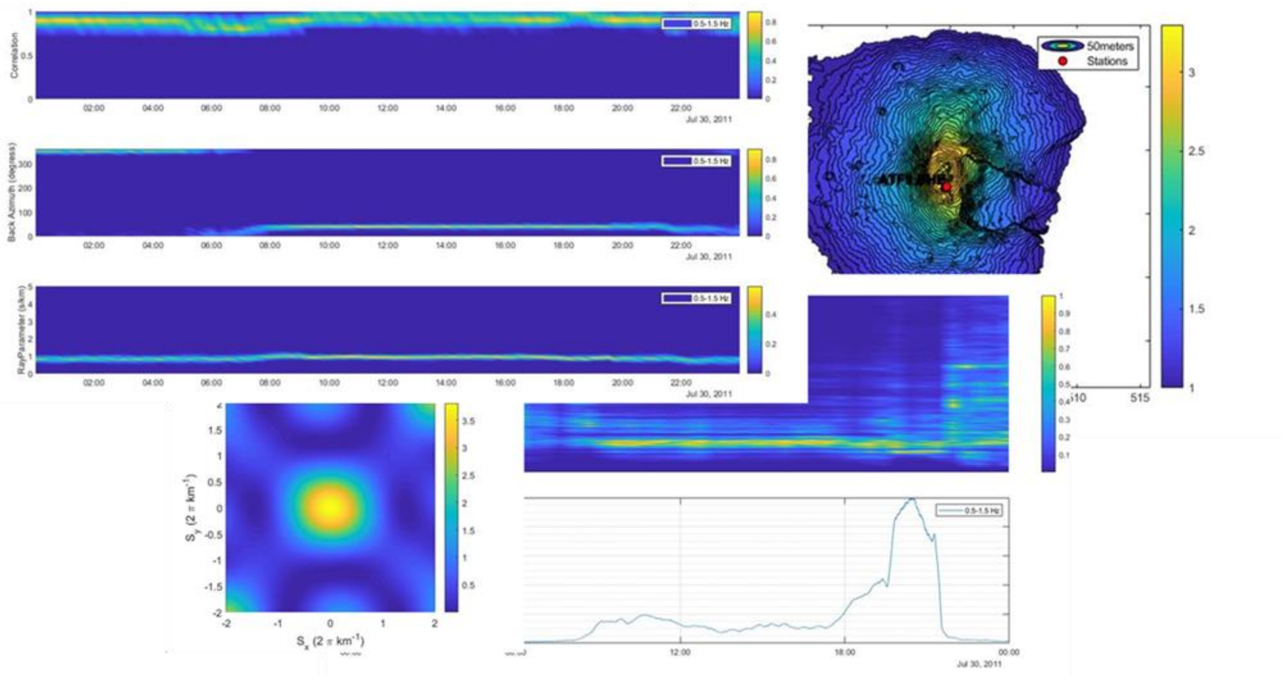
MISARA 1.0.1

User Manual



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1. Introduction

MISARA (Matlab Interface for Seismo-Acoustic aRray Analysis) is a open-source Matlab-based GUI designed to perform analyses of seismic and acoustic waveform data. A suite of well-established algorithms for volcano seismic and acoustic signal processing have been integrated into our GUI interface, with a special focus on array techniques (for more details, see Rost and Thomas, 2000). We note that although MISARA was developed to facilitate the analysis of seismic and acoustic signals in volcanic environments, it can be used for other research purposes. Furthermore, owing to its modular structure, it is possible to easily integrate additional functionalities.

The different data analysis modules of MISARA are independent of each other. The modules were designed to easily manage every step of the data processing and to quickly inspect the results. Most of the processes are automated, reducing user's errors and efforts. One advantage consists of the possibility to reset some parameters directly from the module itself, allowing to repeat the analysis many times. Other fundamental aspects of this modular structure are the possibility to deal with different formats of input traces, the systematic saving of the results and the optional activation of many subroutines.

The main structure of the interface consists of:

- Home window, the main panel for the management of all utilities of MISARA.
- Data preparation window, for the formatting of the Input data.
- Data Pre-processing modules, for the data quality control.
- Signal Features modules, for those analytic routines that support the array methods, such as spectral, amplitude, polarization and detection analysis.
- Array analysis modules, for the source localization methods based on the multichannel techniques.

In next sections, you will find a detailed description about MISARA utilities and functionalities.

1.1 Requirements

MISARA can be run on any operation system with Matlab from Release 2021b. In addition, you need to have the following toolboxes installed:

- Control System Toolbox, version 10.5.
- Financial Toolbox, version 5.12.
- Mapping Toolbox, version 4.7.
- Signal Processing Toolbox, version 8.1.
- Statistics and Machine Learning Toolbox, version 11.4.
- Wavelet Toolbox, version 5.1.

1.2 Citation

This is a modified version of the GSpecDisp package (Sadeghisorkhani et al., 2017).

If you use this code for your work, please cite the following DOI:

- 10.5281/zenodo.7410076

1.3 License

MISARA is free software: you can redistribute it and/or modify it under the terms of the GNU General Public License as published by the Free Software Foundation, either version 3 of the License, or (at your option) any later version. MISARA is distributed in the hope that it will be useful, but WITHOUT ANY WARRANTY; without even the implied warranty of MERCHANTABILITY or FITNESS FOR A PARTICULAR PURPOSE. See the GNU General Public License for more details. You should have received a copy of the GNU General Public License along with the program. If not, see http://www.gnu.org/licenses/.

1.4 Contact

You can send an email to vittorio.minio@phd.unict.it to report suggestions, comments and bugs.

1.5 Starting MISARA

After you have downloaded the software, you should unzip the source code to a suitable directory. To start MISARA, you should run “MISARA.m” by pressing F5 in the Matlab editor. The software automatically sets the main paths and functions, but it requires the installation of the “GIPPtools” and “irisFetch” libraries. For any information, see the section 2.1. After the running, the Home Window (Fig. 1) appears on the screen, allowing you to set the analysis parameters and to use all modules. To test the software, you can refer to “Video Tutorial” from the “Help” menu located in the upper-right part of the Home Window (Fig.1).

The purpose of these video tutorials is to train users to perform different types of analyses of seismic and acoustic waveform data acquired in volcanic environment. In particular they are grouped into three sections. They show you a series of brief tutorials on how to use the software on three real cases studies. In First one, we will perform the analysis of volcanic tremor recorded by a seismic array deployed at Mt. Etna (Italy) in 2011, when the volcano produced intense lava fountain activity from its New South East Crater (NSEC; for more details about volcanic activity, see Bencke et al, 2014). In the second one, we will demonstrate analyses of Long Period (LP) and Very Long Period (VLP) earthquakes recorded by Mt. Etna permanent seismic network in 2010, accompanying explosive activity at the Bocca Nuova crater (BN; for more details about volcanic activity, see Andronico et al, 2010). In the third one, we will show how to analyse the infrasound data acquired by an infrasound array deployed at Mt. Etna in 2019, when the NSEC crater was affected by intense Strombolian activity (for more details about volcanic activity, see De Angelis et al, 2020). The raw data that we will use in these tutorials are in the “MISARA/Data_org/” directory. However, it is possible to use the Matlab data format located in “MISARA/Data_example/” directory.

2. Home Window

The Home Window is the control panel of MISARA, which allows to manage all aspects of data processing, including data source configuration, Input/Output options and the parametrization of all analyses that can be performed on the selected data (Fig 1). For the formatting of the data, it is possible to access to a specific module by the button positioned in the left part of the panel. The analysis modules can be called by the buttons that are located in the left and lower parts of the panel. For the management of the parameters, the Home Window has four menus, which allow it to save and import the latest or the default parameters by the three buttons placed in the lower part of the current menu. These buttons work independently in each of these menus, and it is necessary to save the analysis parameters in every menu to be applied in the subsequent steps. For this reason, we refer these parameters as "fixed parameters", in such way that they are distinguished from the "temporary parameters" used in every module. While the fixed parameters are in the "MISARA/parameters/" folder, the temporary ones are temporarily created exclusively for the single module routines. Notice that the mistakes in the data entry are automatically corrected through the loading of the latest saved parameters. In the following subsections, you will know more about the main elements of the Home Window. In addition, you can find a brief overview of the fixed/temporary parameters at the end of each subsection.

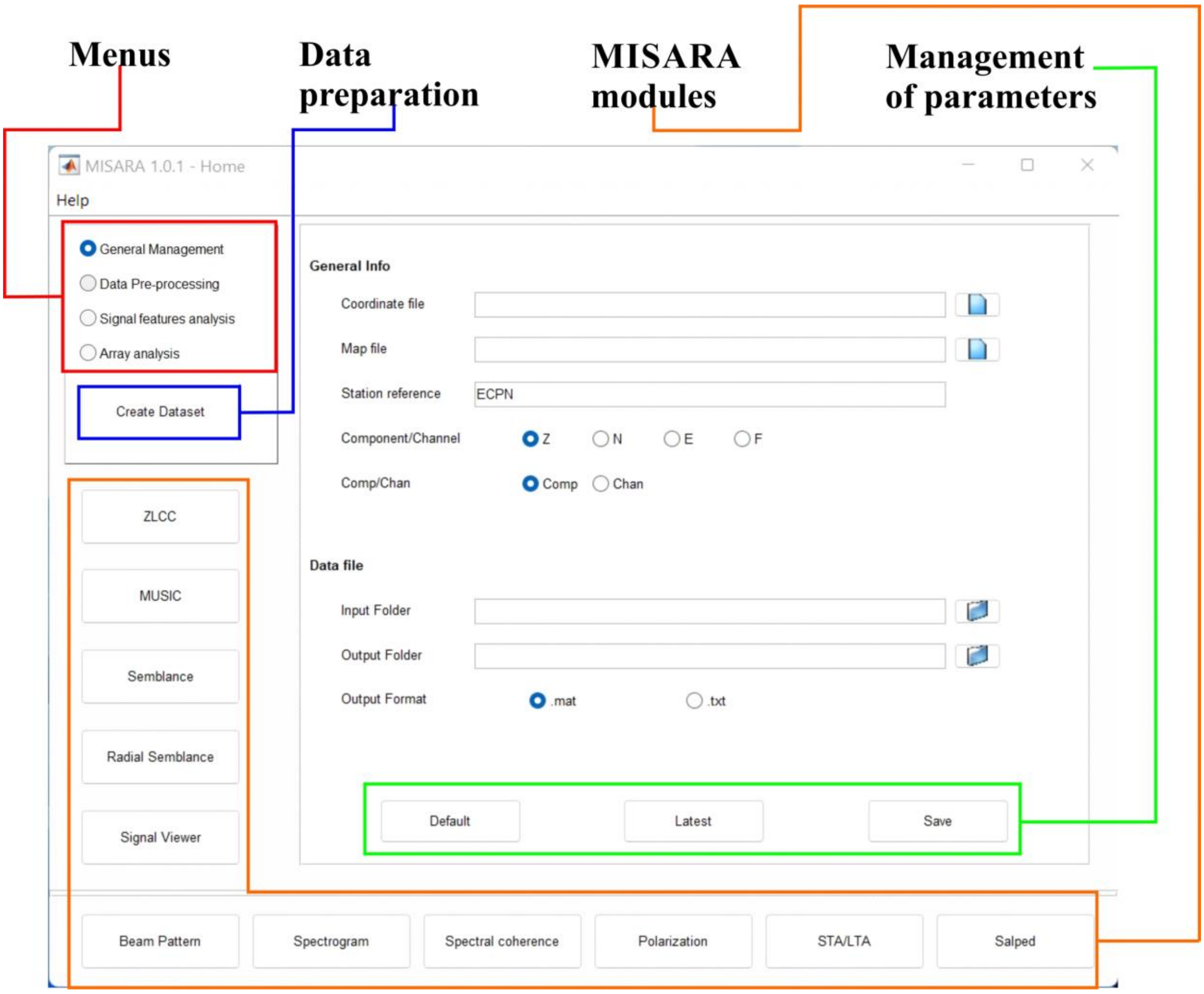

Fig. 1. The Home Window

2.1 Seismo-Acoustic Data Preparation

Before running the MISARA modules, it is necessary to prepare specific data structures in order to ensure the proper functioning of the software. Generally, MISARA works with seismo-acoustic traces expressed in a specific Matlab format (structure arrays) and with specific file and folder names. In particular, these files contain all the information about the trace (e.g., station name, amplitude of the signal etc…) and are formatted on the basis of the structure showed in the figure 2.a. Each of these files must be also written using the following path form: /jld/SSSS.CCC.yyyy.jld.hhmmss.mat, where SSSS, CCC, yyyy, jld, hh, mm, ss represent the station name, the channel/component, the year, the Julian day, the hours, the minutes and the seconds of reference, respectively. In addition, MISARA modules work through some Matlab files/structures linked to the station coordinates (Fig. 2.c and Fig. 2.d) and the parameters for the instrument response correction (Fig 2.b).
In order to address these issues, MISARA has an entire module that is called "Create Dataset" (Fig.3). This module allows to read and convert archive and/or IRIS web-service data into the main data structures used by the software. In particular, in the "Prexisting file" section (Fig. 3), you can:

- Set the automatic mode for formatting the data. You can automatically read and convert specific types of archive data, but only if the XML (eXtensible Markup Language) files are available for each station and component/channel. In this case any information about station (e.g., geographic coordinates, parameters for the Instrument Response correction) are automatically read by the software. In the automatic mode you can:
    - Set the paths of the reading archive data and the saving results. In order to define the I/O folders, you can click on the folder icons that are located beside the text-boxes or you can type in the text-boxes. Notice that you must set the Output folder to start the conversion/save process.
    - Set the path containing the XML files. In order to define this directory, you can click on the folder icon that is located beside the text-box or you can type in the text-box. Notice that you must set this directory to start the conversion/save process.
    - Set the name of the station of reference. For the searching of the Input files, you can type the key word in the text-box. Notice that the change of this parameter clears the list of the selected files.
    - Set the Component or Channel of the reference station. You can choose the component/channel for the searching of the Input files. Notice that "Component system" refers to three component station system (Z-vertical, N-horizontal, E-horizontal), while "Channel system" refers to vertical single component station system (Z, N, E for the seismic station; F for the infrasonic station). Notice that the change of this parameter clears the list of the selected files.
    - Set the format of the Input files. You must choose the format of the reading archive data in order to perform the correct process of conversion. In particular, MISARA supports the following formats: Seismic Analysis Code (SAC), The Standard for the Exchange of Earthquake Data (miniSEED) and DSS-Cube/Data-Cube3 file format. Notice that, for the conversion of the DSS-Cube/Data-Cube3 files, MISARA needs the

installation of the "GIPPtools" package in the module directory (MISARA/CreateData/). For any information about this utility, you can use this link: https://www.gfz-potsdam.de/en/section/geophysical-imaging/infrastructure/geophysical-instrument-pool-potsdam-gipp/software/gipptools/.

  - Load the seismo-acoustic traces through the "Open files" (manual selecting) and "Open folder" (all files which are in the defined folder and sub-folders) buttons.
  - Convert/Save the formatted files in the Output folder through the "Save" button. You can perform the processes of conversion and saving of the archive files using the path-form that is explained above. In addition, this module automatically creates and saves the data structures of the station coordinates and instrumental response. Indeed, during the processing, the module provides the station coordinates into both Universal Transverse Mercator coordinates (UTM) and World Geodetic System 1984 (WGS84), and it automatically saves these parameters (Fig. 2.c and Fig. 2.d) as "/coordinate/coordinate_deg.mat" (WGS84) and "/coordinate/coordinate_m.mat" (UTM) in the selected Output folder. The module also saves the parameters for instrument response correction (Fig. 2.b) as "/Instrument response/correction_parameters.mat" in the selected Output folder. Notice that, during the processing, every command, error and/or warning messages are shown in the text window that is in the lower part of the panel (Fig. 3).

- Set the manual mode for formatting the data. Overall, the manual mode is very similar to the automatic one. You can read and convert specific types of archive data but only for one station and component/channel at time. This mode can be used to manually check/insert any information about station (e.g., geographic coordinates, parameters for the Instrument Response correction). In addition to the common setting of the parameters explained in the previous paragraph, you can:
  - Select manually the XML file of the station of reference by clicking on the file icon located beside the text-box or typing in the text-box. In this case, any information about the station of reference (e.g., geographic coordinates, parameters for the Instrument Response correction) automatically appear on their respective boxes. If the XML file is not available, you can set manually every parameter.
  - Check/Set manually the geographic coordinates of the reference station on the basis of the World Geodetic System 1984 (WGS84). Notice that if you don't type in these text-boxes, then the software returns vectors of "Not a Number" values (NaN).
  - Check/Set manually the parameters for the Instrument Response correction. Notice that if you don't type in these text-boxes, then the software returns vectors of "Not a Number" values (NaN).

In the "Prexisting file" section, the software DON'T automatically perform the instrument response correction, but only the conversion of the traces from counts to m/s or from counts to Pa for seismic and acoustic traces, respectively. Indeed, the instrument response correction of the traces is an optional routine and it could be activated in the Signal Viewer module (see section 3.2)

In the "IRIS file" section (Fig. 3), you can:

- Set the path of the saving results. In order to define the Output folder, you can click on the folder icon that is located beside the text-box or you can type in the text-box. Notice that you must set the Output folder to start the retrieving/saving process.
- Set the name of the reference network.
- Set the name of the reference station.
- Set the location code.
- Set the channel code.
- Set the initial and final time of the trace. Notice that you must use the follow time form: yyyy-MM-DD hh:mm:ss.mat, where yyyy, MM, DD, hh, mm, ss represent the, the year, the month, the day, the hours, the minutes and the seconds of reference, respectively.
- Retrieve/Save the formatted files in the Output folder through the "Save" button. You can access to data stored within the IRIS-DMC via FDSN services and you can retrieve waveforms with channel metadata. The processing of the IRIS Web Service files includes the path-form that is explained above. In addition, this module automatically creates and saves the data structures of the station coordinates and instrumental response as well as explained in the archive data section. Notice that, during the processing, every command, error and/or warning messages are shown in the text window that is located in the lower part of the panel (Fig. 3). Moreover, MISARA needs the installation of the "irisFetch" library in the module directory (MISARA/CreateData/). For any information about these utilities, you can use this link: http://ds.iris.edu/ds/nodes/dmc/software/downloads/irisFetch.m/2-0-6/manual/.

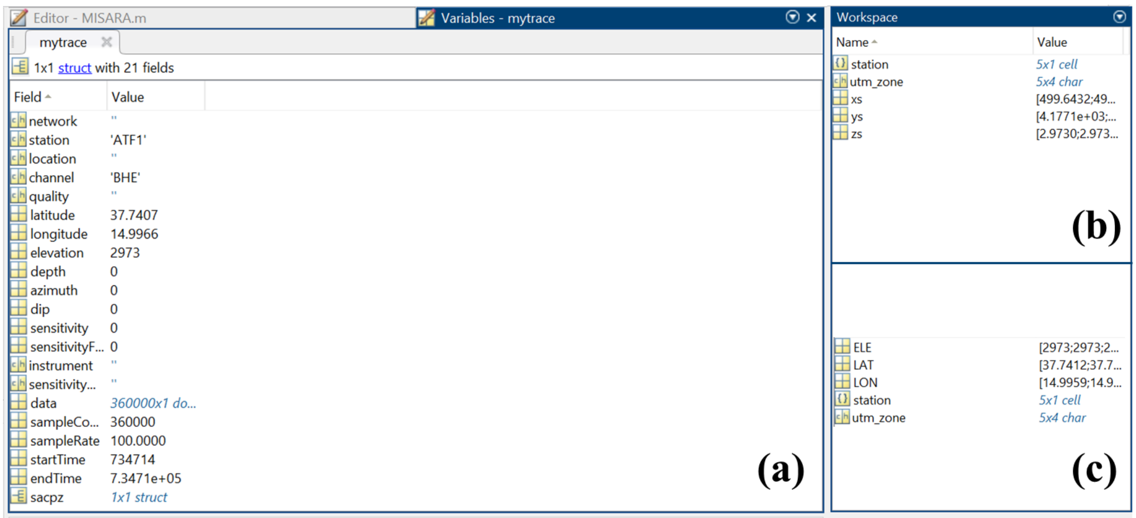

Fig. 2. Examples of the main data structures of MISARA. a) Structure array of a generic seismo-acoustic trace. b) Table of instrument response correction parameters. c) Arrays of the station name and coordinates (UTM system). d) Arrays of the station name and coordinates (WGS84 system).

