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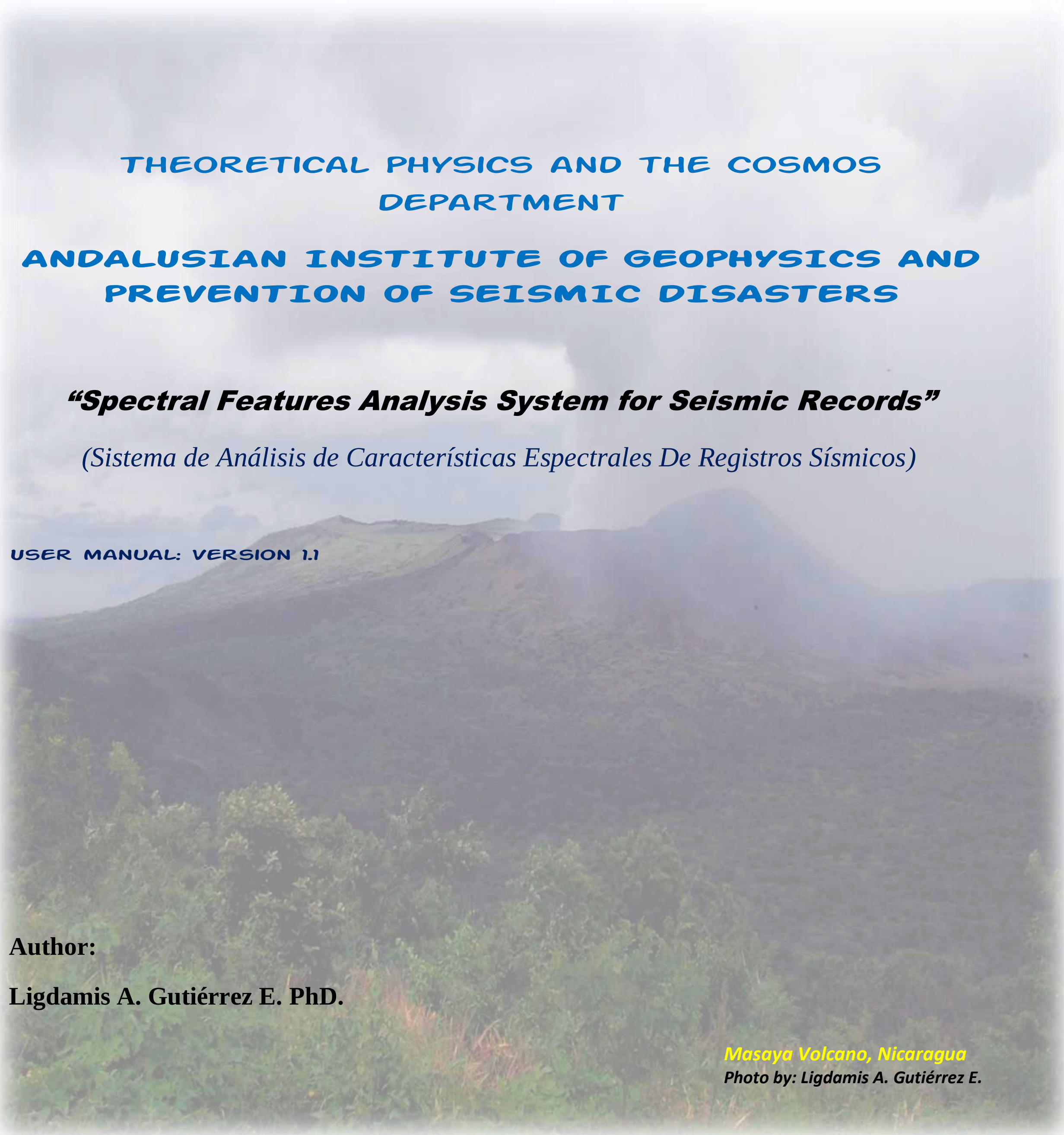

THEORETICAL PHYSICS AND THE COSMOS DEPARTMENT

ANDALUSIAN INSTITUTE OF GEOPHYSICS AND PREVENTION OF SEISMIC DISASTERS

“Spectral Features Analysis System for Seismic Records”

(Sistema de Análisis de Características Espectrales De Registros Sísmicos)

USER MANUAL: VERSION 1.1

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Masaya Volcano, Nicaragua

Photo by: Ligdamis A. Gutiérrez E.

Granada, Spain 2021 - 2023

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1.- Introduction

The Module: "Spectral Features Analysis System for Seismic Records" (*Sistema de Análisis de Características Espectrales de Registros Sísmicos*) is a user-friendly interface that allows for easy and efficient management of the main spectral analysis methods for seismic records. The system is available in both Spanish and English versions. In the appendices, information about the folder structure and its contents can be found. The easy access to each of the seismic analysis elements enables the observer to gain a much clearer understanding of the different types of seismic records produced in a volcano. This serves as a crucial aid for human observers in comprehending the processes occurring during a specific period of volcanic activity.

The application, through its incorporated libraries, allows the reading of various seismic formats such as SAC, MSEED, GSE2, EVT, WAV, among others. Subsequently, various filtering and spectral analysis techniques can be applied to better understand the characteristics of each record. This results in a better understanding of the type of event to which the record may belong, providing the observer with added value for more efficient classification and improved training of seismic signals.

This updated version (1.1) of the analysis module consists of a single interface that encompasses various tools for seismic record analysis. Additionally, the module provides the capability to store graphical results in various formats, such as PNG, JPG, EPS, PS, PDF, RAF, TIF, among others.

The module and the entire system have been developed in Python, version 3.8.6. (The set of libraries is compatible with version 3.10.10). Additionally, a series of open-access libraries are included, which, in conjunction with Python, enable the use of graphical and analytical tools, providing ease of use and enhancing computational power for the user. Some of the main elements and libraries used are listed below:

- **Matplotlib**: Used for creating static, animated, and interactive visualizations in Python. (https://matplotlib.org/stable/users/index.html)
- **NumPy**: A library for numerical operations in Python. (https://numpy.org/doc/stable/user/quickstart.html)
- **PyQt5**: A tool that links with the graphical library Qt5 in C++ (https://pypi.org/project/PyQt5/)
- **Obspy**: A Python toolbox for seismology. (https://docs.obspy.org/)
- **Tkinter**: Graphical User Interface (GUI) (https://docs.python.org/3/library/tkinter.html)

Another key feature of the system is its definition as a cross-platform application, meaning it can operate on various platforms or operating systems, such as Windows (7, 8, 10, 11) in both 32-bit and 64-bit versions. It also supports Linux systems, such as Ubuntu and other similar systems (Debian, Red Hat, Fedora, SUSE, etc.), macOS, and Android for tablets and mobile devices (with Python appropriately adapted for these devices).

NOTE: In the appendices of this document (*as well as in the Readme.txt and Initial_requirements.txt files*), you can find general information on installation for Windows and Linux systems, as well as guidelines for installing the main programs and additional libraries required by Python to properly execute the developed programs in its environment.

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2.- Initial Screen of the System

In the appendices of this document and in the "**README.txt**" file included in the "***Documents***" folder, you will find instructions for installing the system on Windows (*the process on Linux systems is similar*). Essentially, you need to perform two actions:

a) Copy the "Set_tools_System_1_1" folder to "My Documents" on Windows.
b) Copy the "Set_tools_System_1_1.bat" file to the Windows desktop.

Additionally, there are instructions for installing the necessary Python libraries on the system. Once "Set_tools_System_1_1.bat" has been copied to the desktop, you need to right-click on it and select "Run as administrator."

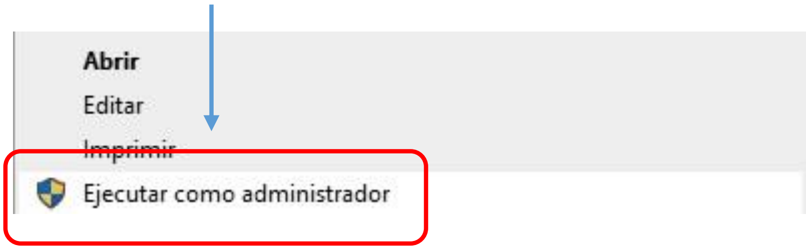

Fig. 1 Popup Window when Right-Clicking on the "Set_tools_System_1_1.bat" File

In the window that opens, click the "Yes" button when prompted with "*Do you want to allow this app to make changes to your computer*?" This is a warning message. However, the application does not make any changes, so you should trust its execution.

Upon clicking "*Yes*," the following command window opens, welcoming you to the system.

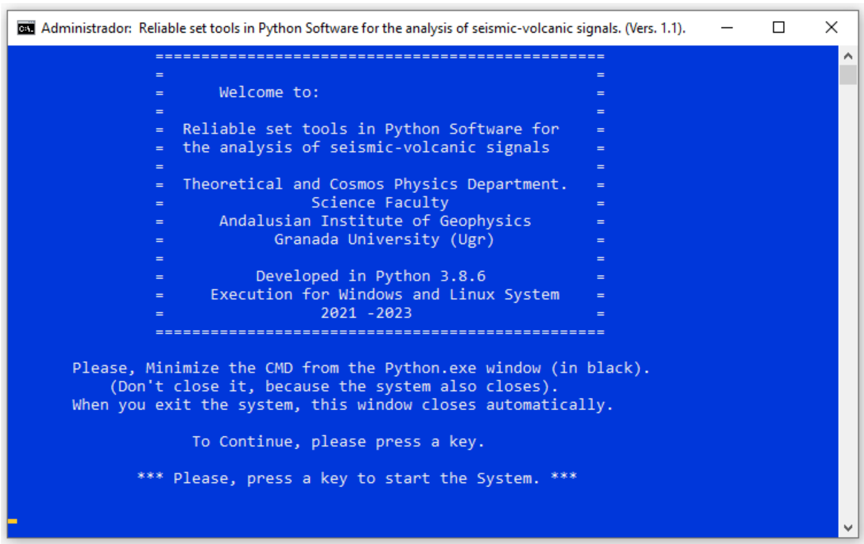

Fig. 2 Welcome Screen and Instructions for Loading the System.

After reading the information in the window, you simply need to press any key to access the system's initial screen. The folder should already be copied to "***My Documents***," and the "**Set_tools_System_1_1.bat**" file contains all the loading instructions.

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The system's initial screen is "**Menu.py**." It appears when any key is pressed on the Welcome screen. Additionally, the Python command window or console is displayed, similar to the following:

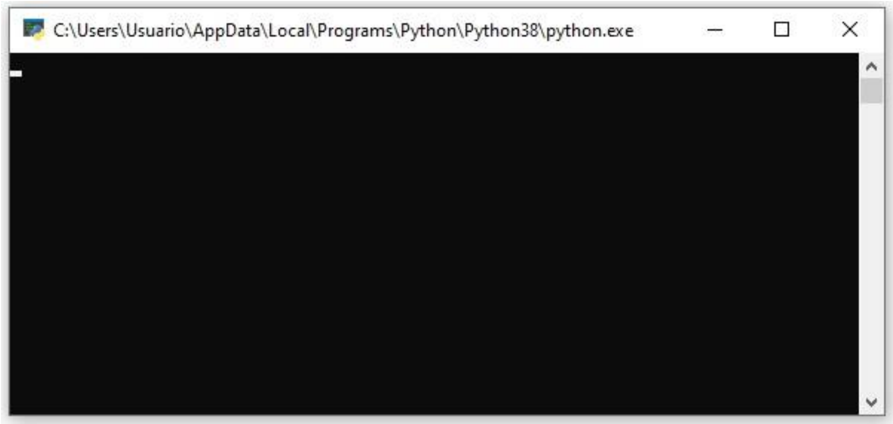
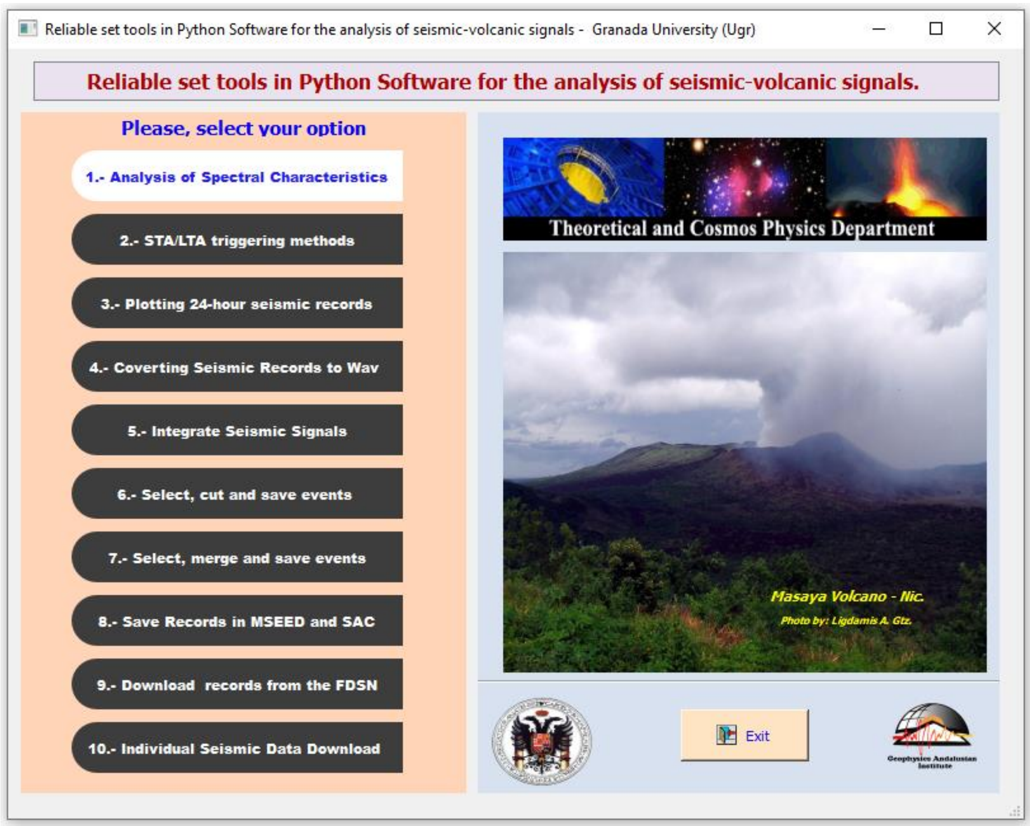


