.0     -6.98384E-5  -4.60461E-5  -6.90506E-5
U1507B001   30.0     -6.09014E-5  -4.06279E-5  -6.10760E-5
U1507B001   35.0     -5.41789E-5  -3.64687E-5  -5.48418E-5
U1507B001   40.0     -4.95503E-5  -3.33774E-5  -5.00430E-5
U1507B001   45.0     -4.44535E-5  -3.00566E-5  -4.54666E-5
U1507B001   50.0     -3.98352E-5  -2.81075E-5  -4.14571E-5
U1507B001   60.0     -3.35216E-5  -2.36917E-5  -3.49746E-5
U1507B001   70.0     -2.78695E-5  -1.93478E-5  -2.92240E-5
U1507B001   80.0     -2.38148E-5  -1.67695E-5  -2.58164E-5
U1507B001   90.0     -1.94629E-5  -1.39544E-5  -2.14934E-5
U1507B001  100.0     -1.57446E-5  -1.15818E-5  -1.77652E-5
```

Figure A1.3. Bremen (.cor) data file format for demagnetization data.

```
koa001a
    koa001a  koa001a
    0.0  78.0  49.0  68.1  35.1  11.0
TH  20  24.4 -31.5 357.2 -51.4 5.10E-07   1.1 316.6   2.3  0.0000  0.0000  0.0000
TH 100  34.6 -23.0  16.5 -49.6 6.82E-08   1.3 319.2  14.3  0.0000  0.0000  0.0000
TH 150  22.6 -30.3 356.5 -49.6 5.55E-08   3.5 314.7   2.2  0.0000  0.0000  0.0000
TH 250   9.3 -51.9 318.2 -55.8 5.74E-08   2.1 322.2 -20.3  0.0000  0.0000  0.0000
TH 300 355.9 -58.8 301.8 -52.2 6.63E-08   1.3 323.4 -30.5  0.0000  0.0000  0.0000
TH 325 352.7 -61.1 297.3 -51.9 6.40E-08   1.1 325.0 -33.0  0.0000  0.0000  0.0000
TH 350 350.6 -60.6 297.2 -50.7 6.28E-08   1.6 323.9 -33.7  0.0000  0.0000  0.0000
TH 375 351.5 -64.0 292.7 -52.5 5.74E-08   1.9 327.8 -34.7  0.0000  0.0000  0.0000
TH 400 357.1 -62.2 297.0 -54.2 5.20E-08   1.1 327.3 -31.7  0.0000  0.0000  0.0000
TH 425 359.3 -64.6 293.7 -55.9 4.51E-08   1.0 330.3 -32.0  0.0000  0.0000  0.0000
TH 450  11.1 -61.4 302.2 -60.3 3.52E-08   1.1 330.7 -25.7  0.0000  0.0000  0.0000
TH 475   1.3 -61.3 299.7 -55.7 3.00E-08   1.7 327.6 -29.5  0.0000  0.0000  0.0000
TH 500  14.8 -73.0 278.0 -62.0 1.60E-08   1.8 342.1 -31.9  0.0000  0.0000  0.0000
TH 525 220.7 -75.3 239.1 -41.4 5.01E-09   6.1  14.4 -51.9  0.0000  0.0000  0.0000
TH 550 193.6   2.8 186.9  21.9 7.95E-09   3.0 109.5 -17.1  0.0000  0.0000  0.0000
TH 575 264.6  49.6 317.3  78.7 2.21E-09  12.1 184.3   0.8  0.0000  0.0000  0.0000
TH 600   6.9 -75.0 274.7 -59.5 5.19E-09   2.7 342.6 -34.8  0.0000  0.0000  0.0000
```

Figure A1.4. CIT data file format for demagnetization data.

This is the *Sample Data File* format designed for *PaleoMag X*. For details, please follow this link:

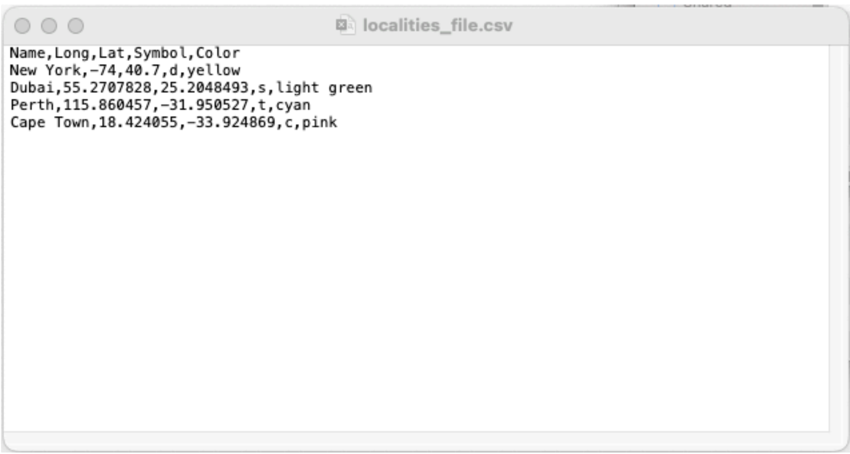
https://cires1.colorado.edu/people/jones.craig/PMag_Formats.html

Appendix 2: Custom APWP file format

```
APWP_file_example.csv
Age,Long,Lat,A95
10,0,85,3.5
20,0,75,4
30,0,65,3.5
40,0,55,3
50,0,45,4
60,10,40,2.5
70,20,35,5
80,30,30,6
90,40,25,5
100,50,20,4
```

Figure A2.1. Example of external APWP file.

Appendix 3: Sites file for mapping tool



localities_file.csv

```
Name,Long,Lat,Symbol,Color
New York,-74,40.7,d,yellow
Dubai,55.2707828,25.2048493,s,light green
Perth,115.860457,-31.950527,t,cyan
Cape Town,18.424055,-33.924869,c,pink
```

Figure A3.1. Example of Sites file to upload on the Site map page.