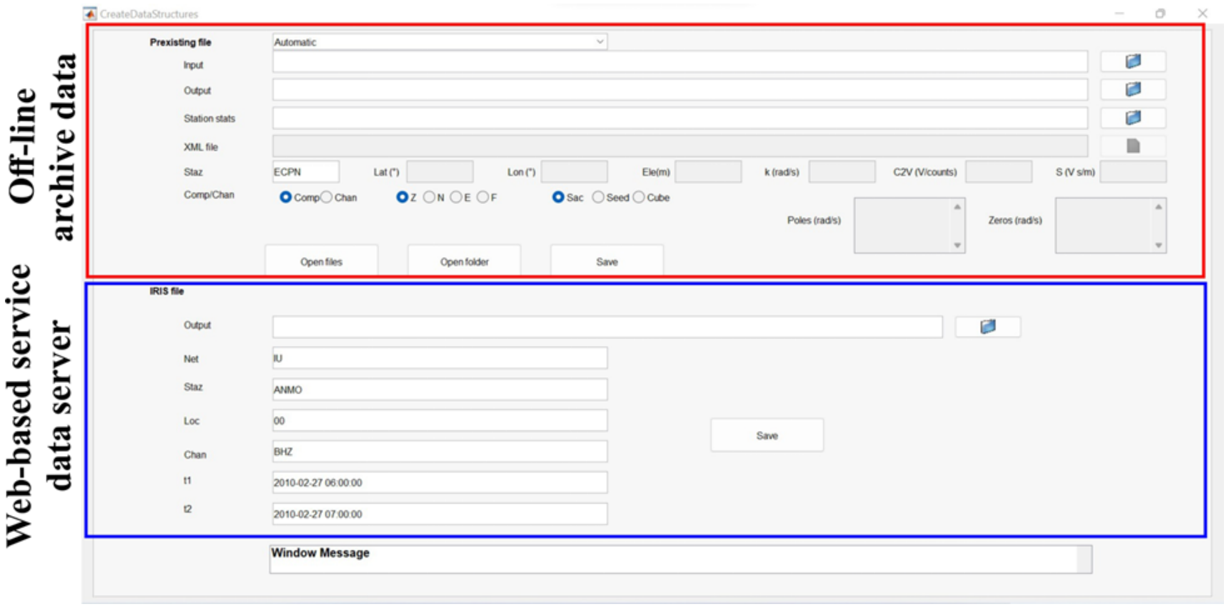

Fig. 3. The Data Preparation Window.

2.1.1 Description of temporary parameters

- **Pre-existing files**
  - Mode: Automatic or manual formatting of the data
  - Input: Path of the Raw data (Automatic/Manual)
  - Output: Path of the Converted data (Automatic/Manual)
  - Station stats: Path of XML files (Only Automatic)
  - XML file: Path and name of XML file. (Only manual)
  - Comp/Chan: Component or Channel of the station and format of the Raw data (Automatic/Manual)
  - Staz: Name of the station (Automatic/Manual)
  - Lat: Latitude of the station (decimal degrees; Only manual)
  - Lon: Longitude of the station (decimal degrees; Only manual)
  - Ele: Elevation of the station (m; Only manual)
  - k: Calibration coefficient (rad/s; Only manual)
  - C2V: Coefficient for conversion from bits to Volts (V/counts; Only manual)
  - S: Coefficient for conversion from Volts to m/s (V s/m; Only manual)
  - Poles: Instrument poles from factory calibration worksheet (rad/s; Only manual)
  - Zeros: Instrument zeroes from factory calibration worksheet (rad/s; Only manual)

- **IRIS data**
  - Output: Path of the Output data
  - Net: Name of the network
  - Staz: Name of the station
  - Loc: Location code
  - Chan: Channel of reference
  - t1, t2: Temporal references of the traces

2.2 General management Menu

This menu of MISARA is dedicated to the management of those parameters used by almost all modules. In particular, in the "General Info" section (Fig. 4), you can:

- Load a Matlab (.mat) file about the station coordinates. This file represents one of the most important data structures of MISARA, because, in the most of modules, the search of multi-station traces is based on the information available in this file. In order to define the location of the file, you can click on the file icon that is located beside the text-box or you can type in the text-box. In this case, you must select one of the two files ("/coordinate/coordinate_deg.mat" or "/coordinate/coordinate_m.mat") automatically created during the process of formatting (see section 2.1). Notice that you must set this path-file to ensure the complete running of the others MISARA modules. After the loading, MISARA automatically overwrites the file with the sorted version of the parameters.
- Load a GeoTIFF (.tif) file about the Digital Elevation Model (DEM) of the region of interest. Eventually, you can read a map file of your region that it will be the base map for some presentations of the results. Notice that the setting of this parameters is optional. In order to define the location of the file, you can click on the file icon that is located beside the text-box or you can type in the text-box. After the loading, MISARA automatically saves the DEM variables as "/parameters/mapfile_deg.mat" (WGS84) and "/parameters/mapfile_m.mat" (UTM system) in the parameters folder.
- Set the name of the station of reference. For the searching of the Input files, you can type the key word in the text-box.
- Set the Component or Channel of the reference station. You can choose the component/channel for the searching of the Input files.

In the "Data file" section, you can:

- Set the paths of the reading data and the saving results. In order to define the I/O folders, you can click on the folder icons that are located beside the text-boxes or you can type in the text-boxes. Notice that you must set the Output folder to start the save process in the MISARA modules.
- Set the format of the saving results. You can save the Output files as a Matlab (.mat) or a text file (.txt). More information about the format of the saving results is available in "MISARA modules" section.

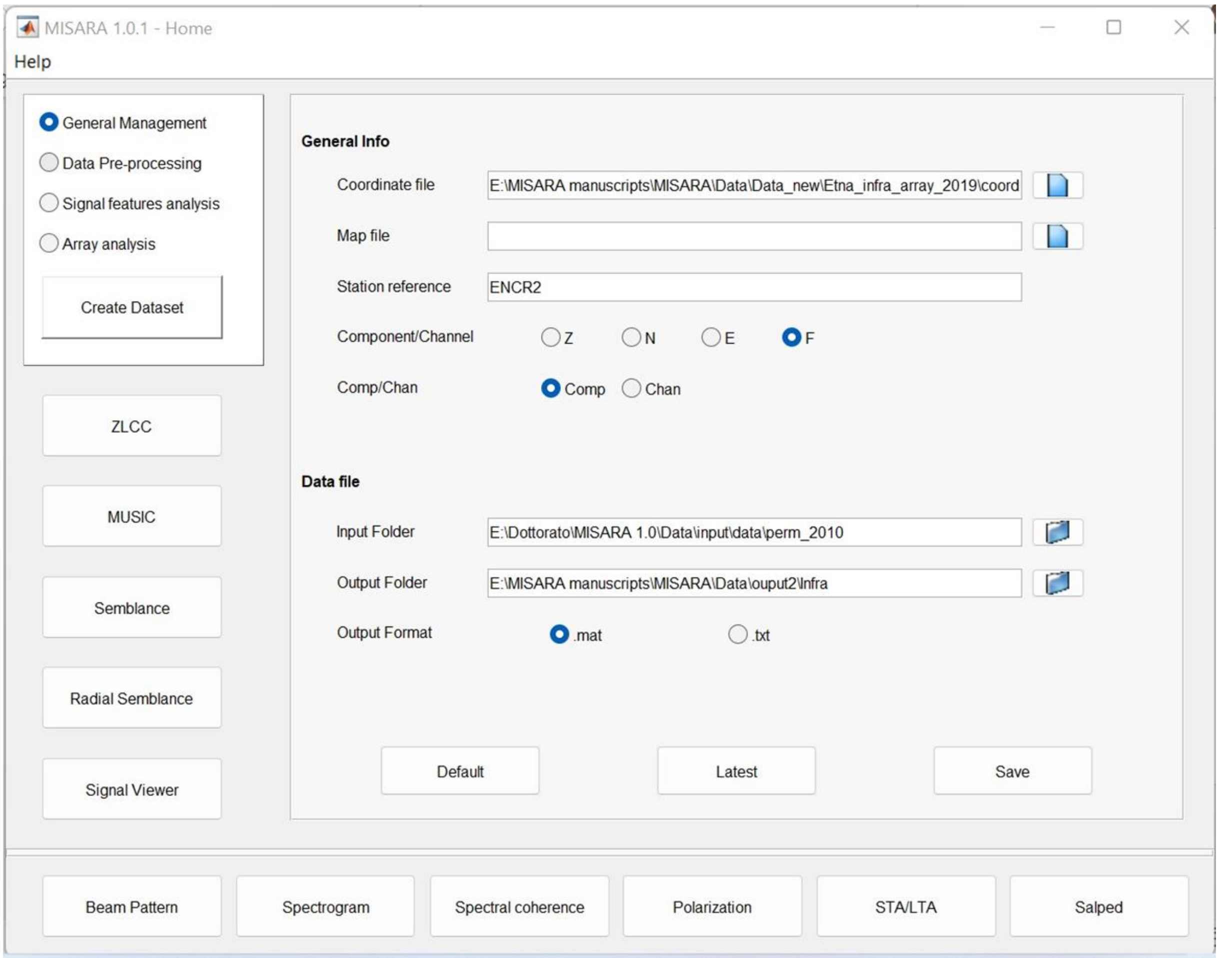

Fig. 4. The Home Window-General Management Menu.

2.2.1 Description of fixed parameters

- **General Info**
  - Coordinate file: File containing station names and coordinates vectors (.mat)
  - Map file: DEM file of the region of interest (.tif)
  - Station reference: Name of the reference station
  - Component/Channel: Component or Channel of the reference station
  - Comp/Chan: Using three component or one component station system
- **Data file**
  - Input Folder: Main path of the Input data
  - Output Folder: Main path of the Output data
  - Output Format: Saving format of the analysis results

2.3 Data Pre-processing Menu

In this menu you can set the fixed parameters used by the “Beam Pattern” and “Signal Viewer” modules.
In particular, in the “Coordinate system/Beam Pattern setting” section (Fig. 5), you can:

- Set the geographic coordinates system. This parameter is very important for those routines of MISARA that involve the station coordinates and the base map of the region of interest. You can choose one of two options: m (UTM system) and degrees (WGS 84). Notice that many modules of MISARA works in UTM coordinate system and. So, if you want to prevent further automatic routines of conversion, we recommend to use the default setting.

- Set the analysis frequencies for the Beam pattern method (see Capon, 1969). You can type the minimum, the maximum and the step values of the frequency analysis in their respective text-boxes.
- Set the dimension of the slowness grid for the “Beam pattern” module. You can type the minimum and the maximum values of the Npoint x Npoint slowness grid in their respective text-boxes.

In the “Instrument correction setting” section (Fig. 5), you can:

- Load a Matlab (.mat) file about the instrument response parameters (optional). In order to define the location of the file, you can click on the file icon that is located beside the text-box or you can type in the text-box. In this case, you must select the file (“/Instrument response/correction_parameters.mat”) automatically created during the process of formatting (see section 2.1). Notice that you must set this path-file to ensure the complete running of the instrument response correction routine only in the “Signal Viewer” module (see section 3.2). After the loading, MISARA automatically overwrites the file with the sorted version of the parameters.
- Set the paths of the uncorrected data and the saving corrected data (optional). In order to define the I/O folders, you can click on the folder icons that are located beside the text-boxes or you can type in the text-boxes. Notice that you must set the Output folder to start the correction and saving routines only in the “Signal Viewer” module (see section 3.2).

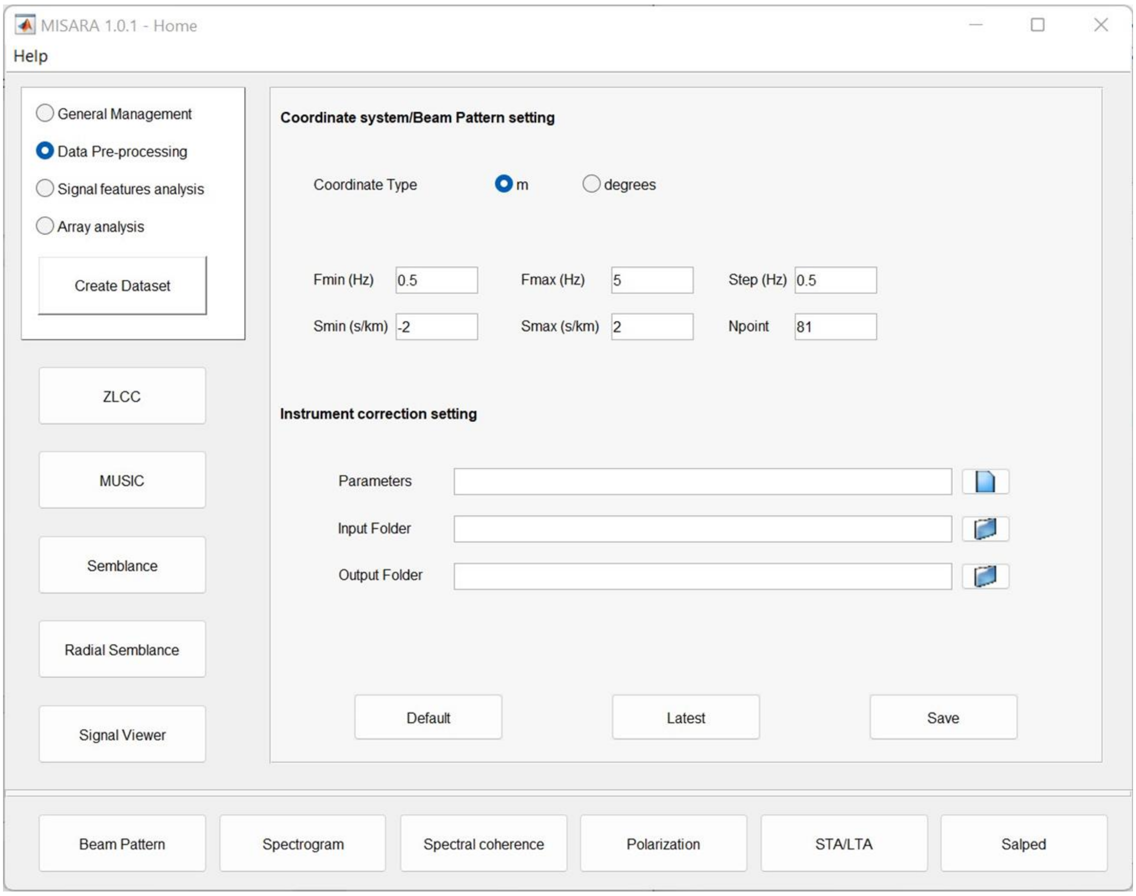

Fig.5. The Home Window-Data Pre-processing Menu.

2.3.1 Description of fixed parameters

- **Coordinate system/Beam Pattern setting**
  - Coordinate Type: Using UTM or WGS84 coordinate system (metrics/decimal degrees)
  - Fmin: Minimum frequency of the analysis range (Hz)
  - Fmax: Maximum frequency of the analysis range (Hz)
  - Step: Frequency step of the analysis range (Hz)
  - Smin: Minimum value of the slowness grid (s/km)
  - Smax: Maximum value of the slowness grid (s/km)
  - Npoint: Number of slowness grid nodes
- **Instrument correction setting**
  - Parameters: File containing a table about the instrument response parameters (.mat)
  - Input Folder: Path of the Input data
  - Output Folder: Path of the Output data

2.4 Signal features analysis Menu

This menu is dedicated to management of the parameters used during the extraction of the main features of the seismic/acoustic signals or during the automatic individuation of the seismo-acoustic events.

In the "Spectral setting" (Fig. 6),
you can:

- Set the fixed parameters for the "Spectrogram" module. You can fix the parameters for the application of the Fast Fourier Transform algorithm (FFT-see Cooley and Tukey, 1965 or Schlindwein et al., 1995 for the method), such as the analysis window, the dimension of the spectrums, the cut-off frequency of the high-pass filter and the number of Discrete Fourier Transform (DFT) in the time. You can type the parameter values in their respective text-boxes.
- Set the fixed parameters for the "Spectral coherence" module. You can define the parameters in order to perform the calculation of the "Magnitude-Squared Coherence" function (MSC-for more details, see Welch, 1967). In particular, you can set the dimension of the spectrums, the cut-off frequency of the high-pass filter and the number of the stations by typing in their respective text-boxes.

In the "RMS setting" (Fig. 6), you can:

- Set the fixed parameters for the "Spectrogram" and "Spectral coherence" modules. For the calculation and visualization of the Root Mean Square (RMS-see Kenney and Keeping, 1962 for the method) of the traces, you can type the parameters, such as the analysis window, the frequency bands and the averaging factor, in their respective text-boxes.

In the "Polarization setting" (Fig. 6), you can:

- Set the fixed parameters for the "Polarization" module. You can set the necessary parameters related to the calculation and visualization of the Polarization attributes (see Jurkevics, 1988 for the method) of the traces. You can type the values of the analysis window, the frequency bands and the averaging factor in their respective text-boxes.

In the "Detection setting" (Fig. 6), you can set the parameters used by "STA/LTA" and "Salped" modules. In this case, the two modules share some of the input parameters (see section 2.4.1). In this setting section, you can:

- Set the fixed parameters for the "STA/LTA" module. The application of the Short Term Average/Long Term Average method (STA/LTA-see Allen, 1978) requires the definition of some parameters, such as the analysis windows, the cut-off frequencies for the band-pass filter and the threshold of the detection. You can type their values in their respective text-boxes.
- Set the fixed parameters for the "Salped" module. You can fix the necessary parameters for the application of the Subband-based Automatic LP Events Detection algorithm (SALPED-see Garcia et al., 2017 for the method), such as the

extraction windows, the cut-off frequencies for the band-pass filters and the threshold of the detection. You can type the parameter values in their respective text-boxes.