Fig. 3 Python Console (CMD) Window (*Should be minimized*)

To avoid obstructing the view, you can and should "minimize" this screen. Do **not** close it, as this would also close the system's startup window. Once you have finished working with the system, this window will close automatically. The initial presentation screen of the system (the module menu) is as follows:



NOTE: When pressing or clicking on a module button, the startup window will close and the module window will open (*this may take a little time depending on the PC's memory. It is recommended to have at least 8 GB of memory in the system, with 16 GB being ideal*).

Fig. 4 **Main Menu Screen.** The module to be worked on is highlighted. Module 1 (Analysis of Spectral Characteristics).

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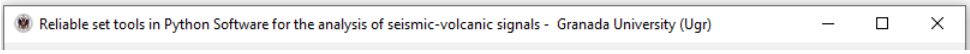
2.1.- Elements of the Initial Screen

As observed in the previous figure, the initial or presentation screen is a simple window composed of:

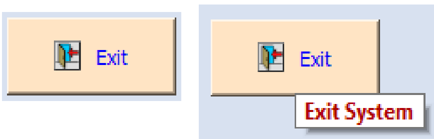
a) A top toolbar with basic information about the module.
b) On the left side, there are 10 execution buttons or command buttons for each module of the system.
c) At the bottom, there is a command button that allows for exiting the system.
d) Additionally, it features a background image representing a volcano (Masaya in Nicaragua), and three images with the logos of the University of Granada, the Andalusian Institute of Geophysics, and the Department of Theoretical and Cosmic Physics.

a) At the top, the icon of the University is visible, along with the module title and a reference to the University of Granada (UGR).



b) On the left side, there are 10 execution buttons or command buttons for each module of the system. When the mouse pointer is placed over each button, it is highlighted in white to indicate that it is being selected. Clicking on a button closes the startup menu window and opens the window for the indicated module (this may take a little time depending on the PC's memory).

c) At the bottom, there is a command button: **Exit**. When the mouse pointer is placed over each button, a text appears indicating the action of that button (Exit System, Start System).



If you click the "Exit" button, a window will appear asking the user if they are sure they want to leave the system.

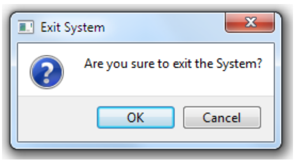


Fig. 5 Text Box Indicating Whether You Want to Exit the System.

If you click "**OK**," the screen will close and the system will exit. If you click "Cancel," you will remain on the initial screen.

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3.- Analysis Screen

The “Analysis Screen” is the main interface of the module, where activities related to record reading tools, filtering, and spectral analysis of seismic records are performed. This screen consists of the following 6 parts.

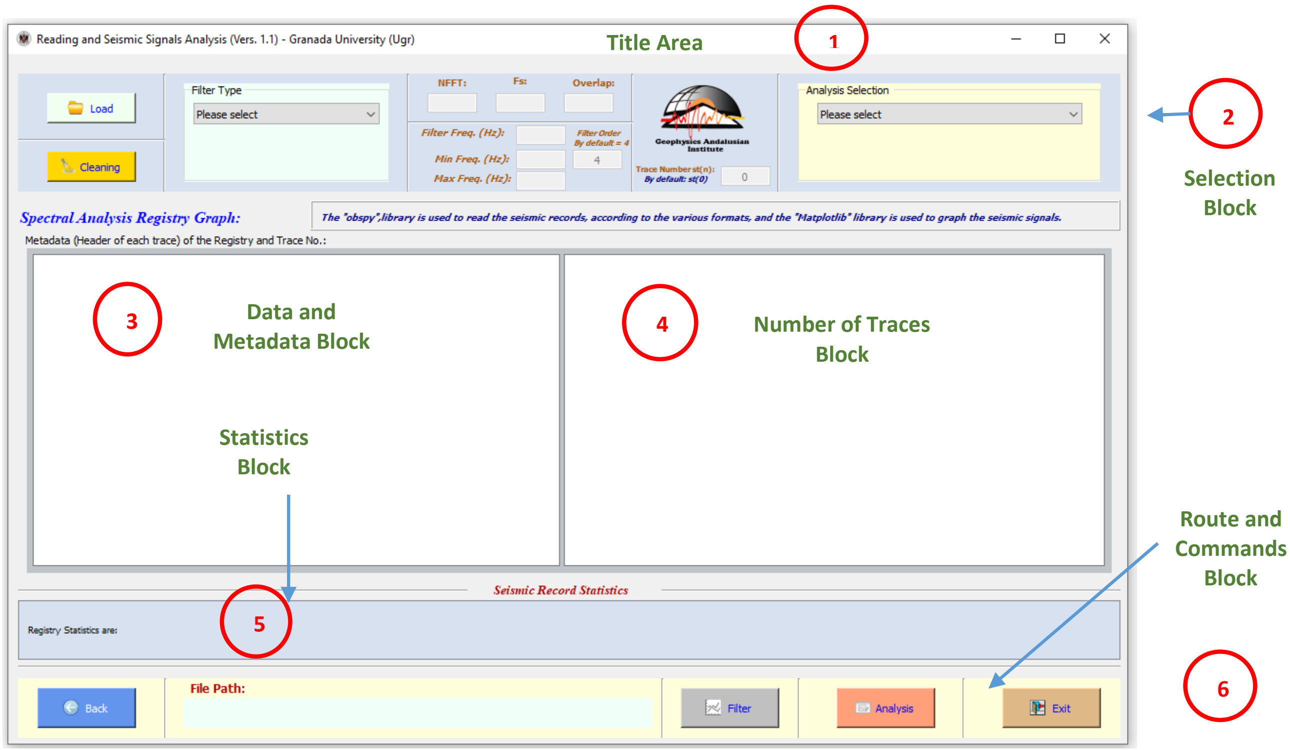
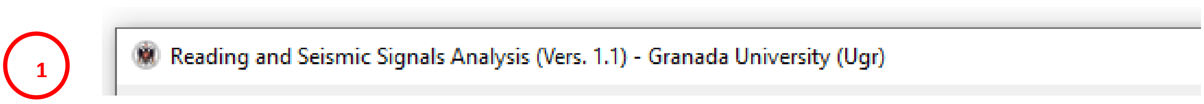


Fig. 6 Elements of the System Analysis Screen.

The screen is composed of various elements for use. At the top, you can see the program name, icon, and university name, as the title (1).



The elements that make up the main screen are detailed below.

3.1.- Elements of the Analysis Screen.

In addition to number (1), the 5 elements of the analysis screen are distributed into five main blocks, numbered from (2-6) in the red circles.

3.1.1.- Selection Block. (2)

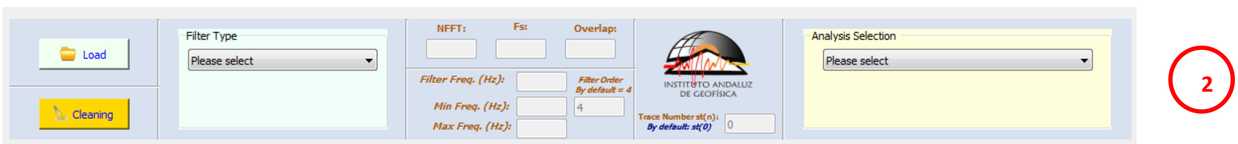


Fig. 7 Elements of the selection block.

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3.1.2. – Data, Metadata, and Number of Traces Presentation Block (3 and 4).

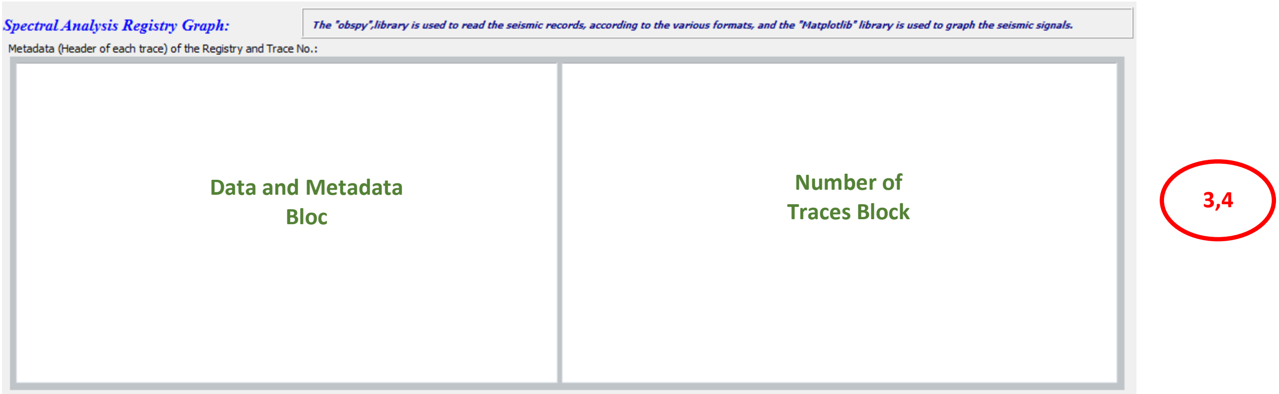

Fig. 8 Data, Metadata, and Number of Traces Block.

3.1.3.- General Statistics Presentation Block of the Record (4).

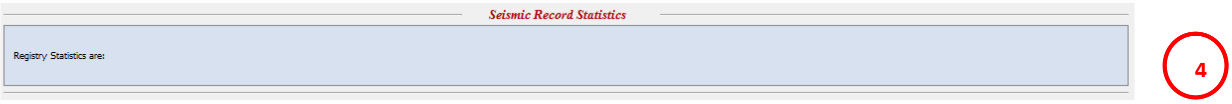

Fig. 9 General Statistics Block of the Record.

3.1.4.- Path Block and Graph Action Commands, Exit and Return (5).

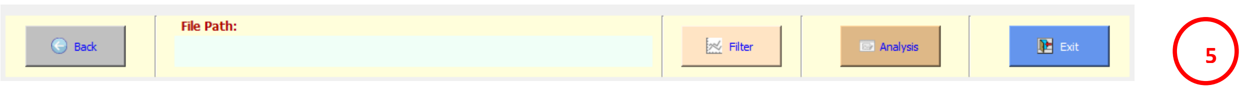

Fig. 10 Path Block, Graphics and Analysis Commands. Exit and Return.

3.2.- Elements of the selection block.

This block is first configured by the section that groups the action buttons for loading the record and clearing data.

These two action buttons, when the mouse pointer is placed over them, indicate the actions they perform.

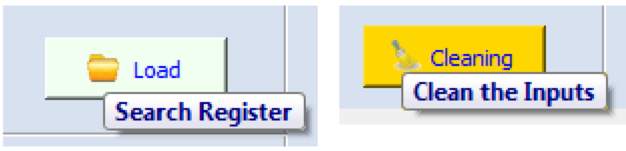

Fig. 11 Botones de Registro y Limpieza de datos.