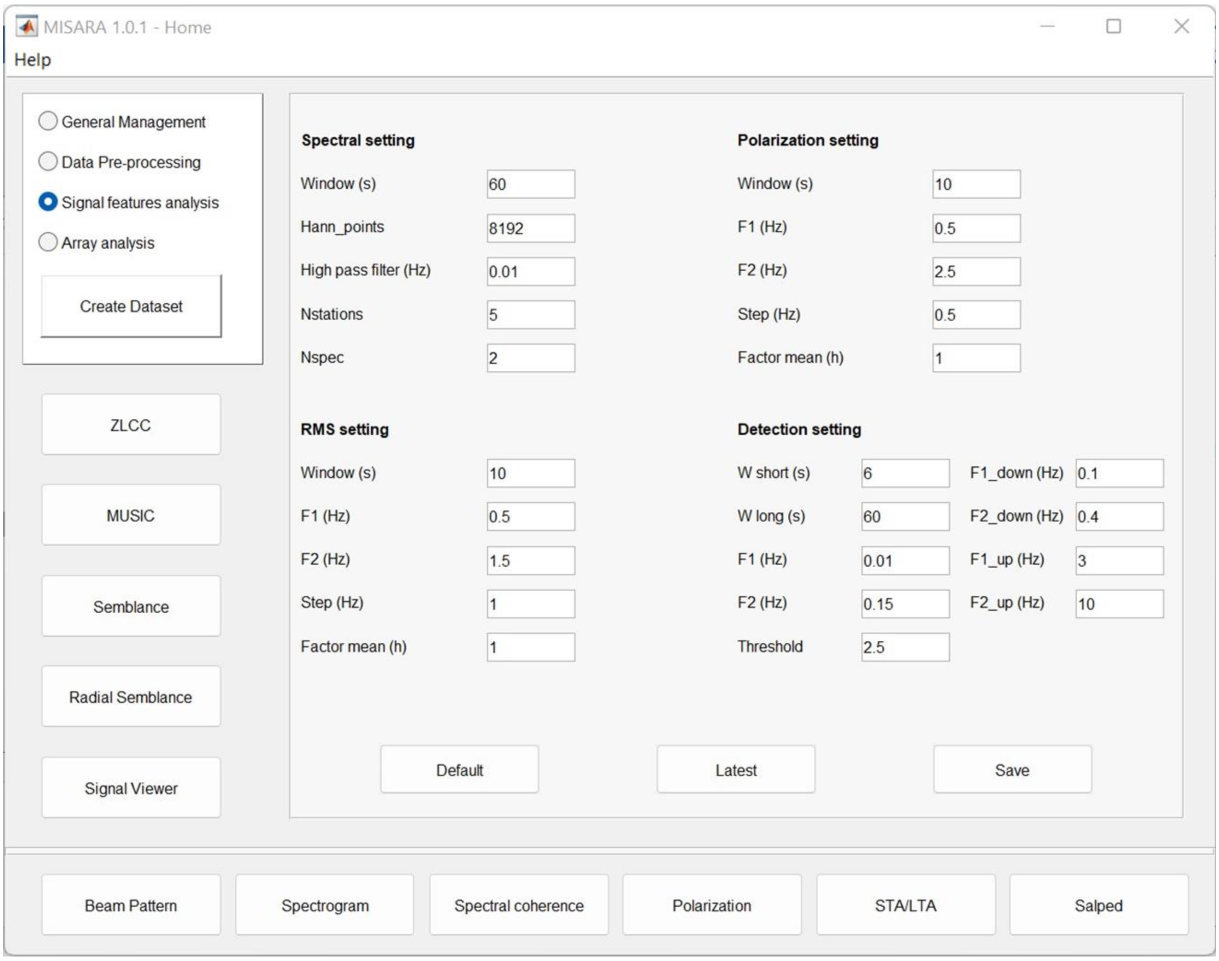

Fig.6. The Home Window-Signal features analysis Menu.

2.4.1 Description of fixed parameters

- **Spectral setting**
  - Window: Length of the window to calculate FFT (s)
  - Hann_points: number of points of the DFT
  - High pass filter: Frequency value for the High-pass filtering (Hz)
  - Nstations: number of stations to use for the Spectral coherence analysis
  - Nspec: number of DFTs per trace
- **RMS setting**
  - Window: Length of the window to calculate RMS (s)
  - F1: Minimum frequency of the analysis range (Hz)
  - F2: Maximum frequency of the analysis range (Hz)
  - Step: Frequency step of the analysis range (Hz)
  - Factor mean: Hours value for the moving average of the results (hours)
- **Polarization setting**
  - Window: Length of the window to calculate polarization attributes (s)

- F1: Minimum frequency of the analysis range (Hz)
- F2: Maximum frequency of the analysis range (Hz)
- Step: Frequency step of the analysis range (Hz)
- Factor mean: Hours value for the moving average of the results (hours)

- **Detection setting**
  - W short: Length of the Short Time window (s; STA/LTA and Salped)
  - W long: Length of the Long Time window (s; STA/LTA and Salped)
  - F1: Minimum frequency of the Central subband (Hz; STA/LTA and Salped)
  - F2: Maximum frequency of the Central subband (Hz; STA/LTA and Salped)
  - Threshold: detection threshold (STA/LTA and Salped)
  - F1_down: Minimum frequency of the Lower subband (Hz; Only Salped)
  - F2_down: Maximum frequency of the Lower subband (Hz; Only Salped)
  - F1_up: Minimum frequency of the Upper subband (Hz; Only Salped)
  - F2_up: Maximum frequency of the Upper subband (Hz; Only Salped)

2.5 Array analysis Menu

In this menu of MISARA you can manage the fixed parameters of some algorithms of the array analysis (see Rost and Thomas, 2002 for the topic), such as the Zero Lag Cross Correlation (ZLCC-see Frankel et al., 1991 for the method), the MUltiple SIgnal Classification method (MUSIC-see Schmidt, 1986 for the method), the Semblance (see Neidel and Tanner, 1971 for the method) and the Radial Semblance algorithms (see Almendros et al., 2002 for the method).
In the “Zero Lag CrossCorrelation setting” section, you can:

- Set the analysis window typing the value in the respective text-box.
- Set the frequency bands. You must define the minimum, the maximum and the step values of the frequency analysis typing in the respective text-boxes.
- Set the parameters for the calculation of the Cross Correlation coefficients, such as the max shifting delay values and the application of the cubic spline interpolation to the cross correlation series. Notice that you can set only the value of the parameter as 1 (activation) or 0 (deactivation).
- Set the waves velocity for the calculation of the incidence angle by typing the respective value in the text-box.

In the “MUSIC setting” section (Fig. 6), you can:

- Set the frequency band, typing the values of the central frequency and the number of interval frequencies in their respective text-boxes.
- Type the length of the Hamming window and the Prewhitening value in their text-boxes.
- Set the width and the spacing of the slowness grid typing in their respective text-boxes.
- Set the parameters that control the analysis window, such as the length, the initial position and the overlap.

- Type the number of sources for the visualization of the results by using the respective text box.

In the “Radial Semblance/Semblance setting” section (Fig. 6), you can set the parameters used by “Radial Semblance” and “Semblance” modules. In this case, the two modules share some of the input parameters (see section 2.5.1). In this setting section, you can:

- Set the fixed parameters for the “Radial Semblance” module. You can set the necessary parameters linked to the application of the algorithm. You can type the values of the analysis window, the frequency band, the waves velocity and the spatial limits of the search grid in their respective text-boxes. Notice that you can also define the activation (yes) or deactivation (no) of the topographic correction routine.
- Set the fixed parameters for the “Semblance” module. You can set the same parameter explained for the previous module. In addition, you can define the parameters for the amplitude decay of the signals with the source-station distance (see Battaglia et al., 2005 for more details), such as the quality factor, the waves velocity, the geometrical spreading and the frequency waves.

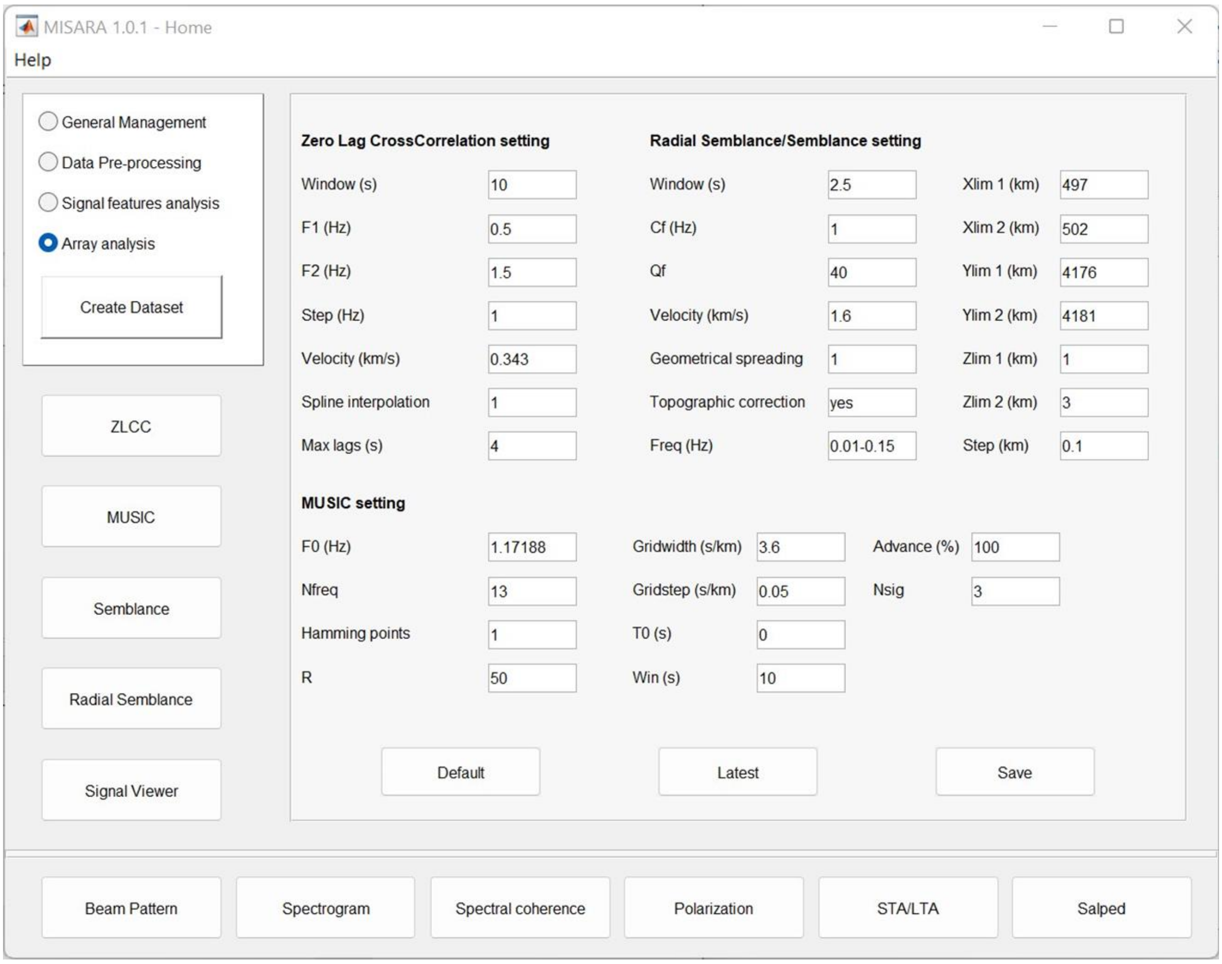

Fig.7. The Home Window-Array analysis Menu.

2.5.1 Description of fixed parameters

- **Zero Lag Cross Correlation setting**
  - Window: Length of the window to calculate kinematic attributes (s)
  - F1: Minimum frequency of the analysis range (Hz)
  - F2: Maximum frequency of the analysis range (Hz)
  - Step: Frequency step of the analysis range (Hz)
  - Velocity: Propagation velocity of the seismic/acoustic waves (km/s)
  - Spline interpolation: Activation/Deactivation of the Cubic spline interpolation (1/0)
  - Max lags: Max delay for the calculation of the Cross Correlation coefficient (s)
- **MUSIC setting**
  - F0: Central frequency of the analysis band (Hz)
  - Nfreq: Number of frequencies of the analysis band
  - Hamming points: Length of the Hamming window (samples)
  - R: Prewhitening factor
  - Gridwidth: Maximum width of the slowness grid (s/km)
  - Gridstep: Spacing between slowness grid nodes (s/km)
  - T0: Initial position of the analysis window along the trace (s)
  - Win: Length of the window to calculate kinematic attributes (s)
  - Advance: Percentage of advancement of the analysis window (%)
  - Nsig: Number of sources
- **Radial Semblance/Semblance setting**
  - Window: Length of the window to calculate Semblance values (s; Radial Semblance/ Semblance)
  - Cf: Central frequency of the analysis band (Hz; Radial Semblance/ Semblance)
  - Qf: Ray-path-averaged quality factor (Semblance)
  - Velocity: Propagation velocity of the seismic/acoustic waves (km/s; Radial Semblance/ Semblance)
  - Geometrical spreading: Geometrical spreading factor (Semblance)
  - Topographic correction: Activation/Deactivation of the topographic correction (yes/no; Radial Semblance/ Semblance)
  - Freq: Frequency range of analysis (Hz; Radial Semblance/ Semblance)
  - Xlim 1, Xlim 2: X-limits of the research grid (km; Radial Semblance/ Semblance)
  - Ylim 1, Ylim 2: Y-limits of the research grid (km; Radial Semblance/ Semblance)
  - Zlim 1, Zlim 2: Z-limits of the research grid (km; Radial Semblance/ Semblance)
  - Step: Step of the research grid (km; Radial Semblance/ Semblance)

3. MISARA Modules

MISARA has 11 modules, 2 for data pre-processing, 5 for the signal features analysis and 4 for the array analysis (Fig. 8). After setting the fixed parameters, you can access to these modules from the left and the lower parts of the Home Window (Fig. 1).

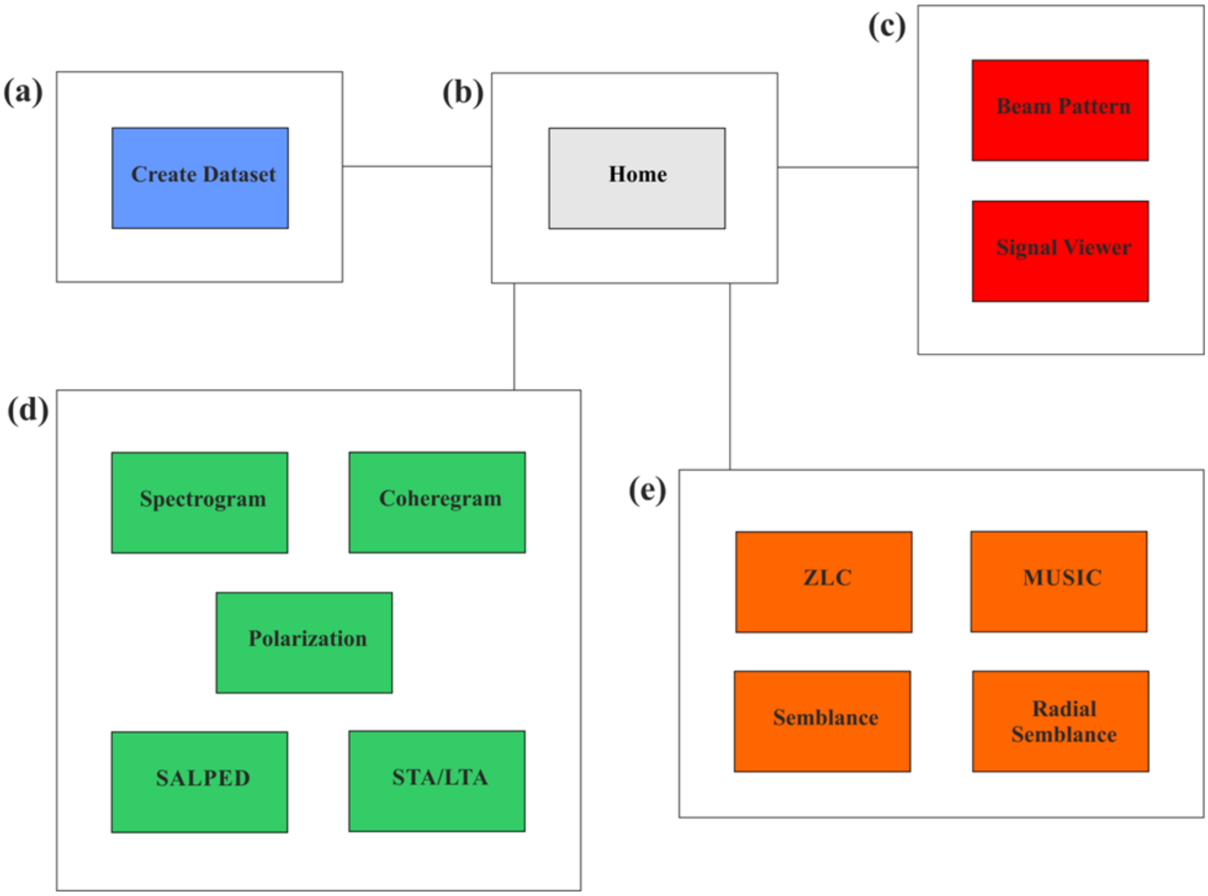

Fig.8. Schematic overview of MISARA. a) Data preparation window, for formatting the Input data. b) Home window, the main panel for the management of all the utilities of MISARA. c) Data Pre-processing, for the data quality control. d) Signal features modules, for those routines that support the array techniques, such as spectral, amplitude, polarization and detection analysis. e) Array analysis modules, for the source localization methods based on the multichannel techniques.

Depending on your purposes, some of these modules may be or not be necessary for the entire data processing. Each module of MISARA is interactive and can be used independently, in order to help you to easily manage each phase of the analysis. Generally, each of these modules presents different functionalities for specific types of analysis, but they share similar design and workflow processes. The panel design of each module (Fig. 9) is mainly composed by:

- The axes of the figure that shows the main results. In the modules of MISARA, you can find a different number of axes. Notice that you can explore the plots through the “Save plot” button.
- The buttons for the reading of the seismo-acoustic traces expressed in the format explained in the section 2.1. In the most of modules, you can use the “Open files”

(manual selection) or the “Open folder” (all files which are in the defined folder and sub-folders) buttons to load the files associated to the name and the component/channel of the reference station. Remember that, in some modules, the names of these files manage the searching of the multi-station traces.

- The buttons for the management of supplementary routines, such as the calculation of the analysis error, the selection of the output results, the type of picking, etc.
- The text-boxes for the management of the temporary parameters. Remember that not all fixed parameters match with the temporary ones, because some of them are exclusively set up in the Home Window and every specific module requires the setting of supplementary parameters. However, the change of the temporary parameters values doesn’t produce any modification on the saved parameters, but it only affects the development of the analysis and the graphic elements of the axes of the figure.
- The command buttons to control any process in the module, such as the calculation and visualization of the results, the saving of the Output data and figures and the calculation and visualization of secondary results.
- The text window, that it shows any information about the data processing through error, warning or command messages.

In the next sections, you will know more about the modules of MISARA. In addition, at the end of each subsection, you will find a brief overview about the format of the Output files and the temporary parameters used by each module.

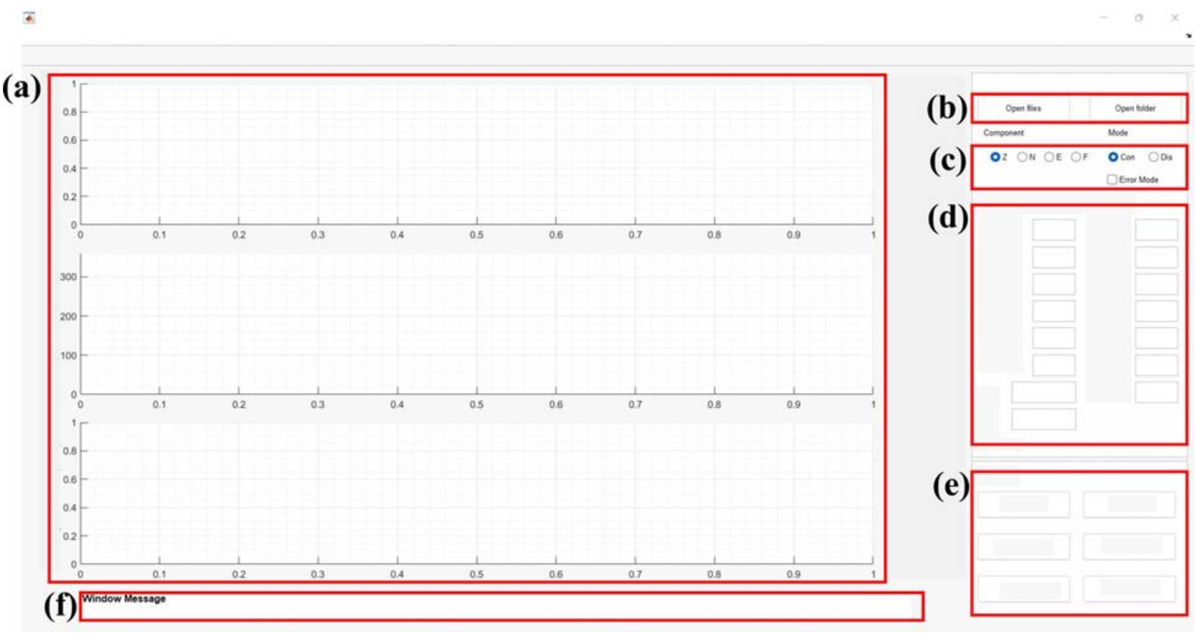

Fig. 9. Generic structure of MISARA modules.