As observed, the **"Load"** button searches for and loads seismic records in various formats. The **Cleaning** button clears or deletes input elements, closes existing graphics, and resets the analysis screen to its initial state, preparing it for a new search and spectral analysis of events.

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3.2.1.- Record Load Button.

The action of the **Load** button allows you to click and open a file explorer window (*by default, it starts at the root directory "C" of the PC*), presenting options for searching various file formats and allowing you to perform the search in the computer's directory. This is shown in the following screen.

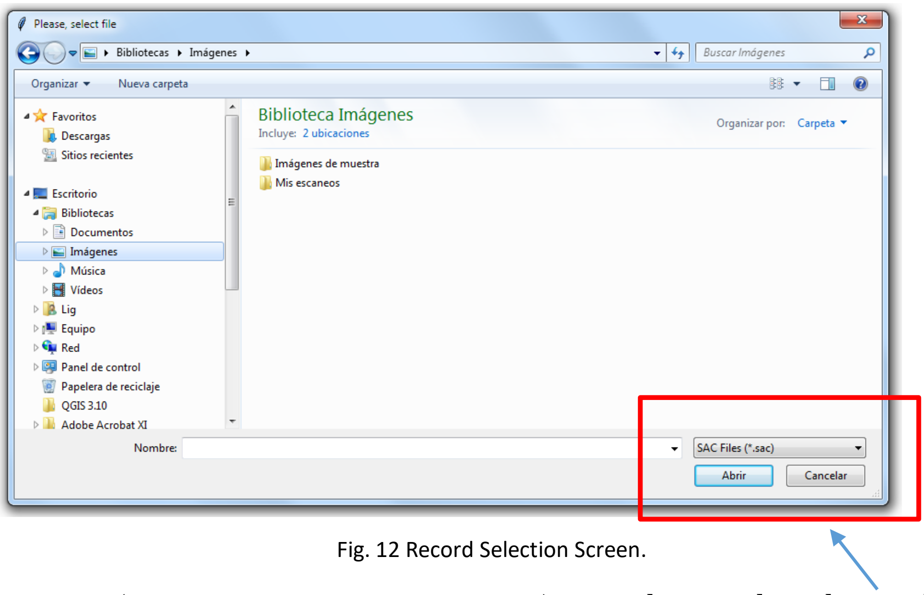


Fig. 12 Record Selection Screen.

In this screen (*Language according to the system*), records are selected according to the desired format (***red box***) such as SAC, MSEED, GSE2, EVT, etc. This is possible through the seismic format reading library **"Obspy"**. Once selected, click the **"Open"** button to load the record onto the analysis screen. Otherwise, click the **"Cancel"** button, and the action will return to the analysis screen. The process of selecting a record is shown in the following screen.

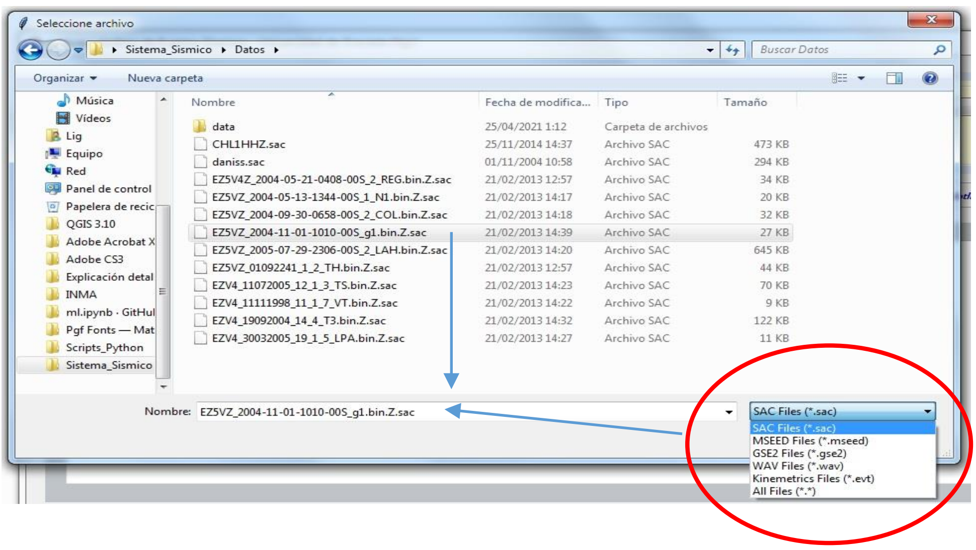


Fig. 13 SAC Record Selection Screen.

On the screen, in the bottom right corner, indicated by the red circle, and displayed through the arrow, is the list of the most common seismic formats supported and/or used by observatories and institutions worldwide (SAC, MSEED, GSE2, WAV, EVT).

When selecting a specific type, records in that format are displayed. For example, the **SAC** records that are stored. By clicking on the desired record, it appears in the **"Name"** box. At this point, you should click the **"Open"** button that was presented on the previous screen, which loads the **"Path"** of the physical location of the record in the system. This path will be displayed in the **"File Path"** box located at the bottom of the analysis screen.

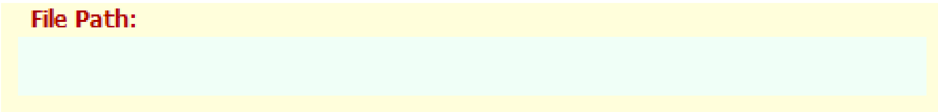
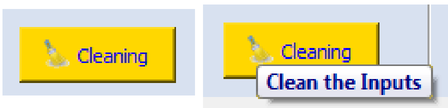
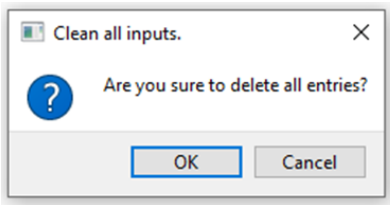


Fig. 14 File Path Box, which displays the location of the record.

This is an important aspect, as it determines whether the physical file location of the stored record on the computer can be located for analysis later. If the file is invalid or cannot be found, a validation window will appear to indicate this (*see Fig. 48, page 25*).

3.2.2.- Cleaning Button.





Clicking this button clears all entries on the screen. It will clean the data entry text boxes and the path or folder where the record to be downloaded will be stored, and it will delete all active entries with data at that moment. It restores the initial values of the main interface (see Fig. 6). When you place the mouse pointer over it, a message appears indicating its function. Clicking the button opens a window asking the user if they are sure they want to delete the data entries. If confirmed, it clears all entries and returns the interface to its initial state. Otherwise, the current entries remain in the interface.

3.2.3.- Filter Type Selection.

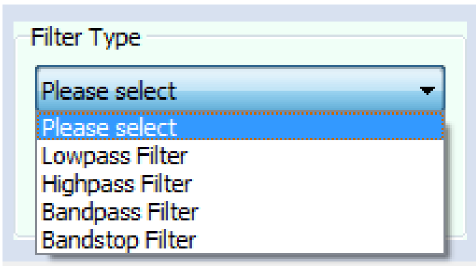


Fig. 15 Filter Type Selection via List

In this section, a drop-down list of the various available filters for analyzing the records is presented. These include filters such as: *Lowpass*, *Highpass*, *Bandpass*, and *Bandstop*. Selecting each of these items will activate one or more of the checkboxes located in the continuous section, which correspond to the data inputs needed for calculations. When the initial value **"*Please Select*"** is chosen, the inputs return to their initial values, as does the analysis list.

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3.2.4.- Input Selection.

Fig. 16 Selection of Input to Calculate and Number of Trace in the Record (default = 0)

These inputs will correspond to the type of selection, whether filter or analysis, made by the user (default filter order = 4). The trace number value is set to default = 0. In cases with multiple traces, for example, in MSEED or SEISAN records that have either three components or various values, the desired trace number starting from zero should be indicated here. The inputs are validated to accept only numbers, including decimals and negatives, except for the discrete wavelet coefficients entries (where labels and data types change). Regarding the filter type, the inputs to be activated are as follows:

3.2.5.- Lowpass Filter Type (Lowpass)[1]

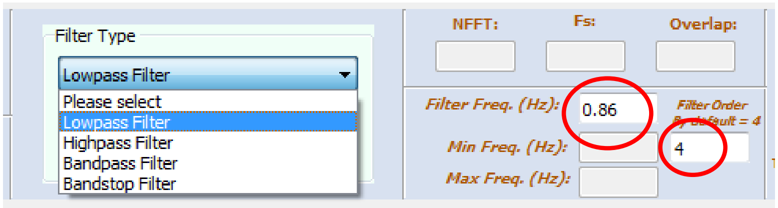
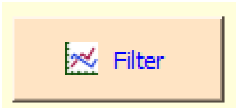


Fig. 17 Example of Lowpass Filter Type Selection. In the red circles, the inputs to be provided (Frequency and Filter Order).

When selecting this type of filter, the following input fields are activated:

a) **Filter Frequency (Hz):** Here, you must enter a valid value for the frequency you wish to use to calculate the type of filter.
b) **Filter Order:** In this field, you must enter a valid value for the order of the filter you wish to use for the calculation. Generally, an order of 2 or 4 is used (by default, it is set to a value of 4).

As observed, the other fields remain inactive. Additionally, the analysis selection list and its corresponding graphing command are deactivated. Once the actions are completed, click the **"Filter"** button. If you wish to graph (click the **"Graph"** button) without entering a valid value or entering a value out of range or invalid in either of the two fields, a validation dialog box will appear indicating that the action needs to be taken. This dialog box also allows the program to continue execution without severe system interruption due to missing data. The two types of incorrect inputs that will be presented are as follows:



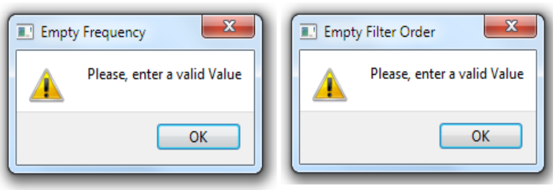


Fig. 18 Frequency and Filter Order Input Validation.

[1] The lowpass filter blocks high-frequency signals and allows low-frequency signals (*frequencies below the cutoff frequency*) to pass through.

3.2.6.- Highpass Filter Type (Highpass)[2]

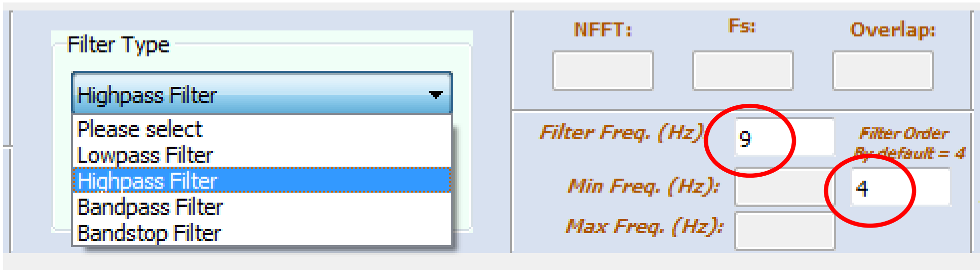
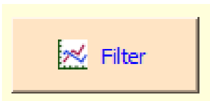


Fig. 19 Selection of Highpass Filter Type. In the red circles, the inputs to be provided (Frequency and Filter Order).

Similar to the previous filter, when selecting this type of filter, the following input fields are activated:

a) **Filter Frequency (Hz):** Here, you must enter a valid value for the frequency you wish to use to calculate the type of filter.
b) **Filter Order:** In this field, you must enter a valid value for the order of the filter you wish to use for the calculation. Generally, an order of 2 or 4 is used (by default, it is set to a value of 4).

As observed, the other fields remain inactive. Additionally, the analysis selection list and its corresponding graphing command are deactivated. Once the actions are completed, click the **"Filter"** button.



The trace number value is set by default to 0. In the case of multiple traces, such as in MSEED or SEISAN records that have either three components or various values, the desired trace number should be specified starting from zero here. If you want to graph (click the **"Filter"** button) without entering a valid value or if you enter a value that is out of range or invalid in either of the two fields, a validation dialog box will appear indicating that action needs to be taken. This dialog box also allows the program to continue running without severe system interruption due to missing data. The two types of incorrect inputs that will be presented are as follows:

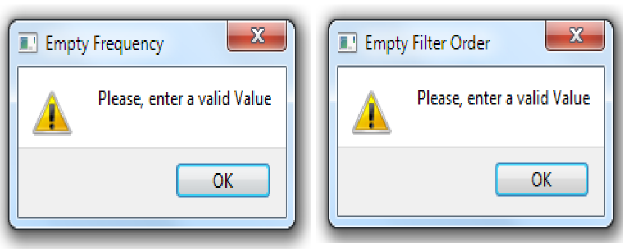


Fig. 20 Validation of Frequency and Filter Order Inputs.