3.1 Beam Pattern Module

This module is used to evaluate the geometry and the properties of the array/network configuration based on the array Beam Pattern (Capon, 1969). For of an array/network geometry, it's possible to evaluate its response function at a selected target frequency.

Observing the fig. 10, you can view the structure of the module, that it consists of:

- Map figure. The left-hand axes show the geometry of the array/network on the DEM of the region. The colorbar of the surface plot refers to the elevation dimension of the DEM, while the legend shows the elevation spacing in the contour plot and the type of station mark. Notice that, if the base map of the region of interest is no correctly defined in the Home Window, the module automatically plots only the array/network elements. Remember also that you can choose the geographic coordinates system (UTM system/WGS84) only in the Home Window (see section 2.3).
- Array response function figure. The right-hand axes show the array response function at different frequencies analysis using the "Pre" and the "Next" buttons. The colorbar of the surface plot refers to the value of the Beam Pattern function. The title shows the analysis frequency used during the processing. Notice that the calculation of the array response function involves the using of the station coordinates in UTM system.
- Station coordinates table. It's possible to edit the geographic coordinates of the stations by using the UI table located in the lower part of the panel. In addition, you can select the stations to use in the data processing through the "Selection" column of the table. Notice that, if the coordinates file is no correctly defined in the Home Window, the module shows a table that contains NaN values. Remember also that you must press the "Update" button to apply a new modification to the station coordinates.
- Settings menu, located in the right part of the panel. You can set the temporary parameters of the module, such as the frequencies analysis, the dimension of the slowness grid and the map attributes.
- Command menu, positioned in the right-lower part of the panel. In the "Beam Pattern" and "Station map" sections, you can press the "Calculation" button to start the Beam Pattern analysis and the map processing, respectively. The results are displayed in their respective axes. For the manual saving of the two graphs, you can press the respective "Save" buttons. Notice that the saving of the array response figure is exclusively performed for the selected frequency.
  In the "Coordinates" section, you can use the "Update" button in order to update the station coordinates. For the permanent saving of the updated coordinates, you can use the "Save button". Remember that the software overwrites the new coordinates in the existing file according to the format explained in the section 2.1.
- Text window, that is located in the lower part of the panel. It's possible to assess any information about the data processing through error, warning or command messages.

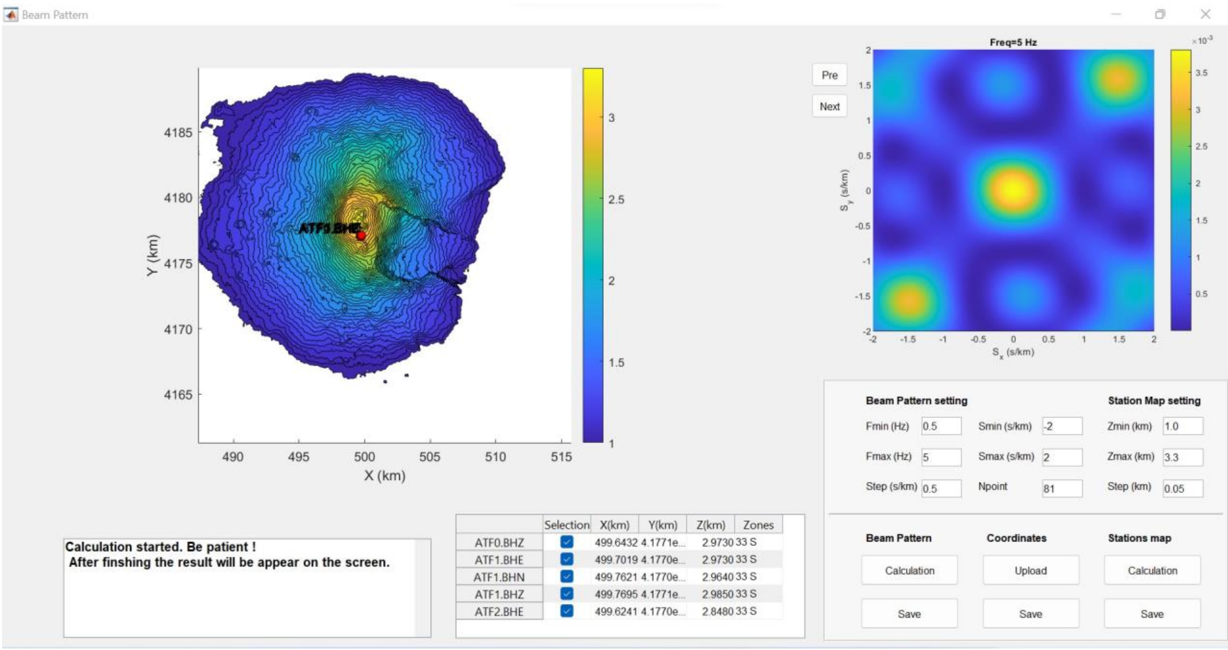

Fig.10. The Beam Pattern Module.

3.1.1 Description of temporary parameters

- **Beam Pattern setting**
  - Fmin: Minimum frequency of the analysis range (Hz)
  - Fmax: Maximum frequency of the analysis range (Hz)
  - Step: Frequency step of the analysis range (Hz)
  - Smin: Minimum value of the slowness grid (s/km)
  - Smax: Maximum value of the slowness grid (s/km)
  - Npoint: Number of slowness grid nodes
- **Station Map setting**
  - Zmin: Minimum elevation value of the region of interest (km)
  - Zmax: Maximum elevation value of the region of interest (km)
  - Step: Elevation spacing of the region of interest (km)
- **Coordinate setting**
  - UI table: Editable station coordinates table

3.1.2 Output file format

- **Station coordinates file**

  You can save the results as Matlab file (.mat). See the section 2.1 for the formatting, the filename and the Output folder.
- **Station Map and Beam Pattern Plot figures**

  You can save as:
  - Matlab figure (.fig)
  - Bitmap file (.bmp)
  - EPS file (.eps)
  - Enhanced metafile (.emf)
  - JPEG image (jpg)
  - Paintbrush 24-bit file (.pcx)

- Portable Bitmap file (.pbm)
- Portable Document Format (.pdf)
- Portable Graymap file (.pgm)
- Portable Network Graphics file (.png)
- Portable Pixmap file (.ppm)
- Scalable Vector Graphics file (.svg)
- TIFF image (.tif)
- TIFF no compression image (.tif)

You can manually set the filename, the Output folder and the file format.

3.2 Signal Viewer Module

The Signal Viewer module is used to verify the seismo-acoustic data quality and, eventually (optional), to correct the traces based on their instrument response.

This module (Fig. 11) is mainly composed by:

- The Signal figure. The main axes of the figure show the normalized amplitude of the uncorrected or corrected traces. The legend, as well as the signals, refers to the name of the reference station. Notice that you must define the correction option on "Yes" to display the corrected traces on the screen.
- The buttons for the reading of the seismo-acoustic traces, located in the north-east part of the panel.
- The supplementary routines. You can activate or deactivate the correction routine for the instrument response. Notice that the file of the correction parameters is only defined in the Home Window (see section 2.3).
- The settings menu, located in the right part of the panel. You can set the temporary parameters of the module, such as the type of component/channel and the name of the sensor, the type of filter (high-pass, low-pass and band pass) and the aesthetic features of the signal figure (temporal axis values, linear/logarithmic scale and velocity/displacement visualization). Remember that the activation of the filtering routines is optional, and it's only aimed for the visual inspection of the results.
- The command menu, located in the right-lower part of the panel. You can press the "Plot signals" button to start the main process and to display the seismo-acoustic traces on the Signal figure. For the manual saving of this graph, you can press the "Save Plot" button.
  You can also perform two secondary processes by pressing the "Plot all stations" and the "Plot Responses" buttons. The first routine displays the multi station traces in a further figure, while the second one shows the nominal frequency response for all sensors through a "Bode plot". In the both figures, you can also change the reference trace through the "Pre" and "Next" buttons. The saving of the two figures is manual and it only involves the selected sensor. Notice that the search of all available traces and correction parameters depends on the coordinates and instrument response files defined in the Home Window, respectively (see sections 2.2 and 2.3). Remember also that you can set manually the aesthetics features of

the Bode plot (for more details, see https://it.mathworks.com/help/ident/ref/lti.bode.html).
To start the correction routine of the traces, you can press the "Save Data" button. The software corrects and saves the multi station traces on the basis of the instrument response parameters and the Output folder defined in the Home Window, respectively (see sections 2.2 and 2.3). The search of all available traces or parameters is the same of the "Plot all stations" routine. Notice that you must define the correction option on "Yes" to start the process.

- Text window, that is located in the lower part of the panel. It's possible to assess any information about the data processing through error, warning or command messages.

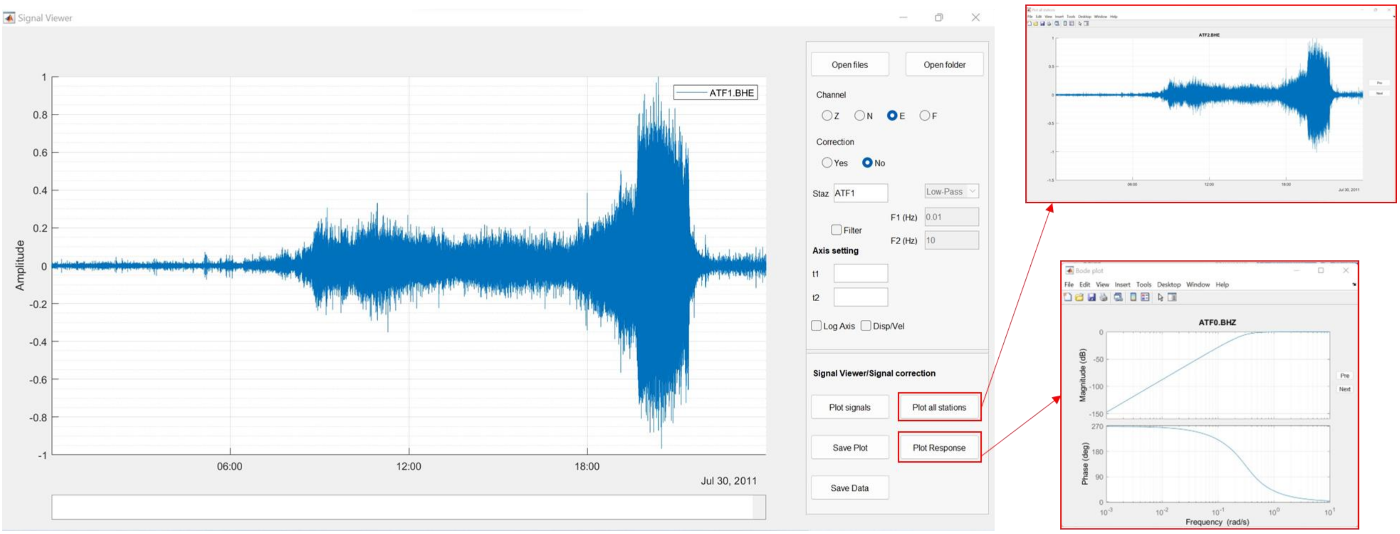

Fig.11. The Signal Viewer Module.

3.2.1 Description of temporary parameters

- **Signal Viewer setting**
  - Component/Channel: Component or Channel of the reference station
  - Correction: Activation/Deactivation of the instrument response correction routine
  - Filter: Activation/Deactivation of the filtering and selection of the filter type
  - F1: Minimum frequency value for the filtering (Hz)
  - F2: Maximum frequency value for the filtering (Hz)
- **Axis setting**
  - Log Axis: Visualization of the axis on linear or semi-logarithmic scale
  - Disp/Vel: Visualization of the signals in displacement or velocity
  - t1, t2: Minimum and Maximum limits for the temporal axis

For the temporal limits, you must use "yyMMdd-HHmmSS" format, where yy, MM, dd, HH, mm, SS represent the years, the months, the days, the hours, the minutes and the seconds of reference.

3.2.2 Output file format

- **Corrected seismo-acoustic traces**
  The Output files contain all the information about the traces (e.g., station name, amplitude of the signal etc…) and are formatted as Matlab files (.mat-see the Fig. 2.a, in the section 2.1). They are written using the following path form: /COR_SIGN/jld/SSSS.CCC.yyyy.jld.hhmmss.mat, where SSSS, CCC, yyyy, jld, hh, mm, ss represent the station name, the channel/component, the year, the Julian day, the hours, the minutes and the seconds, respectively.
- **Signal, Plot all stations and Bode plot figures**
  You can save as:
  - Matlab figure (.fig)
  - Bitmap file (.bmp)
  - EPS file (.eps)
  - Enhanced metafile (.emf)
  - JPEG image (jpg)
  - Paintbrush 24-bit file (.pcx)
  - Portable Bitmap file (.pbm)
  - Portable Document Format (.pdf)
  - Portable Graymap file (.pgm)
  - Portable Network Graphics file (.png)
  - Portable Pixmap file (.ppm)
  - Scalable Vector Graphics file (.svg)
  - TIFF image (.tif)
  - TIFF no compression image (.tif)

You can manually set the filename, the Output folder and the file format.

3.3 Spectrogram Module

The Spectrogram module is used to investigate the time variation of the spectral and amplitude properties of the seismo-acoustic traces and to assess the frequency range in which the energy signal source is radiated. To address these issues, you can perform the calculation of the Spectrogram and the Root Mean Square analysis (RMS). The first is a representation of the temporal variation of the spectral amplitude and frequency of the observed signals. Its calculation requires moving a sliding window over the whole length of the time series and estimating the amplitude spectrum by performing a Fast Fourier Transform algorithm (FFT) for overlapping positions of the window (for more details, see Schlindwein et al., 1995). The second algorithm is the square root of the arithmetic average of the squares of the band-pass filtered signals (for more details, see Kenney and Keeping, 1962).

The design of the module is shown in the figure 12. It consists of:

- Spectrogram figure. The upper axes show the time variation of the spectral amplitude of the signals. The colorbar of the surface plot refers to the values of the spectral peaks. Notice that, if the “Avg Mode” checkbox is activated, the spectrums are averaged/normalized on time on the basis of the “Nspec” parameter (see the section 2.4.1). Remember also that the spectrogram refers to the traces of the reference station defined in the Home Window (see section 2.2).

- RMS figure. The lower axes show the time variation of the RMS of the signals at different frequency bands by using the “Pre” and the “Next” buttons. The legend refers to frequencies used for the analysis. Notice that the RMS amplitude is averaged on time through the “Factor” parameter (see section 3.3.1). Also in this case, the results are related to the traces of the reference station.
- Buttons for the loading of the Input files, located in the upper-right part of the panel.
- Settings menu, located in the right part of the panel. You can set the temporary parameters of the module, such as the type of component/channel, the settings for the RMS analysis (analysis window and frequency, averaging factor) and the aesthetic features of the figures (Axis values, linear/logarithmic scales). Notice that the spectrogram settings are only defined in the Home Window (see section 2.4).
- Command Menu, positioned in the right-lower part of the panel.
  In the “Spectrogram” section, you can press the “Calculation” button to start the calculation of the spectrogram and to display the results on the screen. For the saving of the graph and the results, you can click the “Save Plot” and “Save” buttons, respectively.
  In the “Rms” section, the “Calculation” button starts the RMS analysis. After the processing, the results appear on the screen. The manual save of the RMS figure is exclusively performed for the selected frequency band by pressing the “Save Plot” button. The saving of the results for every frequency band is activated through the “Save button”.
- Text window for the error, warning and command messages. It’s located in the lower part of the panel.

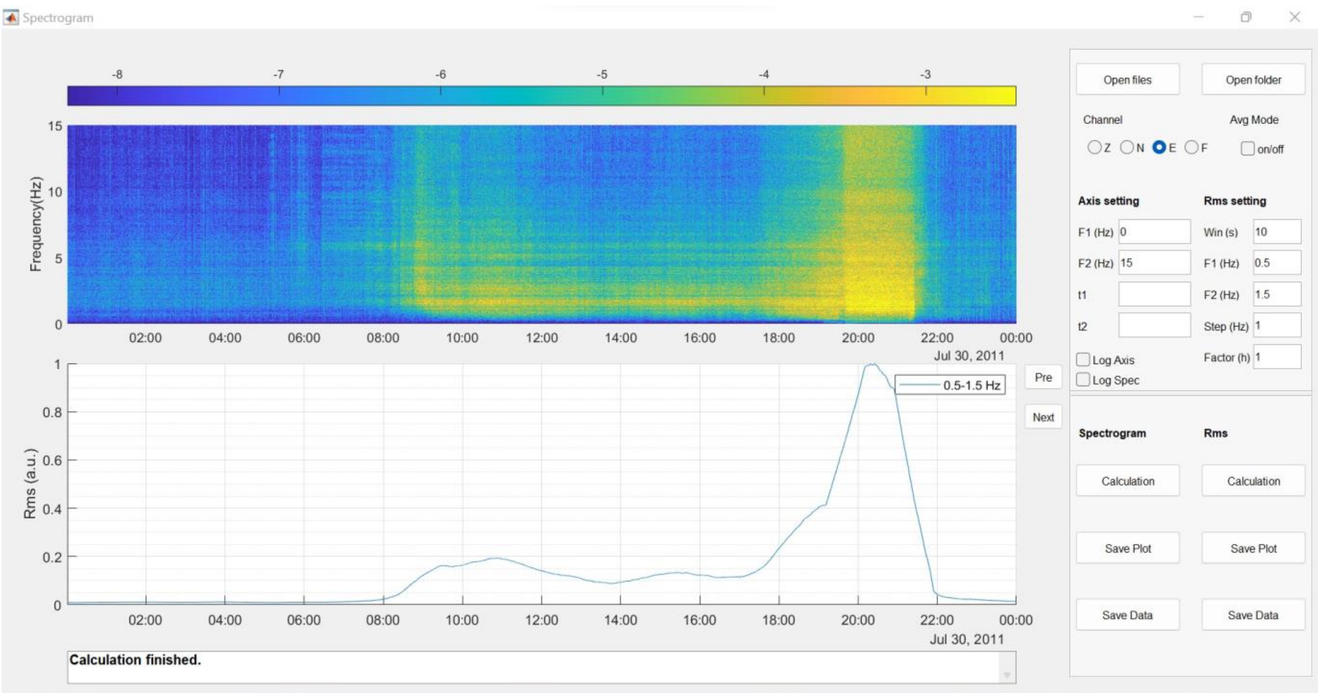

Fig.12. The Spectrogram Module.

3.3.1 Description of temporary parameters

- **Spectrogram and Rms setting**
  - Component/Channel: Component or Channel of the reference station
- **Rms setting**
  - Win: Length of the window to calculate RMS (s)
  - F1: Minimum frequency of the analysis range (Hz)
  - F2: Maximum frequency of the analysis range (Hz)
  - Step: Frequency step of the analysis range (Hz)
  - Factor: Hours value for the moving average of the results (hours)
- **Axis setting**
  - F1: Minimum limit for the frequency axis (Hz)
  - F2: Maximum limit for the frequency axis (Hz)
  - Log Axis: Visualization of the axis on linear or semi-logarithmic scale
  - Log Spec: Visualization of the spectral amplitude on linear or logarithmic scale
  - Avg Mode: Activation/Deactivation averaging of spectrums
  - t1, t2: Minimum and Maximum limits for the temporal axis

For the temporal limits, you must use "yyMMdd-HHmmSS" format, where yy, MM, dd, HH, mm, SS represent the years, the months, the days, the hours, the minutes and the seconds of reference.