[2] The **Highpass Filter** blocks low-frequency signals and allows high-frequency signals (*frequencies higher than the cutoff frequency*) to pass through.

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3.2.7.- Bandpass Filter Type (Bandpass)[3]

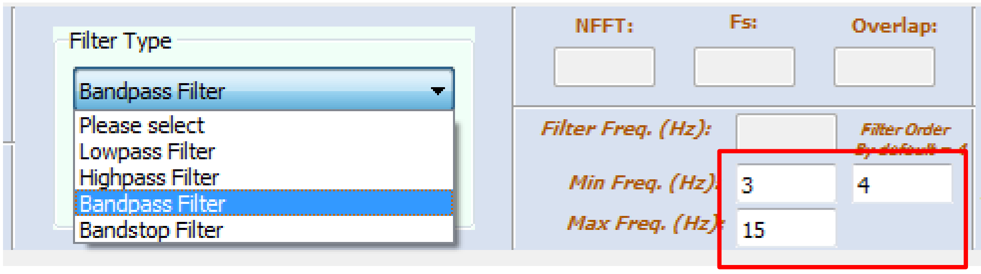
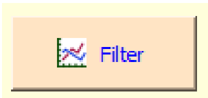


Fig. 21 **Selection of Bandpass Filter Type.** In the red box, the inputs are observed (Min. Frequency, Max. Frequency, and Filter Order).

When selecting this type of filter, the following fields are activated:

a) **Minimum Filter Frequency (Hz):** Here, you need to enter a valid value for the minimum frequency you wish to use for calculating the filter type.
b) **Maximum Filter Frequency (Hz):** In this field, you need to enter a valid value for the maximum frequency you wish to use for calculating the filter type.
c) **Filter Order:** In this field, you need to enter a valid value for the order of the filter you wish to use for the calculation. Typically, the order is 2 or 4 (*the default value is set to 4*).

As observed, the other fields remain inactive. Additionally, the analysis selection list and its corresponding plotting command are deactivated. Once the actions are completed, click the "Filter" button.



The trace number is set to 0 by default. In the case of multiple traces, for example, in MSEED records that have three components or various values, the desired trace number starting from zero should be specified here. If you attempt to plot (*by clicking the "**Filter**" button*) without entering a valid value or if an out-of-range or invalid value is entered in any of the three fields, a validation message will appear. This dialog box will indicate the required action and allows the program to continue running without severe interruption due to missing data. The three types of incorrect entries that may be presented are as follows:

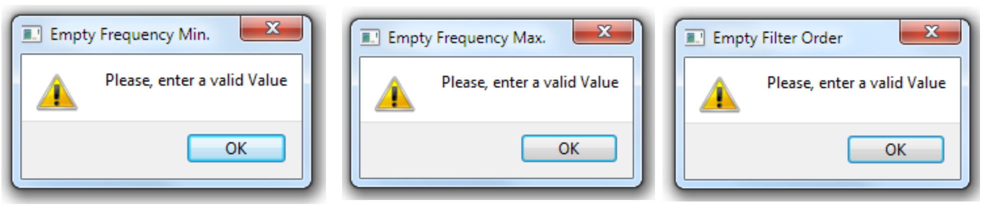


Fig. 22 Validation of the Bandpass Filter Inputs.

[3] The bandpass filter allows spectral content to pass only within a central frequency range. This range is defined by a minimum frequency value and a maximum frequency value. It removes noise associated with both low and high frequencies that may be generated or residual.

3.2.8.- Bandstop Filter (Bandstop)[4]

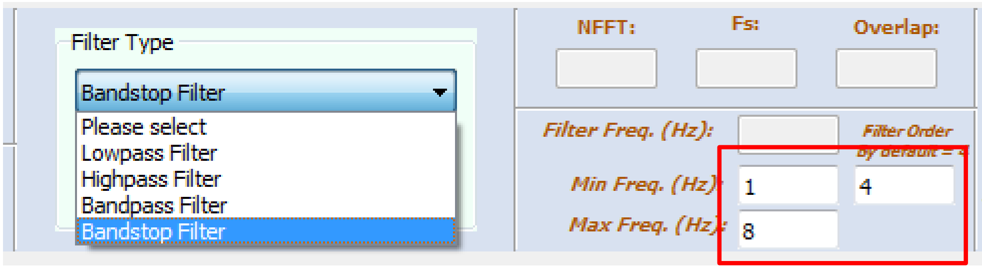
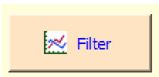


Fig. 23 Selection of Bandstop Filter Type. In the red box, the entries (*Min. Frequency, Max. Frequency, and Filter Order*) are shown

When selecting this type of filter, the following fields are activated:

a) **Minimum Filter Frequency (Hz):** Here, you need to enter a valid value for the minimum frequency you wish to use for calculating the filter type.
b) **Maximum Filter Frequency (Hz):** In this field, you need to enter a valid value for the maximum frequency you wish to use for calculating the filter type.
c) **Filter Order:** In this field, you need to enter a valid value for the order of the filter you wish to use for the calculation. Typically, the order is 2 or 4 (the default value is set to 4).

As observed, the other fields remain inactive. Additionally, the analysis selection list and its corresponding plotting command are deactivated. Once the actions are completed, click the "***Filter***" button.



The trace number is set to 0 by default. In the case of multiple traces, for example, in MSEED records that have three components or various values, the desired trace number starting from zero should be specified here. If you attempt to plot (by clicking the "***Filter***" button) without entering a valid value or if an out-of-range or invalid value is entered in any of the three fields, a validation message will appear. This dialog box will indicate the required action and allows the program to continue running without severe interruption due to missing data. The three types of incorrect entries that may be presented are as follows:

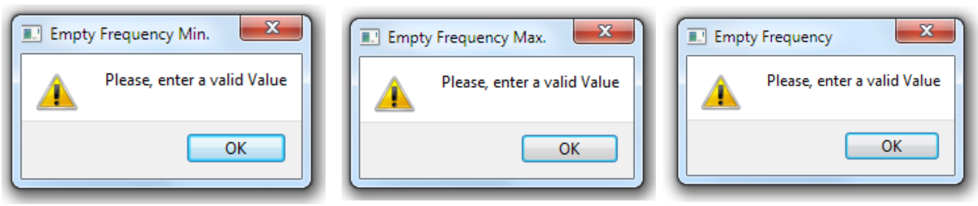


Fig. 24 Validation of the Bandstop Filter Inputs.

[4] The Bandstop filter blocks signals with frequencies between the upper and lower cutoff frequencies. In other words, it eliminates frequencies or stops a specific frequency band.

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3.2.9.- Selection of Spectral Analysis Type.

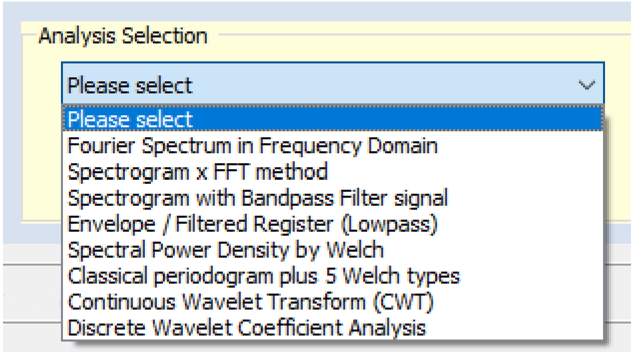


Fig. 25 Selection of spectral analysis type via dropdown list.

Here, a dropdown list of the various types of spectral analyses available for analyzing the records is presented. Similar to the filters, the entries only accept numbers, including decimals and negatives. Eight general types of spectral analyses are listed, as can be observed:

a) Fourier Transform Spectrum in the Frequency Domain.
b) Spectrogram using the Fast Fourier Transform (FFT).
c) Spectrogram with an included band-pass filter.
d) Envelope of the signal filtered by a low-pass filter.
e) Power spectral density using Welch's method.
f) Classical periodogram plus five types of Welch window.
g) Continuous Wavelet Transform (CWT) of the record.
h) Analysis of the Discrete Wavelet Transform Coefficients.

When selecting any item from this section, the button to plot these analyses is automatically activated, and both the selection and the plot button for the filtering options will be deactivated. Similarly to the filtering list, when the initial value "Select" is chosen, the values will reset to their initial state, as will the filtering list. The items that make up the analysis list are detailed below.

3.2.10.- Fourier Transform Spectrum in the Frequency Domain[5].

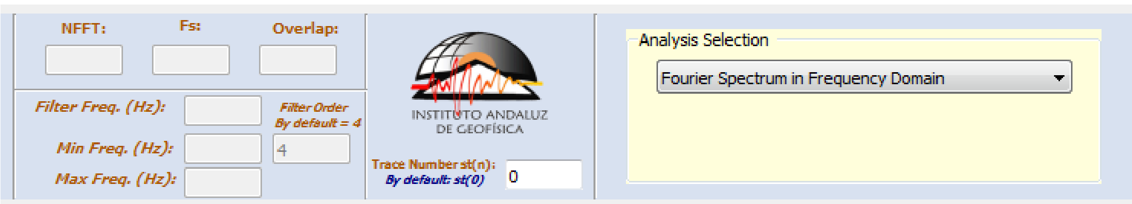
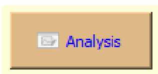


Fig. 26 Selection of Fourier Transform Spectrum in the Frequency Domain.

The calculations to represent the spectrum of the record in the frequency domain are automatically determined. As a result, the following are presented: a) The original record, b) The FFT transform in Frequency, c) The logarithmic magnitude of the spectrum, and d) The phase magnitude of the spectrum. Once this option is selected, click on the 

"***Analysis***" button.

---

[5] Bracewell, R., & Kahn, P. B. (1966). The Fourier transform and its applications. *American Journal of Physics*, *34*(8), 712-712.

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There are no input values. The calculations are included in the code. The trace number is set by default to 0. In case of multiple traces, such as in MSEED or SEISAN records, which may contain either three components or various values, the desired trace number starting from zero should be specified here.

3.2.11.- Spectrogram using the Fast Fourier Transform (FFT)[6].

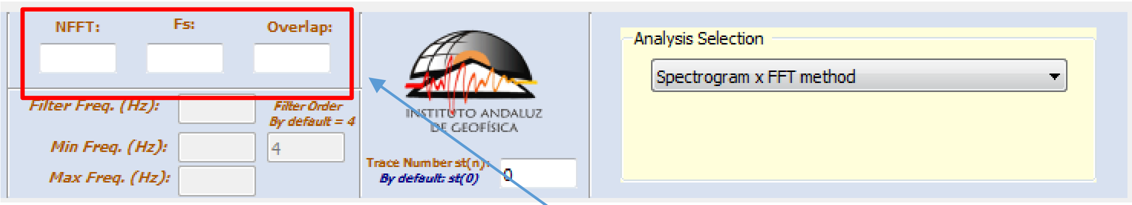
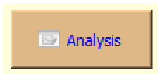


Fig. 27 Selection of Spectrogram using the Fast Fourier Transform (FFT).

Selecting this type of analysis activates three input fields:

a) FFT Sample Size (NFFT): Number of samples for the Fast Fourier Transform (N-FFT). Examples: 128, 512, 1024, 2048, or 4096.
b) Sampling Frequency Value “Fs”.
c) Overlap Sample Number (overlap).

As observed, the other input fields remain inactive. Additionally, the filter selection list and its corresponding plot command are deactivated. Once this option is selected, click the "***Analysis***" button to view the graph



The trace number is set by default to 0 and the filter order number is set by default to 4. If there are multiple traces, such as in MSEED or SEISAN records, which may include either three components or various values, specify the desired trace number starting from zero here. If you attempt to plot (by clicking the "Analysis" button) without entering a valid value, or if an out-of-range or invalid value is entered in any of the three fields, a validation dialog box will appear. This dialog box will indicate that an action is required. It also allows the program to continue running without causing a severe system interruption due to missing data. The three types of incorrect entries that may be displayed are as follows:

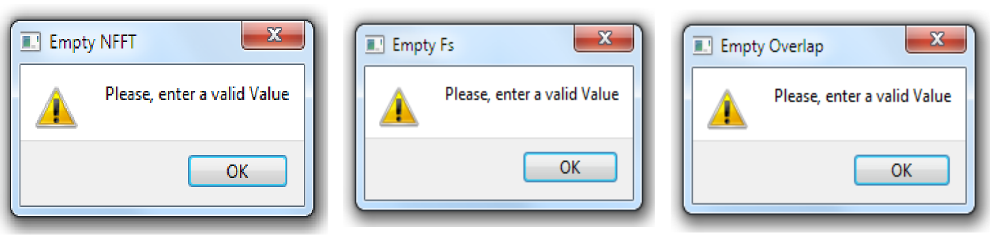


Fig. 28 Validation of entries (NFFT, Fs, and Overlap) for the calculation of the Spectrogram using the Fast Fourier Transform (FFT).

[6] Thyagarajan, K. S., & Thyagarajan, K. S. (2019). Fast Fourier Transform. *Introduction to Digital Signal Processing Using MATLAB with Application to Digital Communications*, 385-426.

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3.2.12.- Spectrogram with an included Bandpass filter.

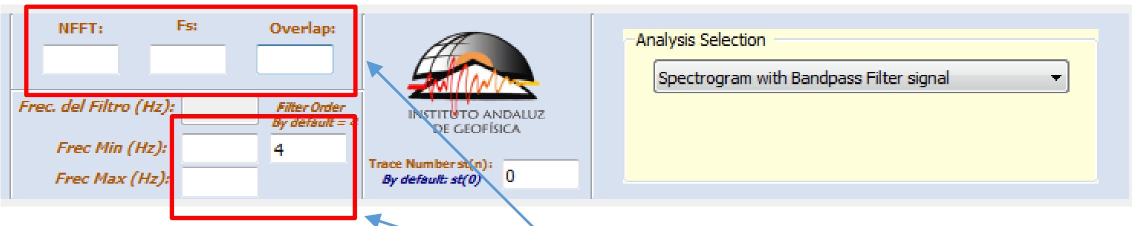
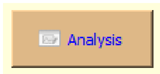


Fig. 29 Selection of Spectrogram with an included Bandpass filter.

Selecting this type of analysis activates six input fields:

a) FFT Sample Size (NFFT)
b) Sampling Frequency Value “Fs”
c) Overlap Sample Number (overlap)
d) Minimum Filter Frequency (Hz)
e) Maximum Filter Frequency (Hz)
f) Filter Order (default = 4).

As observed, the other input fields remain inactive. Additionally, the filter selection list and its corresponding plot command are deactivated. Once this option is selected, click the "Analysis" button to view the graph



The trace number is set by default to 0 and the filter order number is set by default to 4. If there are multiple traces, such as in MSEED or SEISAN records, which may include three components or various values, specify the desired trace number starting from zero here. If you attempt to plot (by clicking the "Analysis" button) without entering a valid value, or if an out-of-range or invalid value is entered in any of the six fields, a validation dialog box will appear. This dialog box will indicate the necessary action and allow the program to continue running without causing a severe system interruption due to missing data.

3.2.13.- Envelope of the signal filtered by a low-pass filter.

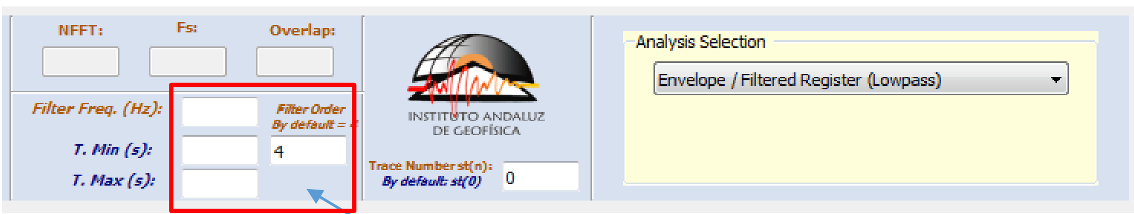


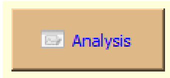
Fig. 30 Selection of Envelope of the signal filtered by a Lowpass filter.

Selecting this type of analysis activates four input fields:

a) Filter Frequency Value (Hz)
b) Minimum Calculation Time (seconds)
c) Maximum Calculation Time (seconds)
d) Filter Order (default = 4).

As observed, the text in the previous boxes designated for minimum and maximum frequency is changed to minimum and maximum time (this value will revert when another type of analysis, filter, or data input cleaning is selected), while the remaining boxes stay inactive. The default trace number = 0. Validation converts the inputs to integers instead of decimals. Additionally, the filter selection list and its corresponding graphing command are deactivated.

Once this option is selected, click the "Analysis button".



The trace number value is set to 0 by default. In the case of multiple traces, for example, in MSEED or SEISAN records that have either the three components or different values, the desired trace number should be indicated here starting from zero. If you attempt to plot (by clicking the 'Analysis' button to plot) without entering a valid value or by entering a value that is out of range or invalid in any of the four boxes, a validation will occur, displaying a dialog box indicating that this action must be performed. This dialog box also allows the program to continue running without a severe system interruption due to missing data. The four incorrect inputs to be displayed are as follows:

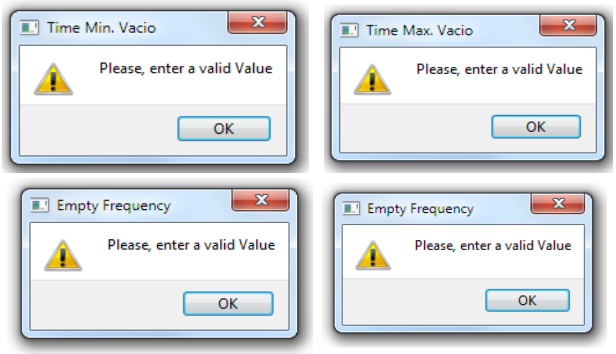


Fig. 31 Validation of the inputs (Minimum Time, Maximum Time, Frequency, and Filter Order) for calculating the Envelope of the signal filtered by a low-pass filter.

3.2.14.- Power spectral density using the Welch method.

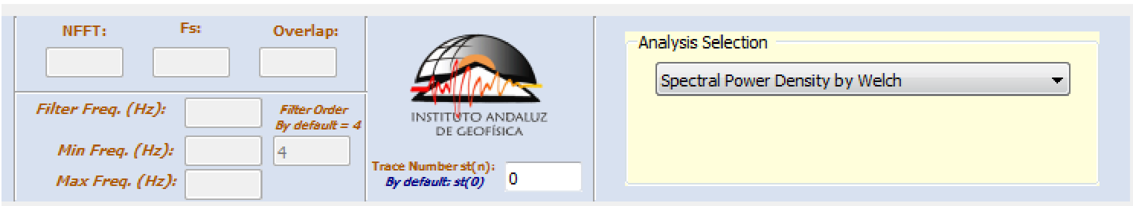
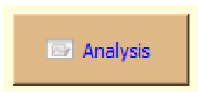


Fig. 32 Selection of Power Spectral Density via the Welch method.

The calculations to represent the spectrum of the record in the frequency domain are automatically determined, so no data entry boxes are activated, and consequently, no input validation occurs. Once this option is selected, click the ***'Analysis'*** button



There are no input values. The calculations are included in the code. The default trace number is set to 0. In the case of multiple traces, such as in MSEED or SEISAN records with either three components or various values, the desired trace number should be indicated here starting from zero.

3.2.15.- Classical periodogram plus 5 Welch types.

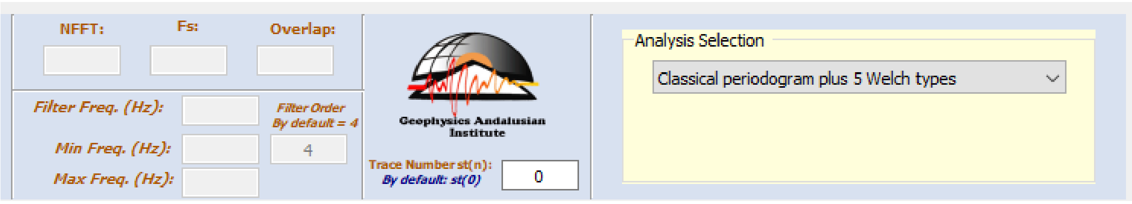


Fig. 33 Selection of Classical periodogram plus 5 Welch types.

The calculations for representing the record's spectrum in the frequency domain are performed automatically, so no data entry fields are activated and therefore no input validation is required. The results are presented as graphs calculated using six different methods: a) **Classical** Periodogram, b) Welch Periodogram with "**Hann**" window, c) Welch Periodogram with "**Hamming**" window, d) Welch Periodogram with "**Barlet**" window, e) Welch Periodogram with "**Backman**" window, and f) Welch Periodogram with "**flattop**" window. Additionally, a new graph comparing the six methods is presented. The trace number defaults to 0. If there are multiple traces, for example, in MSEED or SEISAN records with all three components or multiple trace values, the desired trace number, starting from zero, should be entered here.

3.2.16.- Continuous Wavelet Transform (CWT) of the Record.

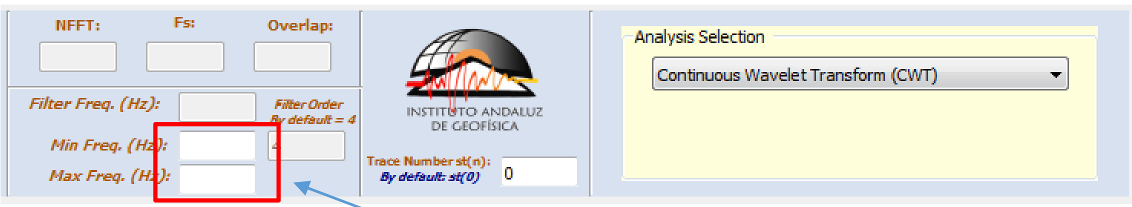


Fig. 34 Selection of Continuous Wavelet Transform (CWT).

Selecting this type of filter activates two data entry boxes:

> **a) Minimum Filter Frequency (Hz):** Here, you should enter a valid value for the minimum frequency you wish to use for calculating the filter type.
> **b) Maximum Filter Frequency (Hz):** In this box, you should enter a valid value for the maximum frequency you wish to use for calculating the filter type.

As observed, the other boxes remain inactive. Additionally, the filter selection list and its corresponding graphing command are deactivated. Once this option is selected, click the 'Analysis' button. (*Be Cautious with large files [1 day or more], as they require significant computational capacity for the Wavelets, which can overwhelm the system*).

The trace number is set to 0 by default. In the case of multiple traces, such as in MSEED or SEISAN records with either three components or various values, specify the desired trace number starting from zero here.

If you attempt to plot (by clicking the 'Graph' button) without entering a valid value or by entering a value that is out of range or invalid in either of the two boxes, a validation will occur, displaying a dialog box indicating that this action needs to be taken. This dialog box also allows the program to continue running without a severe system interruption due to missing data. The two incorrect inputs that will be presented are as follows:

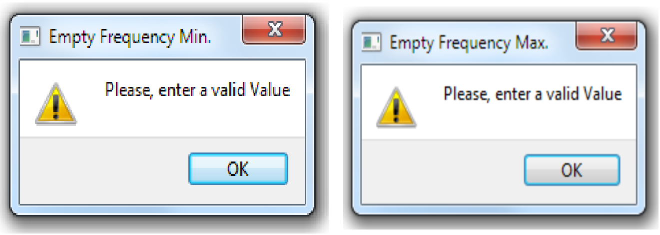


Fig. 35 Validation of the inputs for calculating the Continuous Wavelet Transform (CWT).

3.2.17.- Analysis of the Discrete Wavelet Transform Coefficients.

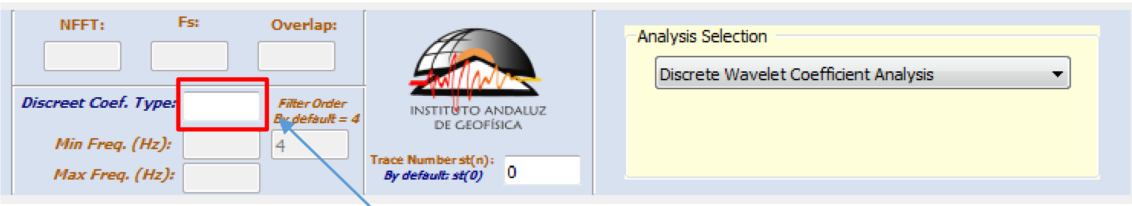


Fig. 36 Selection of Discrete Wavelet Transform Coefficients Analysis.

When selecting this item, a data entry box is activated asking for the input of the 'Discrete Coef. Type' (type of discrete coefficient). Unlike the previous boxes that only accept numerical inputs, this box is validated to also allow the use of alphanumeric characters, which are necessary for the nomenclature of discrete wavelet coefficients. To the user, this process is transparent and validated only in the programming code.

The list of available discrete coefficient types is displayed in the data and metadata section (3), as shown in Figure 37 below. The text entry or coefficient type input in the box can be done by directly typing the value, or by utilizing the fact that the box where the elements are displayed is editable. That is, you can copy (Copy -> Ctrl + C) the desired element or coefficient type (red box) from the list (from the softer to the stronger) and paste (Paste -> Ctrl + V) it into the 'Discrete Coefficient Type' box (red arrow). For example, copy 'sym5' (without quotes) and paste it into the box, then click the "Analysis button.".