3.3.2 Output file format

- **Spectrogram results**

The Output files contain all the information about the spectrogram. They can be formatted as Matlab (.mat) or Text files (.txt). In the first case, the Matlab files contain a table, named "data", that have three columns:

  – Column 1: Time series in datenum format.
  – Column 2: Frequency series in Hz.
  – Column 3: Spectral amplitude

In second case, the Text files have the same three columns.
However, in the both cases, they are written using the following path form: /SPEC/jld/SSSS.CCC.yyyy.jld.hhmmss.format, where SSSS, CCC, yyyy, jld, hh, mm, ss, and format represent the station name, the channel/component, the year, the Julian day, the hours, the minutes, the seconds and the output format (mat/txt), respectively.

- **Rms results**

The Output files contain all the information about the RMS analysis. They can be formatted as Matlab (.mat) or Text files (.txt). In the first case, the Matlab files contain a table, named "data", that have two columns:

  – Column 1: Time series in datenum format.
  – Column 2: Amplitude of RMS of the traces.

In second case, the Text files have the same two columns.

However, in the both cases, they are written using the following path form: /RMS/f1-f2Hz/jld/SSSS.CCC.yyyy.jld.hhmmss.format, where f1, f2, SSSS, CCC, yyyy, jld, hh, mm, ss, format represent the lower limit of the frequency band, the upper limit of the frequency band, the station name, the channel/component, the year, the Julian day, the hours, the minutes, the seconds and the output format (mat/txt), respectively.

- **Spectrogram plot and RMS plot figures**
  You can save as:
  - Matlab figure (.fig)
  - Bitmap file (.bmp)
  - EPS file (.eps)
  - Enhanced metafile (.emf)
  - JPEG image (jpg)
  - Paintbrush 24-bit file (.pcx)
  - Portable Bitmap file (.pbm)
  - Portable Document Format (.pdf)
  - Portable Graymap file (.pgm)
  - Portable Network Graphics file (.png)
  - Portable Pixmap file (.ppm)
  - Scalable Vector Graphics file (.svg)
  - TIFF image (.tif)
  - TIFF no compression image (.tif)

  You can manually set the filename, the Output folder and the file format.

3.4 Spectral Coherence Module

The Spectral Coherence module is used to obtain the time variation of the spectral coherence and amplitude properties of the seismo-acoustic traces. In order to address these issues, you can perform the calculation of the Coheregram and the Root Mean Square analysis (RMS), respectively. The first is based on the "Magnitude-Squared Coherence" algorithm (MSC-for more details, see Welch, 1967). It represents the temporal variation of frequency range in which the coherence among array/network stations is maximized. The second algorithm is the square root of the arithmetic average of the squares of the band-pass filtered signals (for more details, see Kenney and Keeping, 1962).

This module has the same structure of the "Spectrogram" one (Fig. 13). In fact, it's composed by:

- Coheregram figure. The upper axes show the time variation of the MSC function for all independent couples of signals. The colorbar of the surface plot refers to the normalized values of the MSC peaks, while the black marks represent the respective maximum values.
- RMS figure. The lower axes show the time variation of the RMS of the signals at different frequency bands by using the "Pre" and the "Next" buttons. The legend

refers to frequencies used for the analysis. Notice that the RMS amplitude is averaged on time through the “Factor” parameter (see section 3.4.1). In this case, the results are only related to the traces of the reference station defined in the Home Window (see section 2.4).

- Buttons for the reading of the Input files, located in the upper-right part of the panel.
- Settings menu, located in the right part of the panel. You can set the temporary parameters of the module, such as the type of component/channel, the settings for the RMS analysis (analysis window and frequency, averaging factor) and the aesthetic features of the figures (Axis values, linear/logarithmic scales). Notice that the spectral coherence settings are only defined in the Home Window (see section 2.4).
- Command Menu, positioned in the right-lower part of the panel. In the “Spectral coherence” section, you can press the “Calculation” button to display the results of the Spectral coherence analysis on the screen. Notice that this process requires the search of all multi station traces, that is based on the coordinates file defined in the Home Window (see section 2.2). The saving of the graph and the results are performed by clicking the “Save Plot” and “Save” buttons, respectively.
  In the “Rms” section, the “Calculation” button starts the RMS analysis, showing the results on the screen at end of the process. The manual save of the RMS figure is exclusively performed for the selected frequency band by clicking the “Save Plot” button. The saving of the results for every frequency band is activated by pressing the “Save button”.
- Text window for the assessment of the error, warning and command messages. It’s positioned in the lower part of the panel.

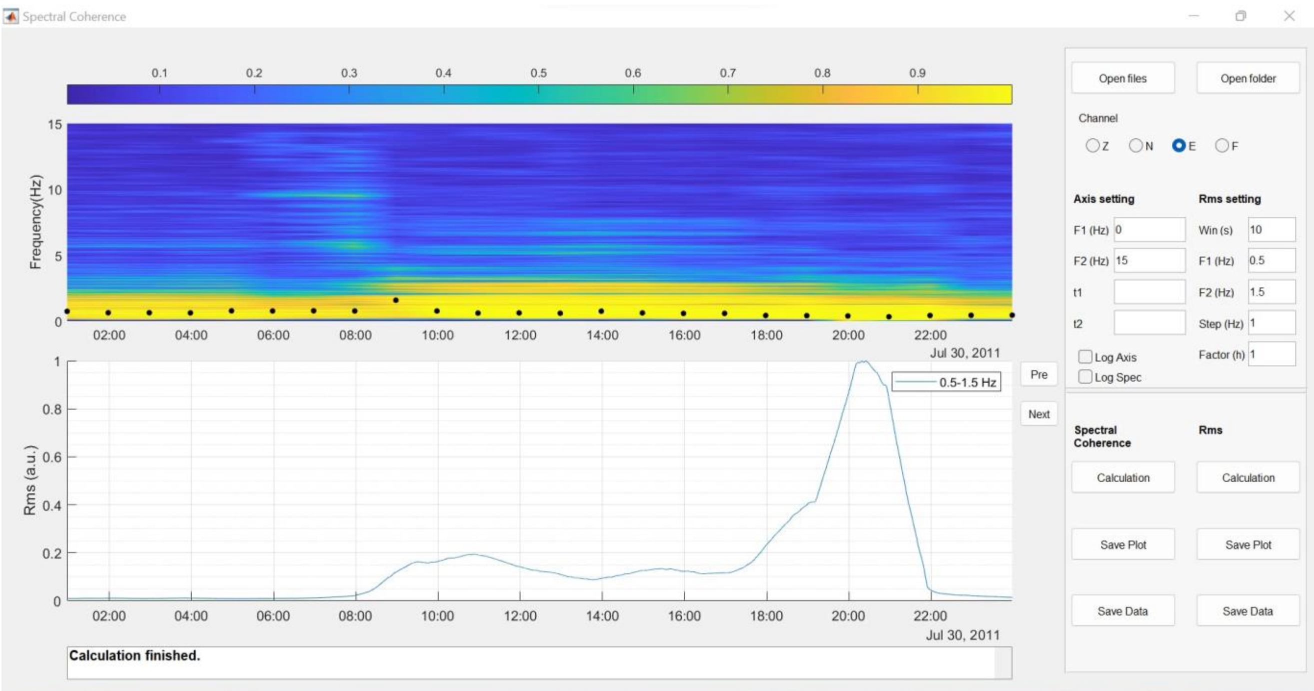

Fig.13. The Spectral Coherence Module

3.4.1 Description of temporary parameters

- **Coheregram and Rms setting**
  - Component/Channel: Component or Channel of the reference station
- **Rms setting**
  - Win: Length of the window to calculate RMS (s)
  - F1: Minimum frequency of the analysis range (Hz)
  - F2: Maximum frequency of the analysis range (Hz)
  - Step: Frequency step of the analysis range (Hz)
  - Factor: Hours value for the moving average of the results (hours)
- **Axis setting**
  - F1: Minimum limit for the frequency axis (Hz)
  - F2: Maximum limit for the frequency axis (Hz)
  - Log Axis: Visualization of the axis on linear or semi-logarithmic scale
  - Log Spec: Visualization of the spectral amplitude on linear or logarithmic scale
  - t1, t2: Minimum and Maximum limits for the temporal axis

  For the temporal limits, you must use "yyMMdd-HHmmSS" format, where yy, MM, dd, HH, mm, SS represent the years, the months, the days, the hours, the minutes and the seconds of reference.

3.4.2 Output file format

- **Spectral coherence results**

  The Output files contain all the information about the coheregram. They can be formatted as Matlab (.mat) or Text files (.txt). In the first case, the Matlab files contain a table, named "data", that have three columns:

  – Column 1: Time series in datenum format.
  – Column 2: Frequency series in Hz.
  – Column 3: Normalized MSC estimate.

  In second case, the Text files have the same three columns.
  However, in the both cases, they are written using the following path form:

  – /COH/jld/CCC.yyyy.jld.hhmmss.format, for three components station system
  – /COH/jld/yyyy.jld.hhmmss.format, for vertical single station system

  where CCC, yyyy, jld, hh, mm, ss, and format represent the channel/component, the year, the Julian day, the hours, the minutes, the seconds and the output format (mat/txt), respectively.
- **Rms results**

  The Output files contain all the information about the RMS analysis. They can be formatted as Matlab (.mat) or Text files (.txt). In the first case, the Matlab files contain a table, named "data", that have two columns:

– Column 1: Time series in datenum format.
– Column 2: Amplitude of RMS of the traces.

In second case, the Text files have the same two columns.
However, in the both cases, they are written using the following path form: /RMS/f1-f2Hz/jld/SSSS.CCC.yyyy.jld.hhmmss.format, where f1, f2, SSSS, CCC, yyyy, jld, hh, mm, ss, format represent the lower limit of the frequency band, the upper limit of the frequency band, the station name, the channel/component, the year, the Julian day, the hours, the minutes, the seconds and the output format (mat/txt), respectively.

- **Coherogram plot and RMS plot figures**
  You can save as:
  – Matlab figure (.fig)
  – Bitmap file (.bmp)
  – EPS file (.eps)
  – Enhanced metafile (.emf)
  – JPEG image (jpg)
  – Paintbrush 24-bit file (.pcx)
  – Portable Bitmap file (.pbm)
  – Portable Document Format (.pdf)
  – Portable Graymap file (.pgm)
  – Portable Network Graphics file (.png)
  – Portable Pixmap file (.ppm)
  – Scalable Vector Graphics file (.svg)
  – TIFF image (.tif)
  – TIFF no compression image (.tif)

You can manually set the filename, the Output folder and the file format.

3.5 Polarization Module

This module is dedicated to performing the particle motion analysis of the only seismic three component traces, to determine the polarization properties (azimuth, incidence angle and rectilinearity) of the analysed wave field. In fact, this part of MISARA is inconsistent with acoustic or single component stations. In particular, the heart of the analysis is based on the eigen-decomposition of the covariance matrix of the three components of ground motion over time windows sliding along the band-pass filtered traces (for more details, see Jurkevics, 1988). Results consist of the time series of polarization azimuth and incidence angles and the rectilinearity coefficient.

The structure of this module (Fig. 14) is characterized by:

- Polarization figure. The upper, central and lower axes show the time series of the polarization azimuth and incidence angles and the rectilinearity coefficient, respectively. The legend refers to frequency band used for the analysis. Using the “Pre” and the “Next” buttons, you can display the results through the different frequency bands. Each time series is filtered by selecting all values over the “Thr” value (see the section 3.5.1). Notice that the polarization attributes are averaged on time through the “Factor” parameter (see the section 3.5.1). The coloured band around the average values represents the confidence interval (±standard deviation value). Moreover, the results are only related to the three components traces of the reference station defined in the Home Window (see section 2.2).

- Buttons for the reading of the Input files, located in the upper-right part of the panel.
- The supplementary routines. You can choose the type of data processing between “Continuous” (Con) or “Discrete” (Dis) mode. The first mode returns the values obtained from all analysis windows. For each single trace, the second one rather provides the values of the analysis window associated with the maximum RMS amplitude. The latter mode is very useful for the Input traces that have a short length.
- Settings menu, located in the right part of the panel. You can set the temporary parameters of the module, such as the type of component/channel, the settings for the covariance matrix decomposition method (analysis window and frequency, averaging factor, rectilinearity threshold) and the aesthetic features of the figures (Axis values, linear/logarithmic scales).
- Command Menu, positioned in the right-lower part of the panel. In the “Polarization” section, the “Calculation” button starts the particle motion analysis, showing the results on the screen at end of the process. The manual save of the Polarization figure is only performed for the selected frequency band by clicking the “Save Plot” button. Pressing the “Polar Scatter” button, you can display the 3D scatter plot of polarization attributes. In this secondary figure, the colorbar refers to the values of the rectilinearity, while the title indicates the azimuthal dimension and current frequency band used for the analysis. The radial dimension represents the polar incidence values. For the selected frequency band, the “Polar Hist” button provides a polar histogram of polarization azimuth. In this figure, the title indicates the azimuthal dimension and current frequency band used for the analysis. The saving of the results for every frequency band is activated by pressing the “Save button”.
- Text window for the visualization of the error, warning, and command messages. It’s positioned in the lower part of the panel.

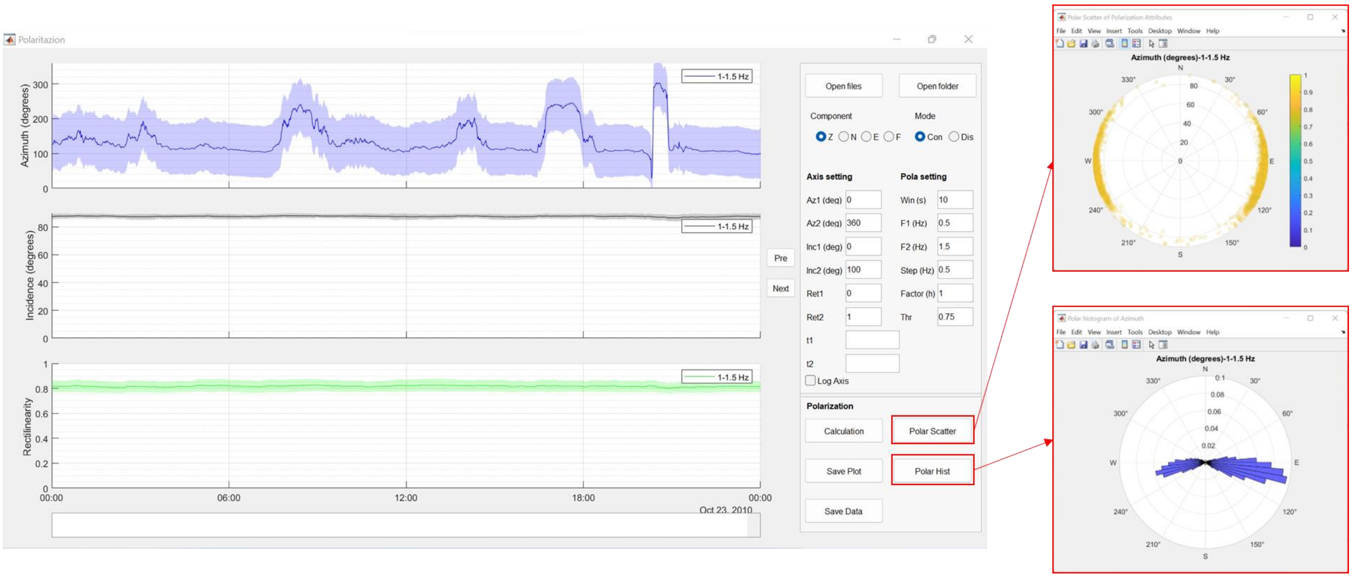

Fig.14. The Polarization Module

3.5.1 Description of temporary parameters

- **Polarization setting**
  - Component/Channel: Component or Channel of the reference station
  - Mode: Selection of the continuous or discrete analysis
  - Win: Length of the window to calculate polarization attributes (s)
  - F1: Minimum frequency of the analysis range (Hz)
  - F2: Maximum frequency of the analysis range (Hz)
  - Step: Frequency step of the analysis range (Hz)
  - Factor: Hours value for the moving average of the results (hours)
  - Thr: Rectilinearity threshold for the selection of the polarization attributes
- **Axis setting**
  - Az1: Minimum limit for the azimuth axis (degrees)
  - Az2: Maximum limit for the azimuth axis (degrees)
  - Inc1: Minimum limit for the incidence axis (degrees)
  - Inc2: Maximum limit for the incidence axis (degrees)
  - Ret1: Minimum limit for the rectilinearity axis
  - Ret2: Maximum limit for the rectilinearity axis
  - t1, t2: Minimum and Maximum limits for the temporal axis
  - Log Axis: Visualization of the axis on linear or semi-logarithmic scale

For the temporal limits, you must use “yyMMdd-HHmmSS” format, where yy, MM, dd, HH, mm, SS represent the years, the months, the days, the hours, the minutes and the seconds of reference.

3.5.2 Output file format

- **Polarization results**

The Output files contain all the information about the polarization attributes. They can be formatted as Matlab (.mat) or Text files (.txt). In the first case, the Matlab files contain a table, named “data”, that have four columns:

- Column 1: Time series in datenum format.
- Column 2: Azimuth angle series in degrees.
- Column 3: Incidence angle series in degrees.
- Column 4: Rectilinearity coefficient series.

In second case, the Text files have the same four columns.
However, in the both cases, they are written using the following path form: /POL/f1-f2Hz/jld/SSSS.yyyy.jld.hhmmss.format, where f1, f2, SSSS, yyyy, jld, hh, mm, ss, format represent the lower limit of the frequency band, the upper limit of the frequency band, the station name, the year, the Julian day, the hours, the minutes, the seconds and the output format (mat/txt), respectively.

- **Polarization Attributes plot, Polar Scatter and Polar Hist figures**
  You can save as:
  - Matlab figure (.fig)
  - Bitmap file (.bmp)
  - EPS file (.eps)
  - Enhanced metafile (.emf)
  - JPEG image (jpg)
  - Paintbrush 24-bit file (.pcx)
  - Portable Bitmap file (.pbm)
  - Portable Document Format (.pdf)
  - Portable Graymap file (.pgm)
  - Portable Network Graphics file (.png)
  - Portable Pixmap file (.ppm)
  - Scalable Vector Graphics file (.svg)
  - TIFF image (.tif)
  - TIFF no compression image (.tif)

You can manually set the filename, the Output folder and the file format.

3.6 STA/LTA Module

The STA/LTA module is used to detect and classify as many seismo-acoustic events as possible by performing the homonymous method. In particular, the "Short Term Average/Long Term Average" method (STA/LTA-for more details, see Allen, 1978) continuously calculates the average values of the absolute amplitude of a band-pass filtered signal in two consecutive moving-time windows. The short term average window (STA) is sensitive to events while the long one (LTA) provides information about the temporal amplitude of the noise at the site. When the ratio of both terms exceeds a threshold value, an event is detected and data starts being recorded. The module is also implemented for the family classification of the events through the visual inspection and the spectral and polarization analysis of the recorded waveforms.

Observing the figure 15, you can admire the module structure, that is composed by:

- Triggers figure. The upper axes show the time variation of the STA/LTA ratio and the threshold used for the event detection. Notice that the results are only referred to the traces of the reference station defined in the Home Window (see section 2.2).

- Events figure. The lower axes show the extracted waveforms by using the “Pre” and “Next” buttons. The legend indicates the time reference of the waveform. Notice that you can inspect the results in both velocity and displacement through the checkbox “Disp/Vel”. Remember also that you can display only those events extracted from the traces of the reference station, that is defined in the Home Window (see section 2.2).
- Buttons for the reading of the Input traces, located in the upper-right part of the panel.
- The supplementary routines. You can choose the type of save of the results between “Automatic” (Aut) or “Manual” (Man) mode. The first mode saves all detected waveforms without actually classifying them into different families. So, in this case, you can only select one family label (We suggest to set the “No Fam” label). The second mode saves exclusively the single waveform that is showed in the figure by pressing the “Pre” and “Next” buttons. In the latter case, you can set manually the family label for each event by clicking the pop-menu button.
- Settings menu, located in the right part of the panel. You can set the temporary parameters of the module, such as the type of component/channel, the settings for the detection (analysis windows and frequency, detection threshold and family classification label), the settings for the spectral and particle motion analysis and the aesthetic features of the figures (linear/logarithmic scales, velocity/displacement visualization). Remember that value of the LTA window is also used to set the duration of the extracted events (two times the LTA duration).
- Command Menu, positioned in the lower-right part of the panel. In the “View all triggers” section, you can press the “Calculation” button to display the results of the detection analysis on the screen. The saving of the graph and the results are performed by clicking the “Save Plot” and “Save” buttons, respectively.