This is also noted as a "**NOTE**" in the instructions at the bottom of the box. When plotting, two graphs are displayed: the first with the original record and the second containing five levels of coefficients, calculated from the chosen discrete wavelet coefficient type.

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“**NOTE:** *You can either type or copy and paste [without quotes] the name you wish to use in the text box.*”

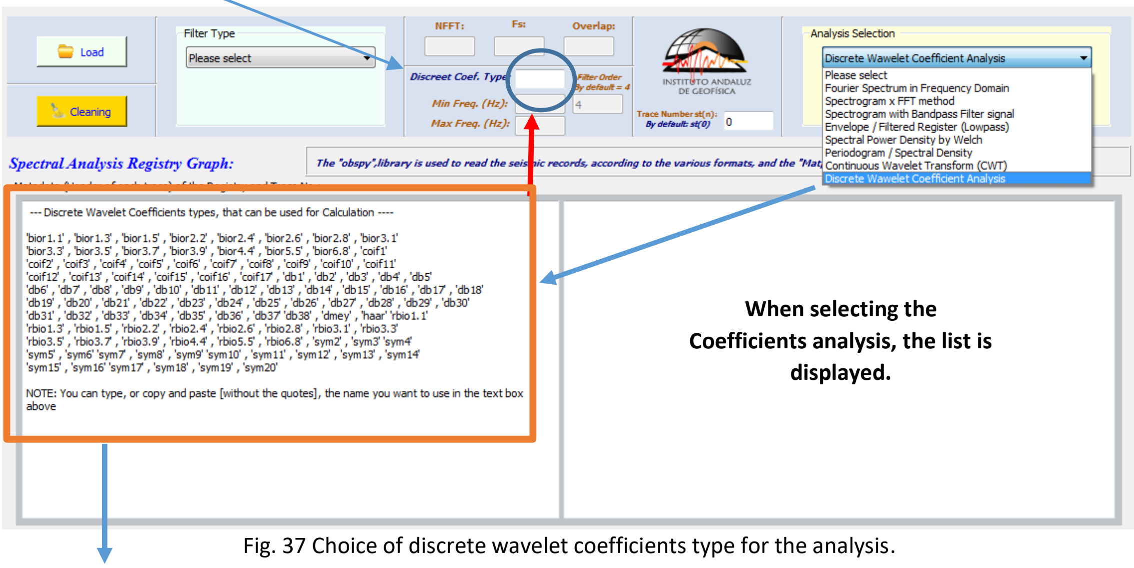

Fig. 37 Choice of discrete wavelet coefficients type for the analysis.

A complete list of available discrete wavelet coefficients is as follows:

--- **Discrete Wavelet Coefficients types that can be used for Calculation** ----

'bior1.1' , 'bior1.3' , 'bior1.5' , 'bior2.2' , 'bior2.4' , 'bior2.6' , 'bior2.8' , 'bior3.1'
'bior3.3' , 'bior3.5' , 'bior3.7' , 'bior3.9' , 'bior4.4' , 'bior5.5' , 'bior6.8' , 'coif1'
'coif2' , 'coif3' , 'coif4' , 'coif5' , 'coif6' , 'coif7' , 'coif8' , 'coif9' , 'coif10' , 'coif11'
'coif12' , 'coif13' , 'coif14' , 'coif15' , 'coif16' , 'coif17' , 'db1' , 'db2' , 'db3' , 'db4' , 'db5'
'db6' , 'db7' , 'db8' , 'db9' , 'db10' , 'db11' , 'db12' , 'db13' , 'db14' , 'db15' , 'db16' , 'db17' , 'db18'
'db19' , 'db20' , 'db21' , 'db22' , 'db23' , 'db24' , 'db25' , 'db26' , 'db27' , 'db28' , 'db29' , 'db30'
'db31' , 'db32' , 'db33' , 'db34' , 'db35' , 'db36' , 'db37' 'db38' , 'dmey' , 'haar' 'rbio1.1'
‘rbio1.3’, ‘rbio1.5’, ‘rbio2.2’, ‘rbio2.4’, ‘rbio2.6’, ‘rbio2.8’, ‘rbio3.1’, 'rbio3.3'
‘rbio3.5’, ‘rbio3.7’, ‘rbio3.9’, ‘rbio4.4’, ‘rbio5.5’, ‘rbio6.8’, ‘sym2’, 'sym3' 'sym4'
'sym5' , 'sym6' 'sym7' , 'sym8' , 'sym9' 'sym10' , 'sym11' , 'sym12' , 'sym13' , 'sym14'
'sym15' , 'sym16' 'sym17' , 'sym18' , 'sym19' , 'sym20'

NOTE: ***You can type, or copy and paste [without the quotes], the name you want to use in the text box above***

If you attempt to plot (by clicking the 'Analysis' button to plot) without entering a valid value or by entering a null value, a validation will occur, displaying a dialog box indicating that this action needs to be taken. The figure is as follows:

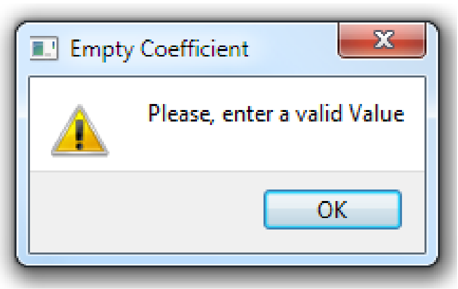

Fig. 38 Validation of the inputs for calculating discrete wavelet coefficients.

3.3.- Data and Metadata Presentation Block (3).

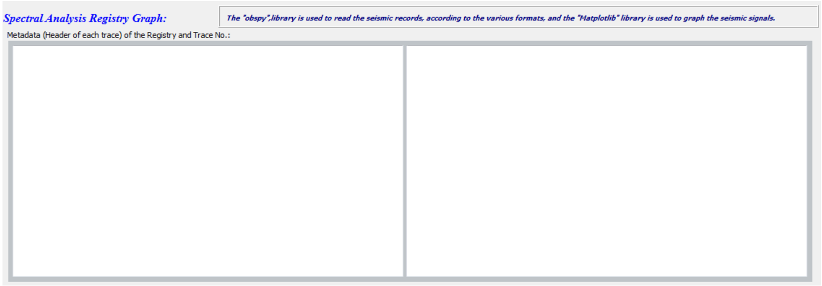

Fig. 39 Data and Metadata Presentation Block.

In this block, the results of analyses related to metadata and record traces are presented. An important aspect to highlight in the 'Data-Metadata and Traces' section is that this area is editable, meaning you can select and copy the information to paste it into a text file, Word document, etc. Additionally, as seen previously, it is used to display various discrete coefficients, allowing you to choose one for the analysis calculation.

An example of the results for Metadata and Traces, corresponding to 'MSEED' type records (*where three traces corresponding to the three components: EHE, EHN, EHZ, Traces 0, 1, and 2 respectively*, are observed). Is shown in the following figure.

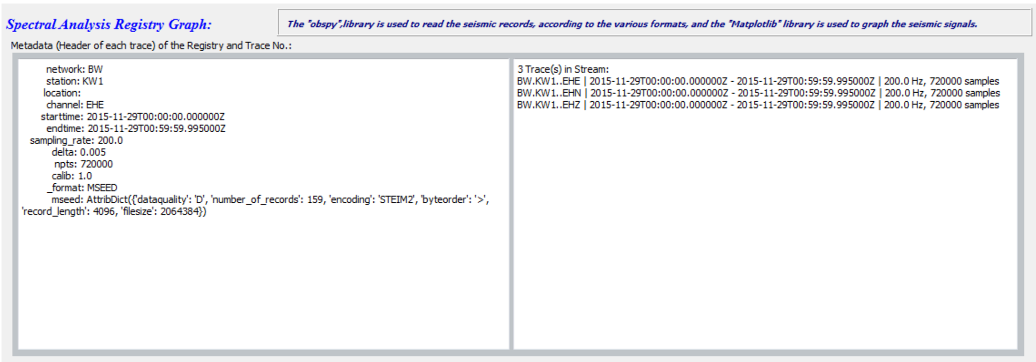

Fig. 40 Block for presenting metadata and traces of a record in "**MSEED**" format.

An example of the result (Metadata and Traces) for a 'SAC' type record is shown in the following figure.

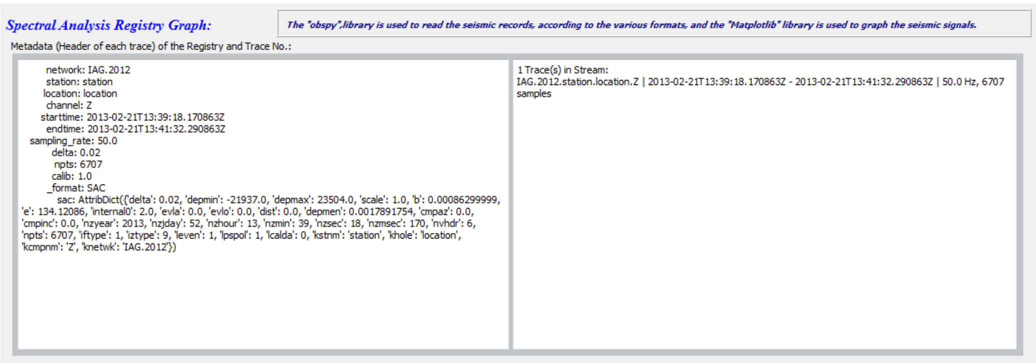

Fig. 41 Metadata and Traces Presentation Block for a "**SAC**" format record.

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An example of the result corresponding to a 'SEISAN' type record, showing multiple traces (44 traces), is shown in the following figure.

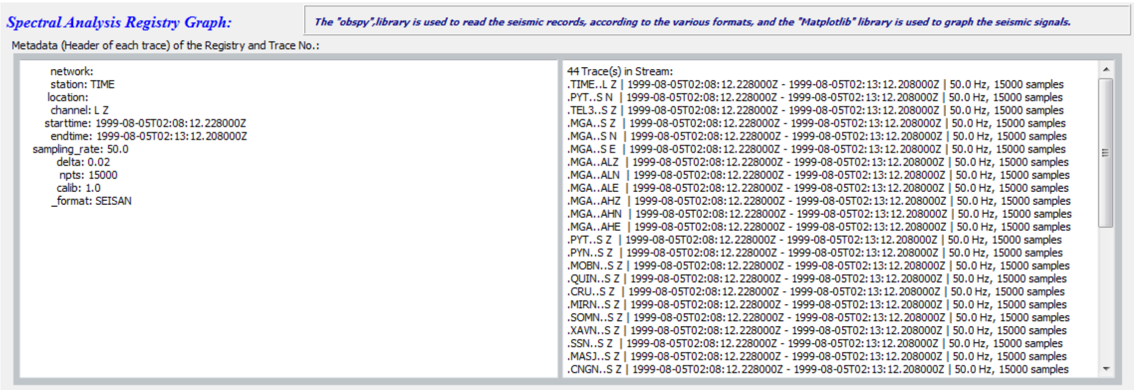

Fig. 42 Metadata Presentation Block for a “**SEISAN**” format record.

Once the calculations are complete and the graphs are presented, the entries in this block can be cleared by selecting a new analysis or filtering option, or by using the 'Cleaning' button, which will erase all existing entries and close any open graphs. Therefore, before proceeding with this step, it is advisable to save any results (graphs or data) if you wish to keep them.

3.4.- General Statistics Presentation Block of the Record (4).

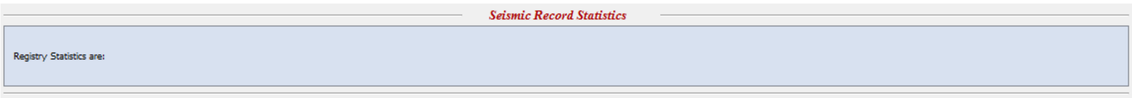

Fig. 43 General Statistics Presentation Block of the Record.

This section presents the general statistics of the record, which include the following elements:

a) The seismic network that recorded the data.
b) The station within that network that recorded the data.
c) The location.
d) The channel through which the data was recorded.
e) Initial recording time.
f) Final recording time.
g) Sampling frequency.
h) Number of samples in the record.
i) Record format type.

An example of the output from performing the calculations is shown in the following figures.

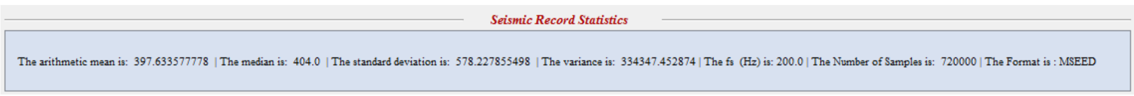

Fig. 44 General Statistics Presentation Block for an “**MSEED”** format record.

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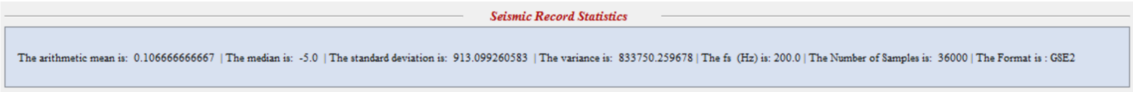


Fig. 45 General Statistics Presentation Block for a “**GSE2”** format record.

Fig. 46 General Statistics Presentation Block for a “**SAC”** format record.

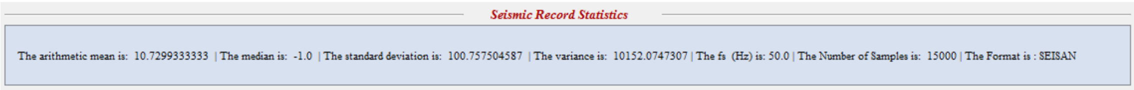


Fig. 47 General Statistics Presentation Block for a “**SEISAN”** format record.

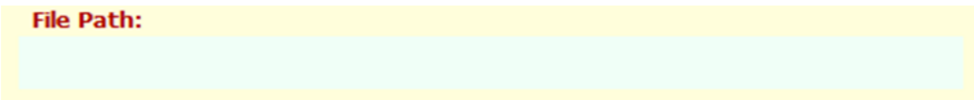
The data presented here can be cleared using the 'Cleaning' button. Unlike the metadata block, the data in this block cannot be edited or copied; it is in read-only mode.

3.5.- Graphics Path and Action Commands Block, Output, and Return (5).

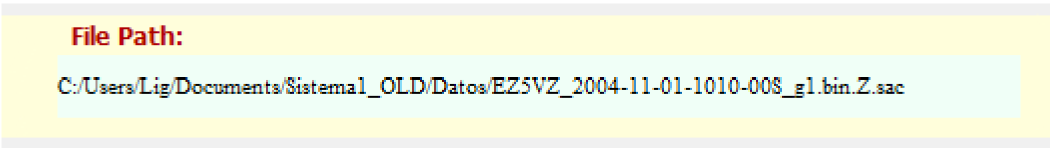
This final block consists of the following elements:

a) “**Back”** button: Allows you to return to the initial system presentation screen. When you hover the mouse pointer over it, a message appears indicating its function.

b) **File Path Presentation Area:** This area displays the path (*file path*), or "path," of the physical file (*where it is stored on the computer*) so that it can be accessed by the system to perform the required calculations



An example of the output from performing the calculations is shown in the following image.



The 'Path' (on the computer) of the record's location is displayed.

c) **Filter** button: Once the types of filters and their inputs are selected, it will perform the calculations and display the corresponding graphs. Hovering the mouse pointer over it will display a message indicating its function.

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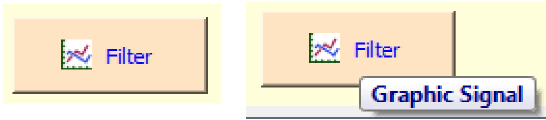
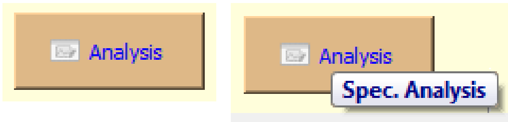
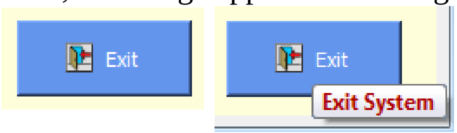


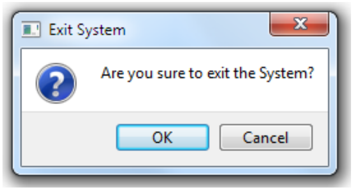
d) **"Analysis" Button:** Similar to the "Filter" button, except that this one works with the selection from the list of spectral analyses. When hovering the mouse pointer over it, a message appears indicating its function. By clicking the button, the calculation is performed, and the graph(s) are displayed.



e) **"Exit" Button:** Allows for a complete exit from the system. Before exiting, it displays a screen asking if you want to leave the system. When hovering the mouse pointer over it, a message appears indicating its function.



In the same way as on the home screen, if the "Exit" button is pressed or clicked, a window appears asking the user if they are sure they want to exit the system.



By clicking "**OK**" the screen closes, and the system exits completely. "**Cancel**" keeps the user on the analysis screen.

3.5.1.- Validation of errors in registration or entries.

When accessing the "***Filter***" and "***Analysis***" buttons, if an invalid entry or a nonexistent or unrecognized record is encountered, a validation will display a message alerting the user to the situation. This allows the user to modify the entries or select a valid record without causing the system to crash or stop.

The screen that is displayed is as follows:

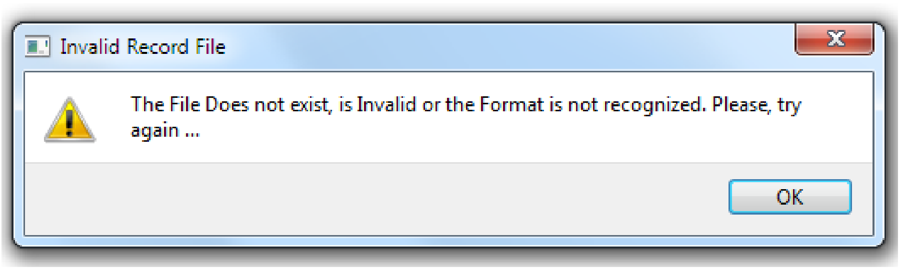


Fig. 48 Validation of invalid entries, formats, or incorrect records.

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According to the message in the previous figure, an error has occurred because the format is not recognized, does not exist, or is invalid. Additionally, the entries may also be outside the permitted range. By pressing the "OK" button, you return to the system to correct the erroneous entries and continue with the record loading and analysis.

4.- Results of Filter and Analysis Sections.

Next, examples of the final results of the filtering and analysis process will be presented.

4.1.- Example of results from record filtering selection.

According to the entire process described earlier, the process for filtering records is very simple and consists of the following steps:

a) Open or select a specific record (*the record is displayed in "File path. By default, the initial path is in the root directory "C" of the PC, whether on Windows or Linux systems*).

b) Select the filter.

c) Enter the filter parameters.

d) Click the "Filter" button to graph the record

By performing the above steps, the result will be presented as follows:

a) The metadata in the Data and Metadata section.

b) The general statistics in the statistics section.

c) The resulting graph of the analysis, composed of the original signal and the filtered signal. This graph can be zoomed in and saved in various formats.

It is important to note that the area in the "Data-Metadata and Traces" section is editable, meaning that you can select and copy the information to paste it into a text file, Word document, etc. The resulting process is shown below, with an example using a record in "SAC" format. The resulting image is as follows.

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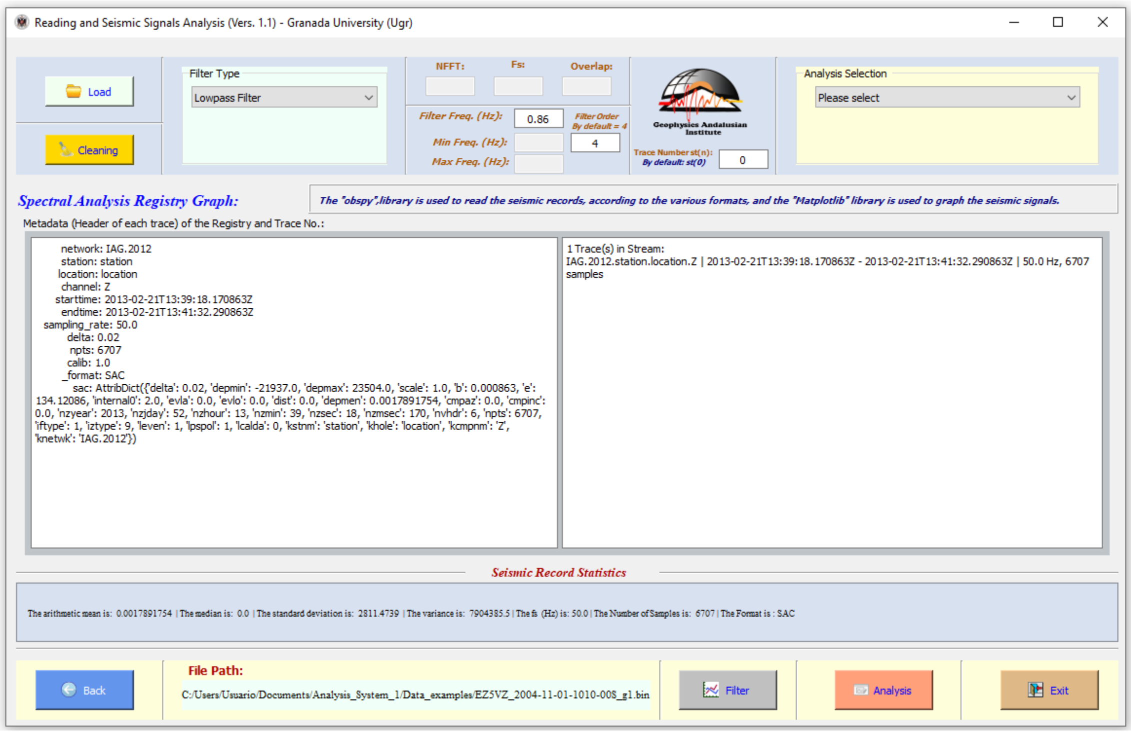

Fig. 49 Final result of the filtering process for an SAC record: File Path, Statistics, and Metadata.

In the figure, under "***File Path***" the complete path where the record to be analyzed is stored is shown. In the "Filter Type" list, the ***Lowpass*** filter has been selected. In the input box, a frequency of 0.86 Hz has been set, with a "***filter order***" = 4. As a result, the content is displayed both in the metadata section and the general statistics section. The record only has one trace, which is trace 0 by default.

4.2.- Example of results from spectral analysis selection.

According to the entire process described earlier, the process for performing spectral analysis on records is very simple and consists of the following steps:

a) Open or select a specific record (the record is displayed in "File path"). It can be the same one that was previously analyzed using filtering.
b) Select the type of spectral analysis, in this case, "Spectrogram using Fast Fourier Transform (FFT)."
c) Enter the data to be calculated (if any) for the valid parameters for each type of analysis in the input box.
d) Click the "Analysis" button.

By performing the above steps, the result will be presented as follows:

a) The metadata in the Data and Metadata section.

b) The general statistics in the statistics section.

c) The resulting graph of the analysis, composed of various signals according to the analysis. This graph can be zoomed in and saved in various formats.

The resulting process is shown below, with an example using a record in "SAC" format. The image of the resulting main interface is as follows.

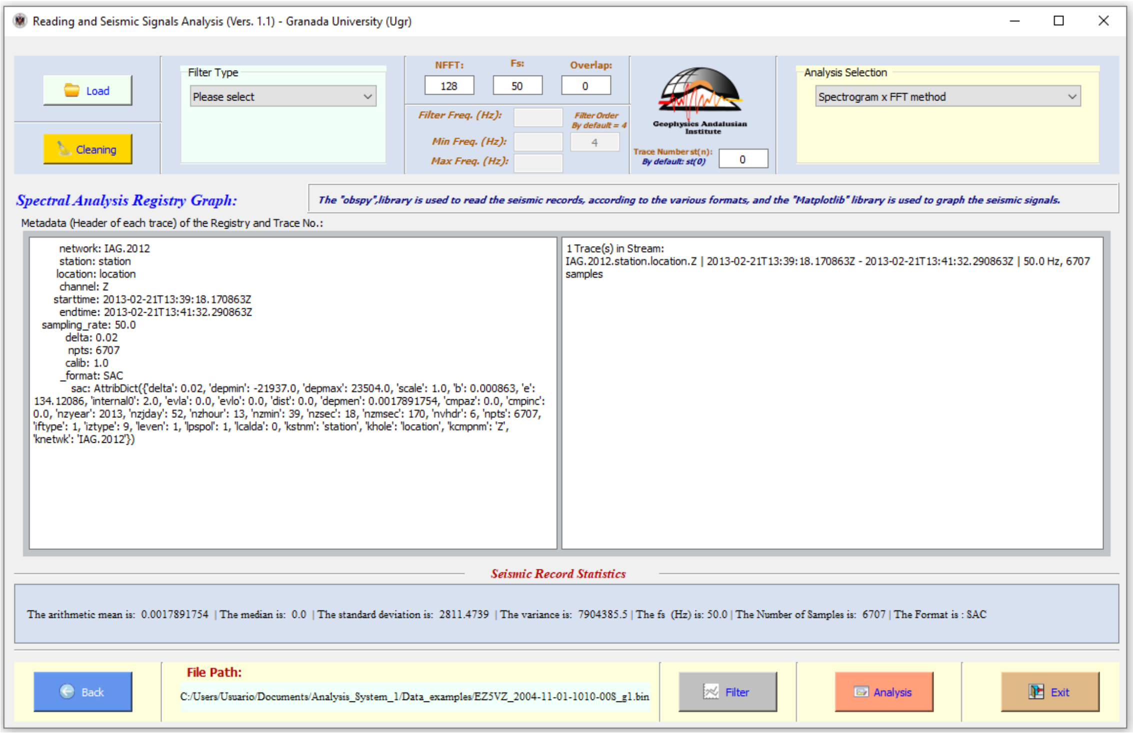

Fig. 50 Final result of the spectral analysis process for a record: File Path, Statistics, and Metadata.