  In the “Select triggers” section, the “Calculation” button starts the extraction of the band-pass filtered waveforms, showing the results on the screen at end of the process. The manual save of the Event figure is exclusively performed for the selected waveform by clicking the “Save Plot” button. For the visualization of the spectral properties of the selected event, you can press the “Plot Spec” button. In this case, a subplot of the spectrogram and the event appears in a secondary figure, showing the similar design of the axes of the “Spectrogram” module. For the visualization of the polarization properties of the selected event, you can click the “Plot Pol” button. This routine only works with three components traces and station coordinates expressed in UTM system. In a further figure, the software shows a subplot about the three sections of the particle motions on the DEM of the region of interest. The title refers to the polarization attributes computed by the covariance matrix decomposition method. If the base map of the region of interest is no correctly defined in the Home Window (see section 2.2), the module automatically plots only the station and the particle motion elements. However, remember that you can choose the geographic coordinates system of the map (UTM system/WGS84) only in the Home Window (see section 2.3). The saving of the events is activated by pressing the “Save button”. In this case, the software saves the unfiltered waveforms related to all available stations, on the basis of the coordinates file defined in the Home Window. Remember to set the saving mode and the family label.

- Text window for the error, warning, and command messages. It’s positioned in the lower part of the panel.

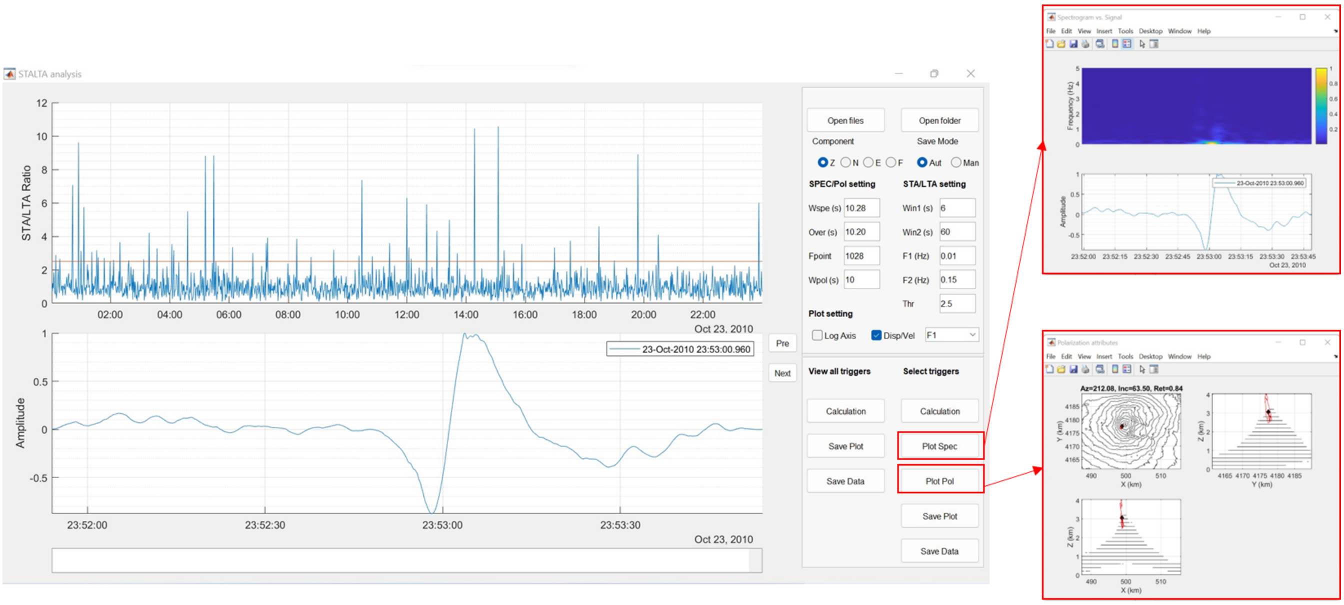

Fig.15. The STA/LTA Module

3.6.1 Description of temporary parameters

- **STA/LTA setting**
  - Component/Channel: Component or Channel of the reference station
  - Save Mode: Selection of the automatic or manual save of the waveforms
  - Win1: Length of the Short Time window (s)
  - Win2: Length of the Long Time window (s)
  - F1: Minimum frequency of the analysis range (Hz)
  - F2: Maximum frequency of the analysis range Hz)
  - Threshold: detection threshold
  - Pop-up menu: Selection of the family label (F1, F2, F3 F4, No Fam)
- **SPEC/Pol setting**
  - WSpe: Length of the window to calculate FFT (s)
  - Over: Length of the window overlap to calculate FFT (s)
  - Fpoint: number of points of the DFT
  - Wpol: Length of the window to calculate polarization attributes (s)
- **Plot setting**
  - Log Axis: Visualization of the axis on linear or semi-logarithmic scale
  - Disp/Vel: Visualization of the waveforms in displacement or velocity

3.6.2 Output file format

- **Triggers data**

  The Output files contain all the information about the trigger times of the detection. They can be formatted as Matlab (.mat) or Text files (.txt). In the first case, the Matlab files contain a table, named “data”, that have one columns. This represents trigger times in datenum format. In second case, the Text files also have the same column. However, in the both cases, they are written using the following path form: /STA_LTA/Time_triggers.format, where format represent the output format (mat/txt).

- **Waveforms**
  The Output files can be formatted as a Matlab (.mat) or Text file (.txt). In the first case, the files contain all the information about the traces (e.g., station name, station coordinates, amplitude of the signal etc…) and they are formatted as shown in the figure 2.a. In the second case, the files rather have two columns:

  - Column 1: Time series in datenum format.
  - Column 2: Amplitude of the unfiltered signal.

  However, in both case, they are written using the following path form: /STA_LTA/Fam/jld/SSSS.CCC.yyyy.jld.hhmmss.format, where Fam, SSSS, CCC, yyyy, jld, hh, mm, ss represent the family label, the station name, the channel/component, the year, the Julian day, the hours, the minutes, the seconds and the output format (mat/txt), respectively.
- **Triggers, Events, Spectrogram vs. Signal and Polarization attributes figures**
  You can save as:
  - Matlab figure (.fig)
  - Bitmap file (.bmp)
  - EPS file (.eps)
  - Enhanced metafile (.emf)
  - JPEG image (jpg)
  - Paintbrush 24-bit file (.pcx)
  - Portable Bitmap file (.pbm)
  - Portable Document Format (.pdf)
  - Portable Graymap file (.pgm)
  - Portable Network Graphics file (.png)
  - Portable Pixmap file (.ppm)
  - Scalable Vector Graphics file (.svg)
  - TIFF image (.tif)
  - TIFF no compression image (.tif)

You can manually set the filename, the Output folder and the file format.

3.7 Salped Module

This module is exclusively performed to detection and classification of Long Period events (LP) on the basis of the characteristic shape, duration, and frequency band of activity. In particular, the signals are first filtered into three frequency subbands. Then, they are processed in parallel to extract subband envelopes and create a Characteristic Function (CF) that enhances LP features. Finally, when the CF exceeds a threshold value, an event is detected and data starts being recorded. For more details, you can see Garcia et al. (2017). Moreover, the module is also implemented for the family classification of the events through the visual inspection and the spectral and polarization analysis of the recorded waveforms.

In the figure 16, you can observe the module design, that is composed by:

- Triggers figure. The upper axes show the time variation of the CF and the threshold used for the event detection. Remember that the results are only related to the traces of the reference station defined in the Home Window (see section 2.2).
- Events figure. The lower axes show the extracted waveforms by using the "Pre" and "Next" buttons. The legend indicates the time reference of the waveform. Notice that you can display the results in both velocity and displacement. In addition, you can plot only those events extracted from the traces of the reference station, that is defined in the Home Window (see section 2.2).
- Buttons for the reading of the Input traces, located in the upper-right part of the panel.
- The supplementary routines. You can set the type saving of the results between "Automatic" (Aut) or "Manual" (Man) mode. The first mode saves all waveforms without classifying them into different families and it permits you to select only one family label (We suggest to set the "No Fam" label). The second mode saves only the single waveform that is displayed in the figure by pressing the "Pre" and "Next" buttons. In the latter case, you can choose manually the family label by clicking the pop-menu button.
- Settings menu, located in the right part of the panel. You can set the temporary parameters of the module, such as the type of component/channel, the settings for the detection (analysis windows and frequency, detection threshold and family classification label), the settings for the spectral and particle motion analysis and the aesthetic features of the figures (linear/logarithmic scales, velocity/displacement visualization). Notice that the lower and the upper subbands are only set in the Home Window (see section 2.4). Remember also that values of the windows "Win 1" and "Win 2" are only used to set the duration of the extracted events, while the detection window is exclusive fixed on the basis of the LP duration (4 seconds).
- Command Menu, positioned in the lower-right part of the panel. In the "View all triggers" section, you can press the "Calculation" button to plot the results of the analysis on the screen. Pressing the "Save Plot" and "Save" buttons, you can save the graph and the results, respectively.
  In the "Select triggers" section, the "Calculation" button performs the extraction of the detected waveforms and the plotting of the results on the screen. The manual save of the Event figure is only performed for the selected waveform by clicking the "Save Plot" button. For the visualization of the spectral properties of the selected event, you can click the "Plot Spec" button. In this case, a subplot of the spectrogram and the event is displayed in a secondary figure. For the visualization of the polarization properties of the selected event, you can press the "Plot Pol" button. In another figure, the software returns a subplot about the three sections of the particle motions on the DEM of the region of interest. If the base map of the region of interest is not correctly defined in the Home Window (see section 2.2), the module automatically displays only the station and the particle motion elements. However, remember that you can choose the geographic coordinates system of the map (UTM system/WGS84) only in the Home Window (see section 2.3). The title of the current figure indicates the polarization attributes computed

by the covariance matrix decomposition method. Remember also that this routine only works with three components traces and station coordinates expressed in UTM system. The “Save button” button actives the save of the events. The module saves the multi station unfiltered waveforms on the basis of the coordinates file defined in the Home Window. Remember to define the saving mode and the family label.

- Text window for the assessment of the error, warning and command messages. It’s positioned in the lower part of the panel.

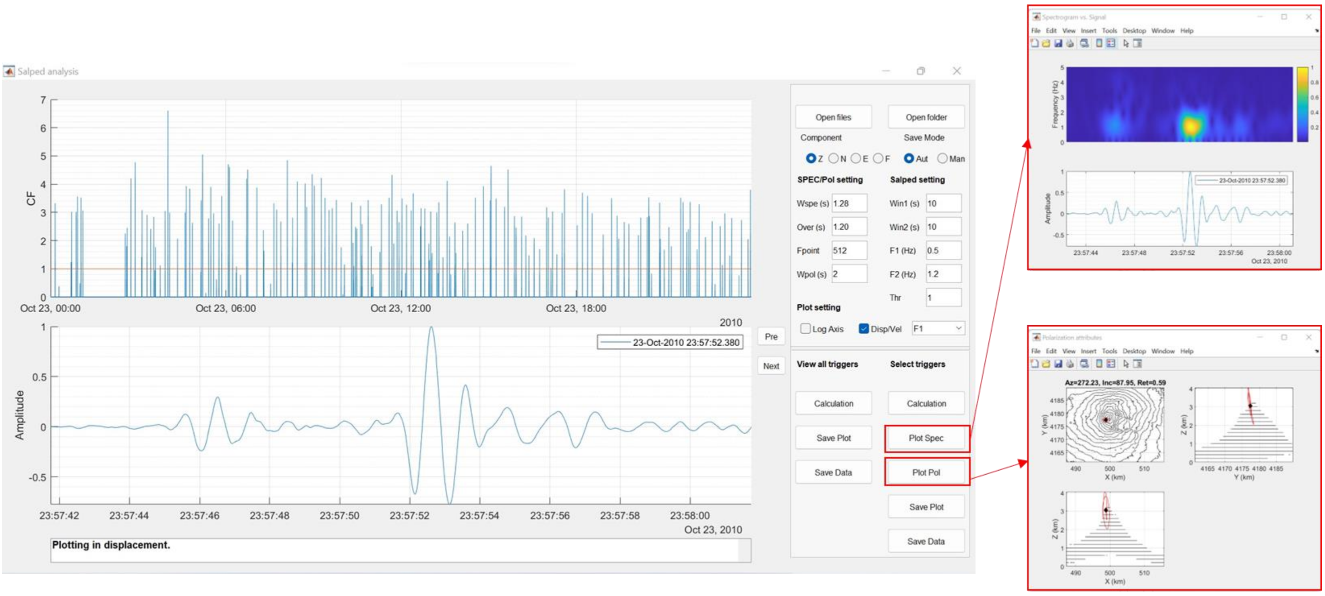

Fig.16. The Salped Module

3.7.1 Description of temporary parameters

- **Salped setting**
    - Component/Channel: Component or Channel of the reference station
    - Save Mode: Selection of the automatic or manual save of the waveforms
    - Win1: Length of the Pre-event window (s)
    - Win2: Length of the Post-event window (s)
    - F1: Minimum frequency of the Central subband (Hz)
    - F2: Maximum frequency of the Central subband (Hz)
    - Threshold: detection threshold
    - Pop-up menu: Selection of the family label (F1, F2, F3 F4, No Fam)
- **SPEC/Pol setting**
    - WSpe: Length of the window to calculate FFT (s)
    - Over: Length of the window overlap to calculate FFT (s)
    - Fpoint: number of points of the DFT
    - Wpol: Length of the window to calculate polarization attributes (s)
- **Plot setting**
    - Log Axis: Visualization of the axis on linear or semi-logarithmic scale
    - Disp/Vel: Visualization of the waveforms in displacement or velocity

3.7.2 Output file format

- **Triggers data**
  The Output files contain all the information about the trigger times of the detection. They can be formatted as Matlab (.mat) or Text files (.txt). In the first case, the Matlab files contain a table, named “data”, that have one columns. This represents trigger times in datenum format. In second case, the Text files also have the same column. However, in the both cases, they are written using the following path form: /Salped/Time_triggers.format, where format represent the output format (mat/txt).
- **Waveforms**
  The Output files can be formatted as a Matlab (.mat) or Text file (.txt). In the first case, the files contain all the information about the traces (e.g., station name, station coordinates, amplitude of the signal etc…) and they are formatted as shown in the figure 2.a. In the second case, the files rather have two columns:

  - Column 1: Time series in datenum format.
  - Column 2: Amplitude of the unfiltered signal.

  However, in both case, they are written using the following path form: /Salped/Fam/jld/SSSS.CCC.yyyy.jld.hhmmss.format, where Fam, SSSS, CCC, yyyy, jld, hh, mm, ss represent the family label, the station name, the channel/component, the year, the Julian day, the hours, the minutes, the seconds and the output format (mat/txt), respectively.
- **Triggers, Events, Spectrogram vs. Signal and Polarization attributes figures**
  You can save as:
  - Matlab figure (.fig)
  - Bitmap file (.bmp)
  - EPS file (.eps)
  - Enhanced metafile (.emf)
  - JPEG image (jpg)
  - Paintbrush 24-bit file (.pcx)
  - Portable Bitmap file (.pbm)
  - Portable Document Format (.pdf)
  - Portable Graymap file (.pgm)
  - Portable Network Graphics file (.png)
  - Portable Pixmap file (.ppm)
  - Scalable Vector Graphics file (.svg)
  - TIFF image (.tif)
  - TIFF no compression image (.tif)

You can manually set the filename, the Output folder and the file format.

3.8 ZLCC Module

This module is dedicated to performing the Zero Lag Cross Correlation analysis (ZLCC-for more details, see Frankel et al., 1991), in order to determine the time variation of the kinematic attributes (back-azimuth and ray parameter) of the analysed wave field. In particular, the main process is based on the calculation of the cross correlation coefficient between station pairs over time windows sliding along the band-pass filtered traces. For all independent station pairs, these coefficients return the delay times of the impinging plane waves that maximize the coherence among signals. The formalism of the generalized inverse of the delay times and sensor positions provides the slowness parameters. In addition, if the velocity value of the waves is available, it's possible to compute the incidence angle from the ray parameter (see Rost and Thomas, 2002). So, the results mainly consist of the time series of back-azimuth and incidence angles, ray parameters and the average cross correlation coefficient. In addition, ZLCC is implemented with the JackKnife method (for more details, see Efron et al., 1982), in order to assess the analysis errors of these parameters.

The structure of this module (Fig. 17) is characterized by:

- ZLCC figure. The upper, central and lower axes show the temporal 3D histogram plots of the average cross-correlation coefficient, the back-azimuth angle and the ray parameters, respectively. The colorbar of the surface plot refers to the values of the histogram probability. The legend refers to frequency band used for the analysis. Using the "Pre" and the "Next" buttons, you can display the results through the different frequency bands. Notice that the bins of histograms are fixed (0.1 for the cross-correlation coefficient, 10° for back azimuth and 0.1 s/km for ray parameter), except for the time dimension (see the "Xbin" parameter in the section 3.8.1)
- Buttons for the reading of the Input files, located in the upper-right part of the panel.
- The supplementary routines. You can choose the data processing between "Continuous" (Con) or "Discrete" (Dis) mode. The first mode returns the values obtained from all analysis windows. For each single trace, the second one provides the values of the analysis window associated with the maximum value of the average cross-correlation coefficient. The latter mode is very useful for the Input traces that have a short length. In, addition, you can also define the activation or deactivation of the JackKnife routine by clicking the "Error Mode" checkbox. This process is very useful to assess the stability of the obtained results.
- Settings menu, located in the right part of the panel. You can set the temporary parameters of the module, such as the type of component/channel, the settings for the ZLC analysis (analysis window and frequency, temporal bins of the Histograms, velocity waves, correlation threshold) and the aesthetic features of the figures (Axis values, linear/logarithmic scales).
- Command Menu, positioned in the right-lower part of the panel. In the "ZLC" section, the "Calculation" button starts the array analysis, showing the results on the screen at end of the process. Notice that this process requires the search of all multi station traces, that is based on the coordinates file defined in the Home Window (see section 2.2). In addition, remember that the module works with station coordinates expressed in UTM system. The manual save of the ZLC figure

is only performed for the selected frequency band by clicking the “Save Plot” button. Pressing the “Ray vs. Az” and “Slow Grid” buttons, you can display the 3D histograms of the ray parameter-back azimuth and horizontal slowness, respectively. In the secondary figures, the colorbar refers to the values of the histogram probability, while the legend indicates the current frequency band used for the analysis. For the selected frequency band, the “Hist” button provides a subplot about statistical information of the results, as the histogram of the incidence, the rose diagram of the back azimuth and the boxplots of the analysis errors. The legend of the first two plots indicates the current frequency band. Notice that, if the error routine is deactivated, the software returns only the subplot of incidence and back-azimuth histograms. Remember also that all kinematic attributes are filtered by selecting all values exceed the “Thr” value (see section 3.8.1). The saving of the results for every frequency band is activated by pressing the “Save button”. Notice that, if the error analysis isn’t activated, the module saves the error variables as NaN vectors.

- Text window for the visualization of the error, warning and command messages. It’s positioned in the lower part of the panel.

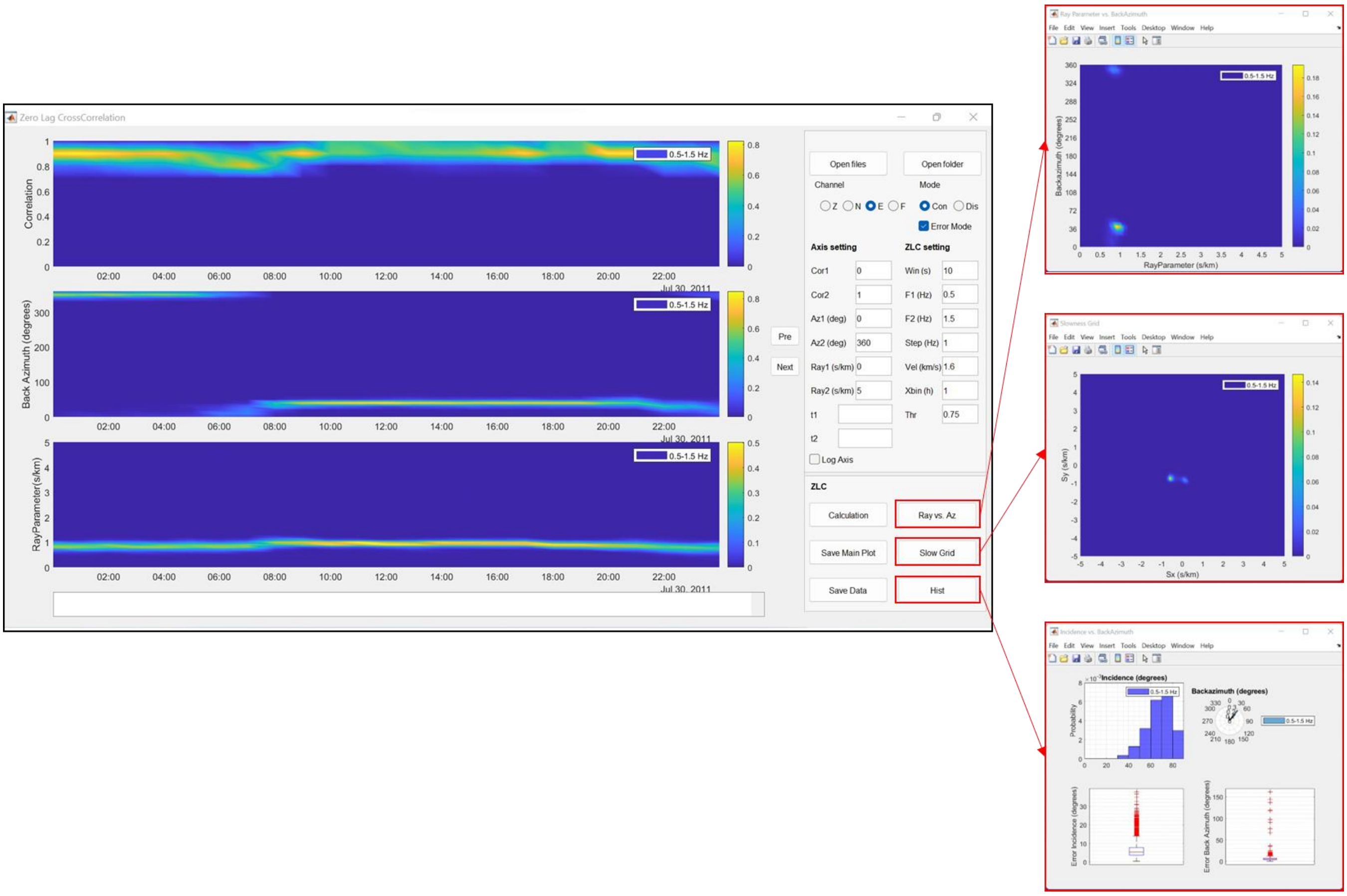

Fig.17. The ZLC Module

3.8.1 Description of temporary parameters

- **ZLC setting**
  - Component/Channel: Component or Channel of the reference station
  - Mode: Selection of the continuous or discrete analysis
  - Error Mode: Activation/Deactivation of the analytical errors routines
  - Win: Length of the window to calculate kinematic attributes (s)
  - F1: Minimum frequency of the analysis range (Hz)
  - F2: Maximum frequency of the analysis range (Hz)
  - Step: Frequency step of the analysis range (Hz)
  - Vel: Propagation velocity of the seismic/acoustic waves (km/s)
  - Xbin: Temporal width of the 3D histogram bins (hours)
  - Thr: Cross correlation threshold for the selection of the kinematic attributes
- **Axis setting**
  - Cor1: Minimum limit for the cross-correlation axis
  - Cor 2: Maximum limit for the cross-correlation axis
  - Az1: Minimum limit for the back-azimuth axis (degrees)
  - Az2: Maximum limit for the back-azimuth axis (degrees)
  - Ray1: Minimum limit for the ray parameter axis (s/km)
  - Ray2: Maximum limit for the ray parameter axis (s/km)
  - Log Axis: Visualization of the axis on linear or semi-logarithmic scale
  - t1, t2: Minimum and Maximum limits for the temporal axis

For the temporal limits, you must use "yyMMdd-HHmmSS" format, where yy, MM, dd, HH, mm, SS represent the years, the months, the days, the hours, the minutes and the seconds of reference.

3.8.2 Output file format

- **ZLCC results**

The Output files contain all the information about the kinematics attributes. They can be formatted as Matlab (.mat) or Text files (.txt). In the first case, the Matlab files contain a table, named "data", that have ten columns:

- Column 1: Time series in datenum format.
- Column 2: Back-azimuth series in degrees.
- Column 3: Ray parameter series in s/km.
- Column 4: Incidence series in degrees.
- Column 5: Back-azimuth error series in degrees.
- Column 6: Ray parameter error series in s/km.
- Column 7: Incidence error series in degrees.
- Column 8: X-component of the horizontal slowness series in s/km
- Column 9: Y-component of the horizontal slowness series in s/km
- Column 10: Average cross correlation coefficient series

In second case, the Text files have the same ten columns.
However, in the both cases, they are written using the following path form:

- /ZLC/f1-f2Hz/jld/CCC.yyyy.jld.hhmmss.format, for three components station system
- /ZLC/f1-f2Hz/jld/yyyy.jld.hhmmss.format, for vertical single station system

where f1, f2, CCC, yyyy, jld, hh, mm, ss, and format represent the lower limit of the frequency band, the upper limit of the frequency band, the component, the year, the Julian day, the hours, the minutes, the seconds and the output format (mat/txt), respectively.

- **ZLC plot, Slowness Grid, Ray Parameter vs. BackAzimuth and Incidence vs. BackAzimuth figures**
  You can save as:
  - Matlab figure (.fig)
  - Bitmap file (.bmp)
  - EPS file (.eps)
  - Enhanced metafile (.emf)
  - JPEG image (jpg)
  - Paintbrush 24-bit file (.pcx)
  - Portable Bitmap file (.pbm)
  - Portable Document Format (.pdf)
  - Portable Graymap file (.pgm)
  - Portable Network Graphics file (.png)
  - Portable Pixmap file (.ppm)
  - Scalable Vector Graphics file (.svg)
  - TIFF image (.tif)
  - TIFF no compression image (.tif)

You can manually set the filename, the Output folder and the file format.

3.9 MUSIC Module

This module permits you to use the Multiple Signal Classification method (MUSIC-for more details, see Schmidt, 1986), to determine the kinematic properties (back-azimuth and ray parameter) of the coherent signals present in the observed wave field. This algorithm offers the advantage to resolve multiple, closely spaced sources simultaneously impinging at the array/network through plane waves. In particular, the method consists of the calculation of the spatial cross-spectral matrix over windows sliding along records by averaging the Fourier coefficients over overlapped frequency bands. For each time window and frequency band, the size of the eigenvalues of this matrix provides the number of source signals impinging at the array/network. For the cross-spectral matrix eigenvectors spanning in the signal subspace, the array response and the number of sensors, the slowness spectrums are estimated over a square search grid. The dominant peaks of these spectrums provides the kinematic parameters. So, the results of the analysis consist of time series of back-azimuth angles, ray parameters and the slowness spectrum. In addition, if the velocity value of the waves is available, it’s possible to compute the incidence angle from the ray parameter (see Rost and Thomas, 2002).

The design of MUSIC module (Fig. 18) consists of:

- MUSIC figure. The upper, central and lower axes show the temporal 3D histogram plots of the normalized slowness spectrum, the back-azimuth angle and the ray parameters, respectively. The colorbar of the surface plot refers to the values of the histogram probability. The legend indicates the source signal retrieved. Using the “Pre” and the “Next” buttons, you can display the results through the dimension of the signal subspace. Notice that the bins of histograms are fixed (0.1 for the slowness spectrum, 10° for back-azimuth and 0.1 s/km for ray parameter), except for the time dimension (see the “Xbin” parameter in the section 3.9.1). Remember also that the “Nsig” parameter controls exclusively the number of signal sources to use for the visualization of the results. In fact, the dimension of the signal subspace is only determined through the “Neig” parameter (see the section 3.9.1).
- Buttons for the reading of the seismo-acoustic traces, located in the upper-right part of the panel.
- The supplementary routines. You can select the type of data processing. The “Continuous” mode (Con) returns the values retrieved from all analysis windows. For each single trace, the “Discrete” one (Dis) provides the values of the analysis window associated with the maximum value of RMS amplitude. The latter mode is very useful for the Input traces that have a short length.
- Settings menu, located in the right part of the panel. You can set the temporary parameters of the module, such as the type of component/channel, the settings for the MUSIC analysis (analysis window and frequency, temporal bins of the Histograms, velocity waves, eigenvalues threshold, etc…) and the aesthetic features of the figures (Axis values, linear/logarithmic scales). Notice that some parameters are only defined in the Home Window (see section 2.5).
- Command Menu, positioned in the right-lower part of the panel. In the “MUSIC” section, the “Calculation” button starts the analysis routines. The results are shown on the screen at end of the processing. Notice that these processes need the search of all multi station traces on the basis of the coordinates file defined in the Home Window (see section 2.2). In addition, remember that the module works with UTM system coordinates. The manual save of the MUSIC figure involves exclusively the results of the selected source signal by clicking the “Save Plot” button. Pressing the “Ray vs. Az” and “Slow Grid” buttons, you can plot the 3D histograms of the ray parameter-back azimuth and horizontal slowness, respectively. In the secondary figures, the colorbar refers to the values of the histogram probability, while the legend indicates the current source signal. The “Hist” button creates a subplot about the histogram of the incidence and the rose diagram of the back azimuth. In this secondary figure, the legend refers to the current size of the signal subspace. The saving of the results for all source signals is performed by pressing the “Save button”.
- Text window for the assessment of the error, warning and command messages. It’s positioned in the lower part of the panel.

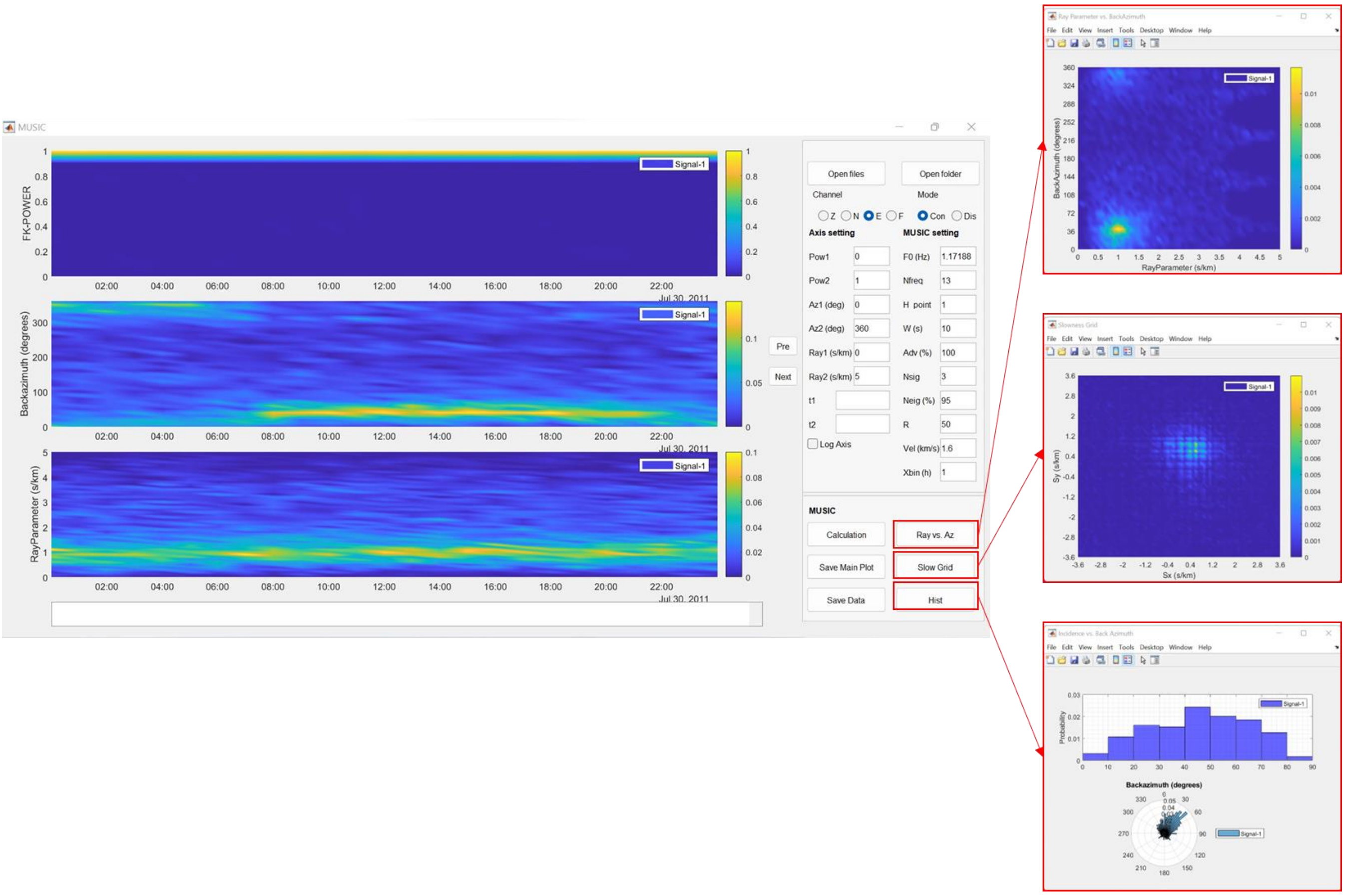

Fig.18. The MUSIC Module

3.9.1 Description of temporary parameters

- **MUSIC setting**
  - Component/Channel: Component or Channel of the reference station
  - Mode: Selection of the continuous or discrete analysis
  - F0: Central frequency of the analysis band (Hz)
  - Nfreq: Number of frequencies of the analysis band
  - H_point: Length of the Hamming window (samples)
  - W: Length of the window to calculate kinematic attributes (s)
  - Ad: Percentage of advancement of the analysis window (%)
  - Nsig: Number of sources
  - Neig: eigenvalues threshold of the total sum of eigenvalues (%)
  - R: Prewhitening factor
  - Vel: Propagation velocity of the seismic/acoustic waves (km/s)
  - Xbin: Temporal width of the 3D histogram bins (hours)
- **Axis setting**
  - Pow1: Minimum limit for the cross-power spectrum axis
  - Pow2: Maximum limit for the cross-power spectrum axis
  - Az1: Minimum limit for the back-azimuth axis (degrees)
  - Az2: Maximum limit for the back-azimuth axis (degrees)
  - Ray1: Minimum limit for the ray parameter axis (s/km)
  - Ray2: Maximum limit for the ray parameter axis (s/km)
  - Log Axis: Visualization of the axis on linear or semi-logarithmic scale

- t1, t2: Minimum and Maximum limits for the temporal axis

For the temporal limits, you must use “yyMMdd-HHmmSS” format, where yy, MM, dd, HH, mm, SS represent the years, the months, the days, the hours, the minutes and the seconds of reference.

3.9.2 Output file format

- **MUSIC results**

  The Output files contain all the information about the kinematics attributes. They can be formatted as Matlab (.mat) or Text files (.txt). In the first case, the Matlab files contain a table, named “data”, that have seven columns:

  - Column 1: Time series in datenum format.
  - Column 2: Back-azimuth series in degrees.
  - Column 3: Ray parameter series in s/km.
  - Column 4: Incidence series in degrees.
  - Column 5: X-component of the horizontal slowness series in s/km
  - Column 6: Y-component of the horizontal slowness series in s/km
  - Column 7: Normalized slowness spectrum series.

  In second case, the Text files have the same seven columns.
  However, in the both cases, they are written using the following path form:

  - /MUSIC/Sign-k/jld/CCC.yyyy.jld.hhmmss.format, for three components station system
  - /MUSIC/Sign-k/jld/yyyy.jld.hhmmss.format, for vertical single station system

  where k, CCC, yyyy, jld, hh, mm, ss, and format represent the number of sources, the component, the year, the Julian day, the hours, the minutes, the seconds and the output format (mat/txt), respectively.
- **MUSIC plot, Slowness Grid, Ray Parameter vs. BackAzimuth and Incidence vs. BackAzimuth figures**

  You can save as:
  - Matlab figure (.fig)
  - Bitmap file (.bmp)
  - EPS file (.eps)
  - Enhanced metafile (.emf)
  - JPEG image (jpg)
  - Paintbrush 24-bit file (.pcx)
  - Portable Bitmap file (.pbm)
  - Portable Document Format (.pdf)
  - Portable Graymap file (.pgm)
  - Portable Network Graphics file (.png)
  - Portable Pixmap file (.ppm)

– Scalable Vector Graphics file (.svg)
– TIFF image (.tif)
– TIFF no compression image (.tif)

You can manually set the filename, the Output folder and the file format.

3.10 Semblance Module

This module is dedicated to the investigation of the source location of the analysed wave field by performing the Semblance method (for more details, see Neidel and Tanner 1971). In particular, the procedure includes several steps. First of all, three-dimensional grid of assumed source positions is defined in order to determine the spatial extent of the region of interest. For each node of the grid, the origin time and the theoretical travel times are calculated at the reference sensor and at all the stations, respectively, by assuming a certain value of propagation velocity of the waves. Then, using these travel times and the origin time and assuming the amplitude decay of the signal with the node-station distance (see Battaglia et al., 2005 for more details), the traces at the different receivers are delayed to estimate the Semblance values for every node position. The source location is determined at the node where the delayed signals show the largest Semblance value. Finally, in order to assess the localization errors, the method is implemented with the JackKnife method (for more details, see Efron, 1982).

The structure of this module (Fig. 19) is characterized by:

- Semblance figure. The left, right-upper and right-lower axes show the three sections of the Semblance distribution. The colorbars of the surface plots refer to the Semblance values. The title contains all analysis information, such as the time reference, the coordinates of the maximum value of Semblance (Semblance value and X, Y, Z coordinates in km) and the localization errors (expressed in km). If the Error mode is deactivated, the error variables in title are associated with NaN values. Using the "Pre" and the "Next" buttons, you can display the results for each Input file. Remember that the setting of the geographic coordinates system affects only the visualization elements of the module. In addition, notice that the topographic correction can be only activated in the Home Window (see section 2.5).
- Buttons for the reading of the Input files, positioned in the upper-right part of the panel. Notice that the Input files are located in a specific folder, the name of which indicates the family labels explained in the "STA/LTA" or "Salped" modules (F1, F2, F3, F4, No Fam).
- The supplementary routines. You can choose different way to process the data by clicking on the pop menu. The "Continuous" mode applies the Semblance method over time windows sliding along the traces. The Semblance grids computed on all analysis windows are averaged obtaining one composite grid for each Input trace. The "Auto-Discrete" mode rather performs the method over one temporal window, that is selected on the basis of an automatic routine. In the latter, the upper limit of the window is retrieved through the picking of a "down" phase onset starting from the time position of the maximum amplitude of the signal (see the example in the Fig. 20). The "Man-Discrete" mode is very similar to the last, except for the

picking routine. In fact, you can set manually the upper limit of the analysis window through the dedicated interface (Fig. 20). In this latter case, you can move the cursor to your desired location and press a mouse button allowing to identify the respective time coordinate.

In, addition, you can also define the activation or deactivation of the JackKnife routine by clicking the "Error Mode" checkbox. This process is very useful to assess the stability of the obtained results.

- Settings menu, located in the right part of the panel. You can set the temporary parameters of the module, such as the type of component/channel, the settings for the Semblance analysis (analysis window and frequency, grid limits, velocity waves, parameters for the amplitude decay) and the aesthetic features of the figures (Axis values).
- Command Menu, positioned in the right-lower part of the panel. In the "Semblance" section, the "Calculation" button starts the analysis. The results are displayed on the screen at end of the process. Notice that this calculation requires the search of all multi station traces on the basis of the coordinates file defined in the Home Window (see section 2.2). In addition, remember that the module only works with station coordinates expressed in UTM system and with DEM file defined in the Home Window (see section 2.2). The manual save of the Semblance figure is only performed for the selected file by clicking the "Save Main Plot" button. Pressing the "Volume" button, you can display the values of Semblance higher than 90 % of the maximum value (red volume) on the DEM of the region of interest (contour plot). In this secondary figure, the routine also shows the stations used during the analysis (red marks) and the same title showed in the main figure for the selected file. The "Scatter locs" button rather provides the 2D scatter plot of all localizations on the DEM of the region of interest (contour plot). The colorbar and marks refer to the maximum Semblance values, while the size of the mark is proportional to the vector sum of the errors. The black marks rather represent the station locations. The saving of the results for every file is activated by pressing the "Save Data" button. Notice that, if the error analysis isn't activated, the module saves the error variables as NaN vectors.
- Text window for the visualization of the error, warning and command messages. It's positioned in the left-lower part of the panel.

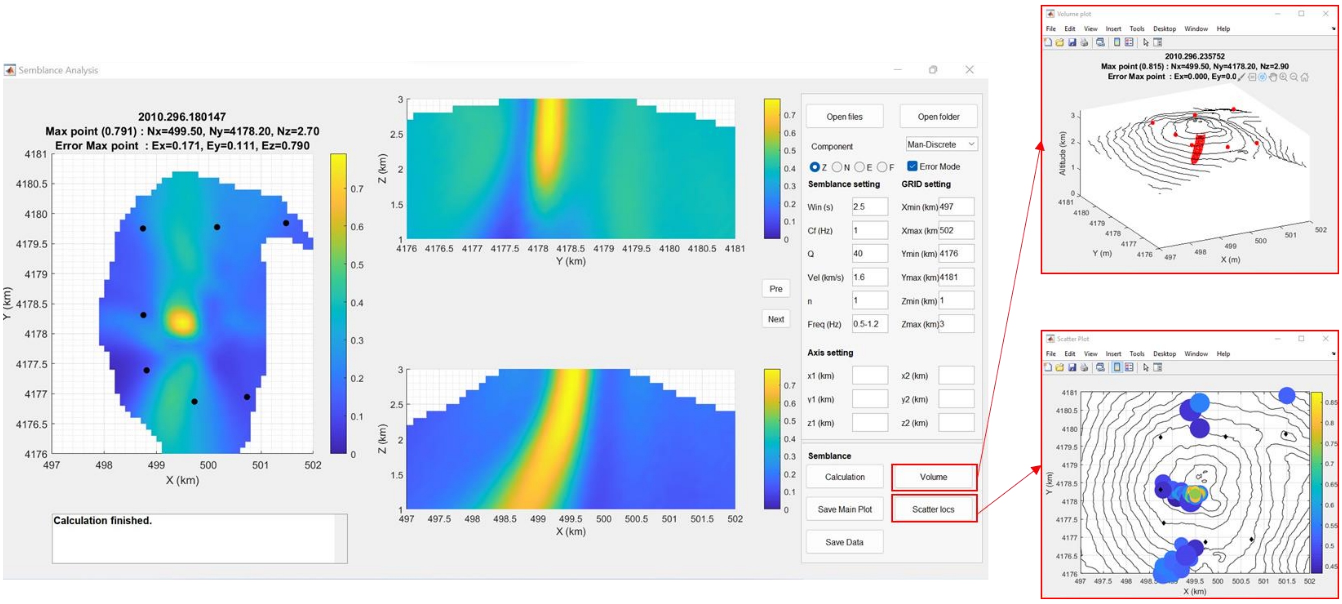

Fig.19. The Semblance Module

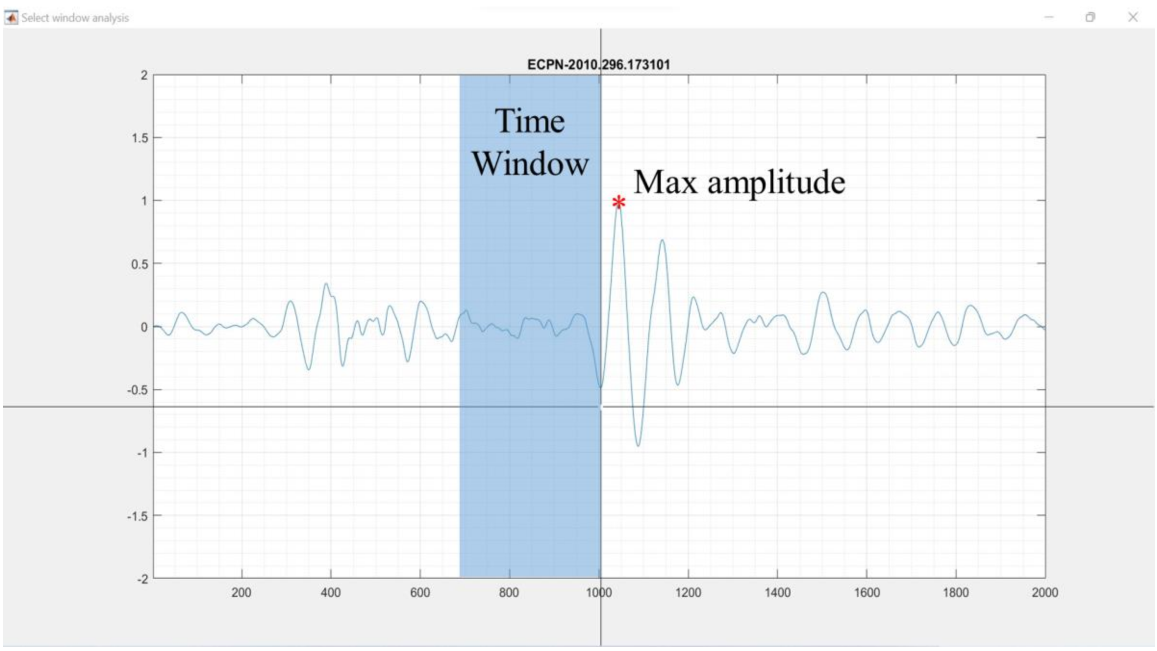

Fig.20. Example of the manual selection of the analysis window (2.5 seconds) on LP waveform.

3.10.1 Description of temporary parameters

- **Semblance setting**
  - Component/Channel: Component or Channel of the reference station
  - Pop-up menu: Selection of the automatic or manual picking of the events and
  - the continuous or discrete analysis
  - Error Mode: Activation/Deactivation of the analytical errors routines
  - Win: Length of the window to calculate Semblance values (s)

- Cf: Central frequency of the analysis band (Hz)
- Q: Ray-path-averaged quality factor
- Vel: Propagation velocity of the seismic/acoustic waves (km/s)
- n: Geometrical spreading factor
- Freq: Frequency range of analysis (Hz)

- **GRID setting**
  - Xmin: Minimum X-limit of the research grid (km)
  - Xmax: Maximum X-limit of the research grid (km)
  - Ymin: Minimum Y-limit of the research grid (km)
  - Ymax: Maximum Y-limit of the research grid (km)
  - Zmin: Minimum Z-limit of the research grid (km)
  - Zmax: Maximum Z-limit of the research grid (km)
- **Axis setting**
  - x1: Minimum X-limit for the Semblance axis
  - x2: Maximum X-limit for the Semblance axis
  - y1: Minimum Y-limit for the Semblance axis
  - y2: Maximum Y-limit for the Semblance axis
  - z1: Minimum Z-limit for the Semblance axis
  - z2: Maximum Z-limit for the Semblance axis

3.10.2 Output file format

- **Semblance results**

  The Output files contain all the information about the localization attributes. They can be formatted as Matlab (.mat) or Text files (.txt). In the first case, the Matlab files contain a table, named "data", that have nine columns:

  - Column 1: Time series in datenum format.
  - Column 2: X source coordinate in km (UTM system).
  - Column 3: Y source coordinate in km (UTM system).
  - Column 4: Z source coordinate in km (UTM system).
  - Column 5: Semblance value associated to the source position.
  - Column 6: Error of X source coordinate in km.
  - Column 7: Error of Y source coordinate in km.
  - Column 8: Error of Z source coordinate in km.
  - Column 9: Semblance Grid.

  In second case, the Text files have the same columns, except for the ninth one. In fact, the information about the Semblance Grid are located in a further Text file, the filename of which contains the suffix "_GRID".
  However, in the all cases, they are written using the following path form:

  - /Semblance/Family/jld/CCC.yyyy.jld.hhmmss.format, for three components station system
  - /Semblance/Family /jld/yyyy.jld.hhmmss.format, for vertical single station system

where Family, CCC, yyyy, jld, hh, mm, ss, and format represent the Family label, the component, the year, the Julian day, the hours, the minutes, the seconds and the output format (mat/txt), respectively.

- **Semblance Grid, Volume plot and Scatter plot figures**
  You can save as:
  - Matlab figure (.fig)
  - Bitmap file (.bmp)
  - EPS file (.eps)
  - Enhanced metafile (.emf)
  - JPEG image (jpg)
  - Paintbrush 24-bit file (.pcx)
  - Portable Bitmap file (.pbm)
  - Portable Document Format (.pdf)
  - Portable Graymap file (.pgm)
  - Portable Network Graphics file (.png)
  - Portable Pixmap file (.ppm)
  - Scalable Vector Graphics file (.svg)
  - TIFF image (.tif)
  - TIFF no compression image (.tif)

You can manually set the filename, the Output folder and the file format.

3.11 Radial Semblance Module

This module is used to the determine the source location of the analysed signals through the Radial Semblance method (for more details, see Almendros et al., 2002). This localization method is specifically designed for the location of isotropic sources with a network/array of three-component sensors. In particular, it is based on estimation of Semblance (see the Semblance module) weighted according to the rectilinearity of the particle motions. The application of the method needs several steps. First of all, it consists in the definition of three-dimensional grid of assumed source positions. For each node of the grid, the origin time and the theoretical travel times are calculated at the reference and all the stations, respectively, by fixing a value of propagation velocity of the waves. Then, through the travel times and the origin time, the radial components of traces at the different stations are time-shifted to estimate the Radial Semblance values. In this case, the traces are normalized by the 3D RMS amplitude of the signal. The source location is computed at the node where the delayed signals have the largest Semblance value. Finally, the method is implemented with the JackKnife method (for more details, see Efron, 1982) for the validation of the results.

Observing the fig. 21, you can view the structure of the module, that it consists of:

- Radial Semblance figure. The left, right-upper and right-lower axes display the three sections of the Radial Semblance distribution. The colorbars indicates the

Radial Semblance values. The title contains the main information of the results, that are the time reference, the coordinates of the maximum value of Radial Semblance (the Radial Semblance value and X, Y, Z coordinates in km) and the localization errors (expressed in km). In this title, if the Error mode isn't activated, the error parameters are shown as NaN values. Using the "Pre" and the "Next" buttons, you can refresh the axes viewing the results for each Input file. Remember that the setting of the geographic coordinates system involves only the plotting elements of the module. In addition, notice that the topographic correction can be only set in the Home Window (see section 2.5).

- Buttons for the reading of the Input files, positioned in the upper-right part of the panel. Notice that the Input traces are defined in a specific folder, the name of which refers to the family labels (F1, F2, F3, F4, No Fam).
- The supplementary routines. You can select different modalities for the data processing by clicking on the pop menu. The "Continuous" mode performs the method over time windows sliding along the signals. The Radial Semblance valued obtained for all temporal windows are averaged into unique grid. The "Auto-Discrete" mode rather uses one analysis window selected through an automatic routine that returns its upper limit. This process consists in the picking of a "down" phase onset from the temporal position of the maximum amplitude of the signal (see the example in the Fig. 20). The "Man-Discrete" mode is very similar to the last, except for the picking routine. In fact, the upper limit of the analysis window is set through the dedicated interface (Fig. 20), in which you can move the cursor to identify the desired x-coordinate.
  In, addition, you can also activate the JackKnife analysis by clicking the "Error Mode" checkbox, to assess the stability of the results.
- Settings menu, located in the right part of the panel. You can set the temporary parameters of the module, such as the type of component/channel, the settings for the Semblance analysis (analysis window and frequency, grid limits, velocity waves) and the aesthetic features of the figures (Axis values).
- Command Menu, positioned in the right-lower part of the panel. In the "Semblance" section, the "Calculation" button starts the main process. The results are shown on the screen at end of the calculation. Notice that this module needs the search of all multi three component station signals on the basis of the coordinates file defined in the Home Window (see section 2.2). In addition, remember that the module works exclusively with station coordinates expressed in UTM system and with DEM file defined in the Home Window (see section 2.3). The manual save of the Radial Semblance figure is only performed for the selected trace by pressing the "Save Main Plot" button. The "Volume" button displays the values of Radial Semblance higher than 90 % of the maximum value (red volume) on the DEM of the region of interest (contour plot). For the selected trace, this further figure is also composed by the stations locations (red marks) and the same title viewed in the main figure. The "Scatter locs" button rather returns the 2D scatter plot of all localizations on the DEM of the region of interest (contour plot). The colorbar and marks indicate the maximum Radial Semblance values, while the size of the mark is proportional to the vector sum of the errors. The black marks refer to the station positions. The saving of the results for every localizations is performed by clicking the "Save Data" button. Notice that the deactivation of the

JackKnife routine affects the saving of the analysis errors, that are saved as NaN vectors.

- Text window for the visualization of the error, warning and command messages. It’s positioned in the left-lower part of the panel.

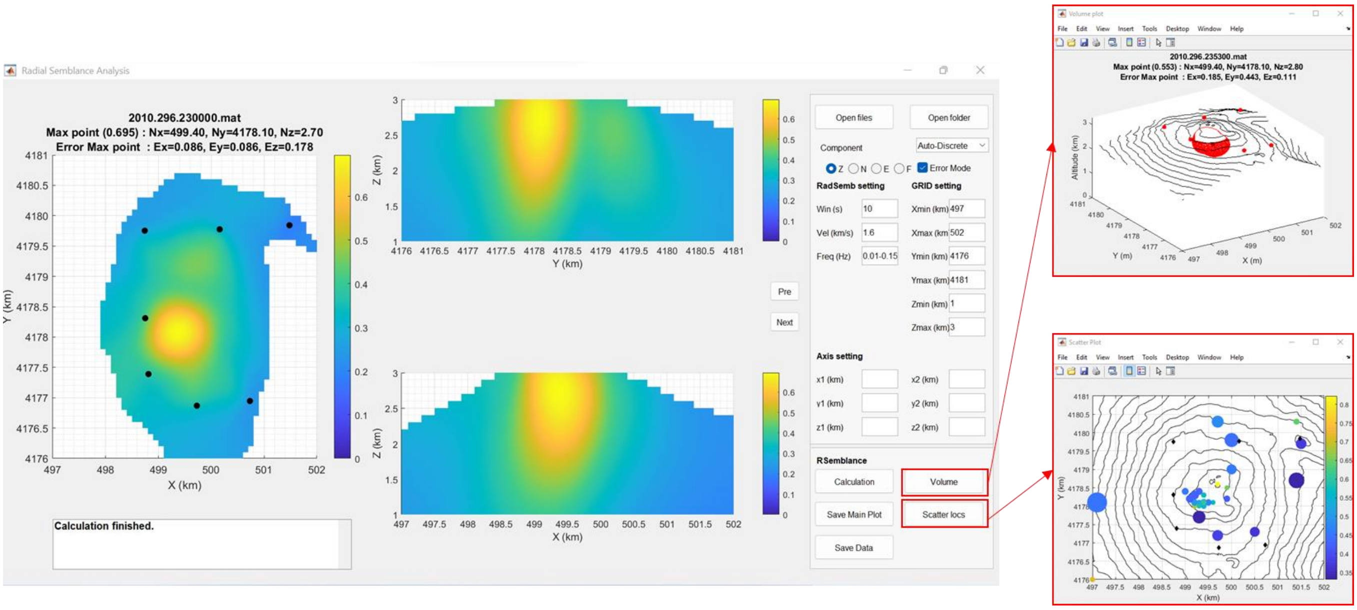

Fig.21. The Radial Semblance Module

3.11.1 Description of temporary parameters

- **Radial Semblance setting**
  - Component/Channel: Component or Channel of the reference station
  - Pop-up menu: Selection of the automatic or manual picking of the events and
  - the continuous or discrete analysis
  - Error Mode: Activation/Deactivation of the analytical errors routines
  - Win: Length of the window to calculate Radial Semblance values (s)
  - Vel: Propagation velocity of the seismic/acoustic waves (km/s)
  - Freq: Frequency range of analysis (Hz)
- **GRID setting**
  - Xmin: Minimum X-limit of the research grid (km)
  - Xmax: Maximum X-limit of the research grid (km)
  - Ymin: Minimum Y-limit of the research grid (km)
  - Ymax: Maximum Y-limit of the research grid (km)
  - Zmin: Minimum Z-limit of the research grid (km)
  - Zmax: Maximum Z-limit of the research grid (km)
- **Axis setting**
  - x1: Minimum X-limit for the Radial Semblance axis
  - x2: Maximum X-limit for the Radial Semblance axis
  - y1: Minimum Y-limit for the Radial Semblance axis
  - y2: Maximum Y-limit for the Radial Semblance axis
  - z1: Minimum Z-limit for the Radial Semblance axis

- z2: Maximum Z-limit for the Radial Semblance axis

3.11.2 Output file format

- **Radial Semblance results**
  The Output files contain all the information about the localization attributes. They can be formatted as Matlab (.mat) or Text files (.txt). In the first case, the Matlab files contain a table, named "data", that have nine columns:

  - Column 1: Time series in datenum format.
  - Column 2: X source coordinate in km (UTM system).
  - Column 3: Y source coordinate in km (UTM system).
  - Column 4: Z source coordinate in km (UTM system).
  - Column 5: Radial Semblance value associated to the source position.
  - Column 6: Error of X source coordinate in km.
  - Column 7: Error of Y source coordinate in km.
  - Column 8: Error of Z source coordinate in km.
  - Column 9: Radial Semblance Grid.

  In second case, the Text files have the same columns, except for the ninth one. In fact, the information about the Radial Semblance Grid are located in a further Text file, the filename of which contains the suffix "_GRID".
  However, in the all cases, they are written using the following path form: /RSemblance/Family/jld/yyyy.jld.hhmmss.format, where Family, yyyy, jld, hh, mm, ss, and format represent the Family label, the year, the Julian day, the hours, the minutes, the seconds and the output format (mat/txt), respectively.
- **Radial Semblance Grid, Volume plot and Scatter plot figures**
  You can save as:
  - Matlab figure (.fig)
  - Bitmap file (.bmp)
  - EPS file (.eps)
  - Enhanced metafile (.emf)
  - JPEG image (jpg)
  - Paintbrush 24-bit file (.pcx)
  - Portable Bitmap file (.pbm)
  - Portable Document Format (.pdf)
  - Portable Graymap file (.pgm)
  - Portable Network Graphics file (.png)
  - Portable Pixmap file (.ppm)
  - Scalable Vector Graphics file (.svg)
  - TIFF image (.tif)
  - TIFF no compression image (.tif)

  You can manually set the filename, the Output folder and the file format.

4. References

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5. External links

- https://www.gfz-potsdam.de/en/home/
- https://www.iris.edu/hq/
- https://www.mathworks.com/