In the figure, under "***File Path***", the complete path where the record to be analyzed is stored is shown. In the "Analysis Selection" list, "*Spectrogram using FFT method*" has been chosen. In the input box, the FFT number is set to 128, the sampling frequency is set to 50 (*as deduced from the general statistics section from the previous filtering*), and an overlap of 0 is established. As a result, the content is displayed both in the metadata section and the general statistics section. The record has only one trace, which is trace 0 by default.

The graphical results can be observed in the following sections.

5.- Resulting Graphs.

Next, we will present an example of graphical results from both the filtering process and the spectral analysis process.

5.1.- Filter Graphs and Zoom of Records.

As examples, the graphical results of the original record and the filtered record in SAC and GSE2 formats are presented, along with the zoom performed on the resulting graphs. It is worth noting that when zooming in on one of the two sections of the graph (original and filtered), the other section updates automatically. In other words, zooming in on one section adjusts the time vector in both graphs.

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a) SAC Record Graph with Lowpass Filter.

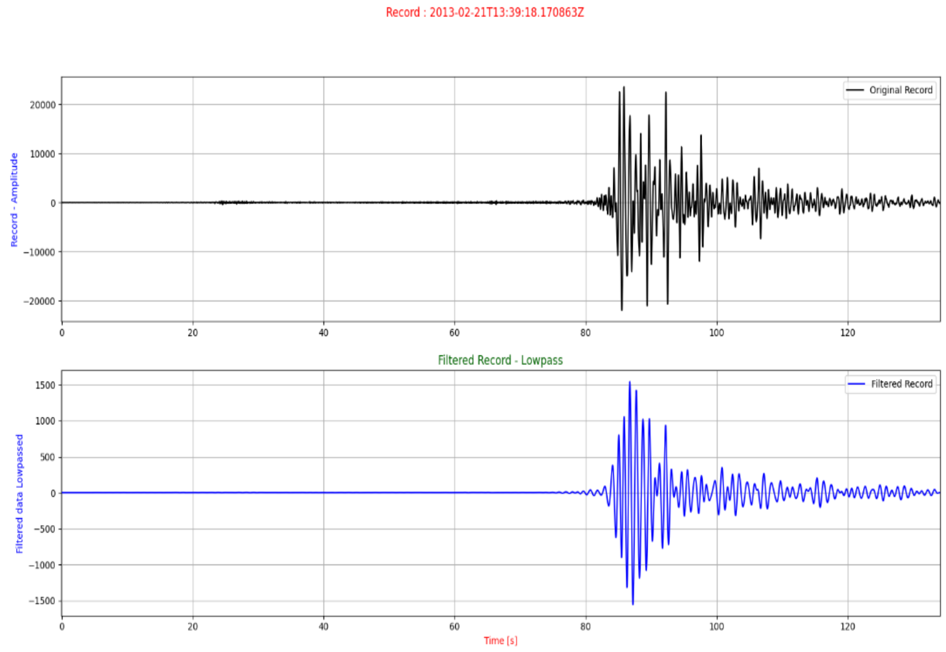

Fig. 51 Example of SAC Record Graph with Lowpass Filter at 0.86 Hz and Filter Order 4.

b) Zoom of the SAC Record Graph with Lowpass Filter.

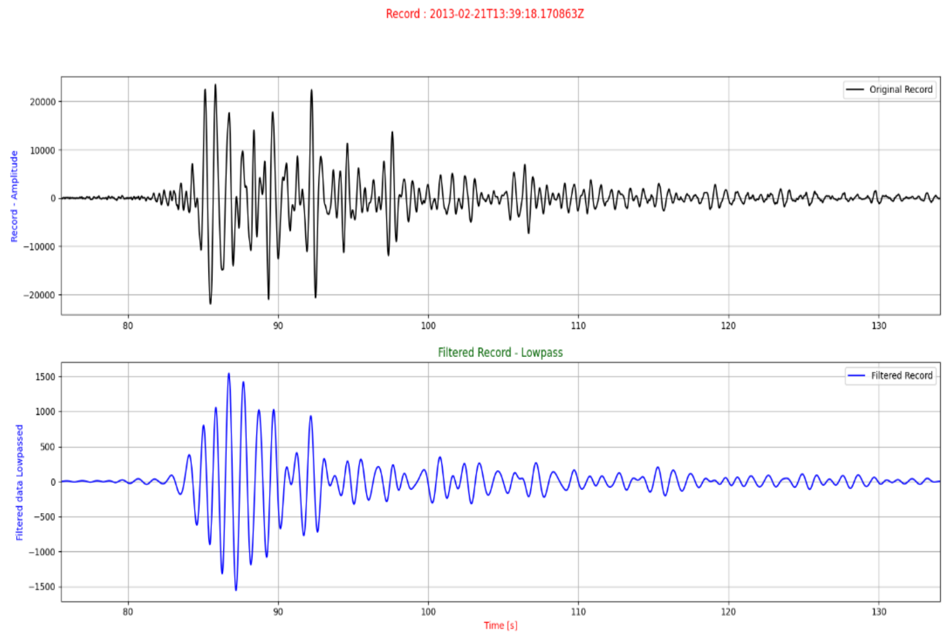

Fig. 52 Example of Zoom on the SAC Record Graph with Lowpass Filter at 0.86 Hz and Filter Order 4.

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c) GSE2 Record Graph with Lowpass Filter.

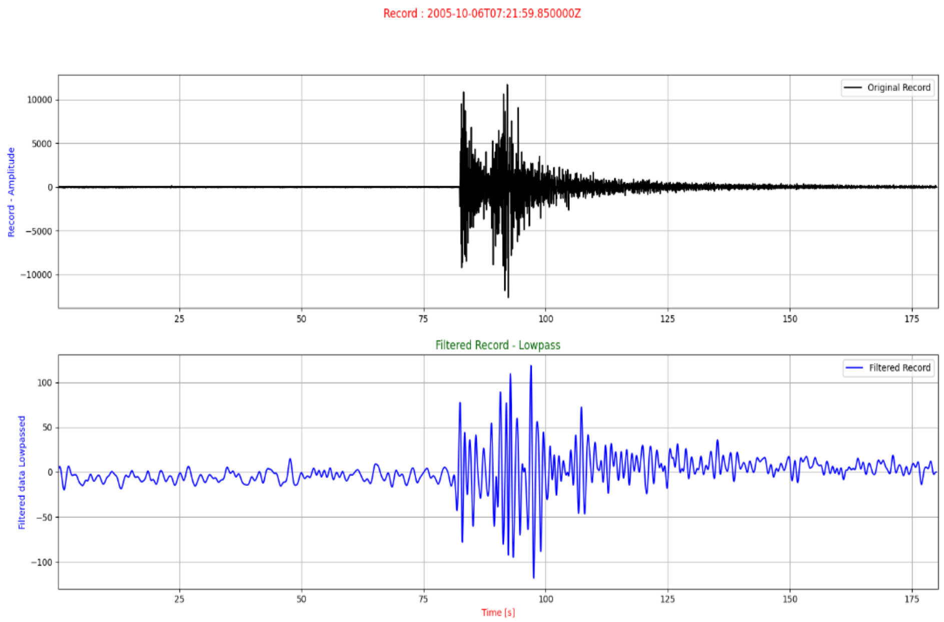

Fig. 53 Example of GSE2 Record Graph with Lowpass Filter at 0.86 Hz and Filter Order 4.

d) Zoom of the GSE2 Record Graph with Lowpass Filter.

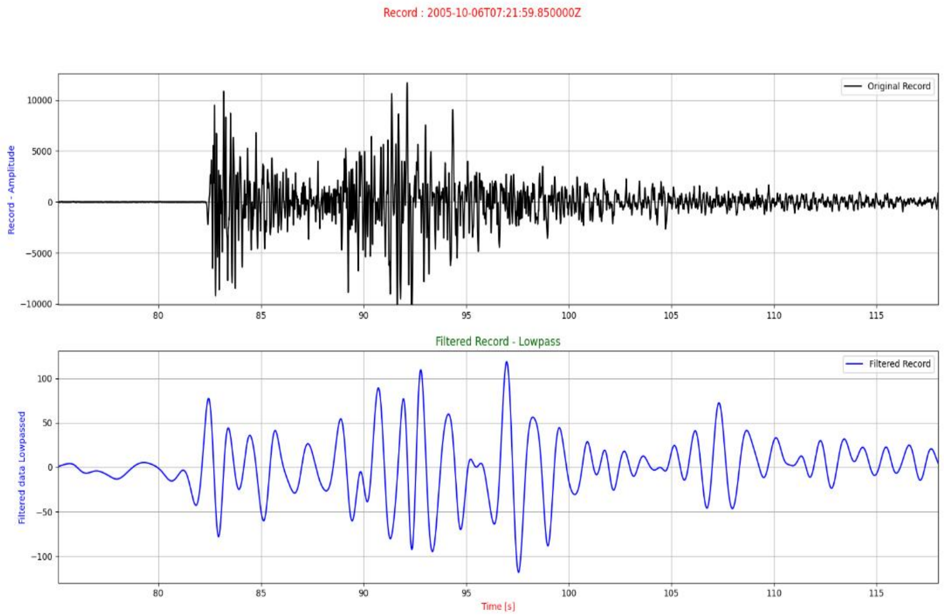

Fig. 54 Example of Zoom on the GSE2 Record Graph with Lowpass Filter at 0.86 Hz and Filter Order 4.

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e) SAC Record Graph with Highpass Filter.

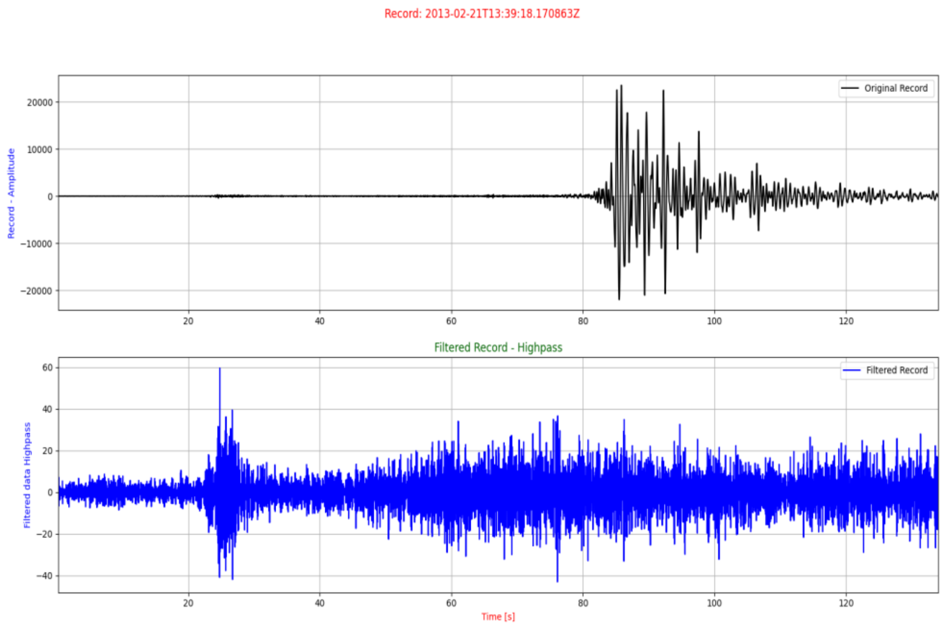

Fig. 55 Example of SAC Record Graph with *Highpass* Filter at 12 Hz and Filter Order 4.

f) Zoom of the SAC Record Graph with Highpass Filter.

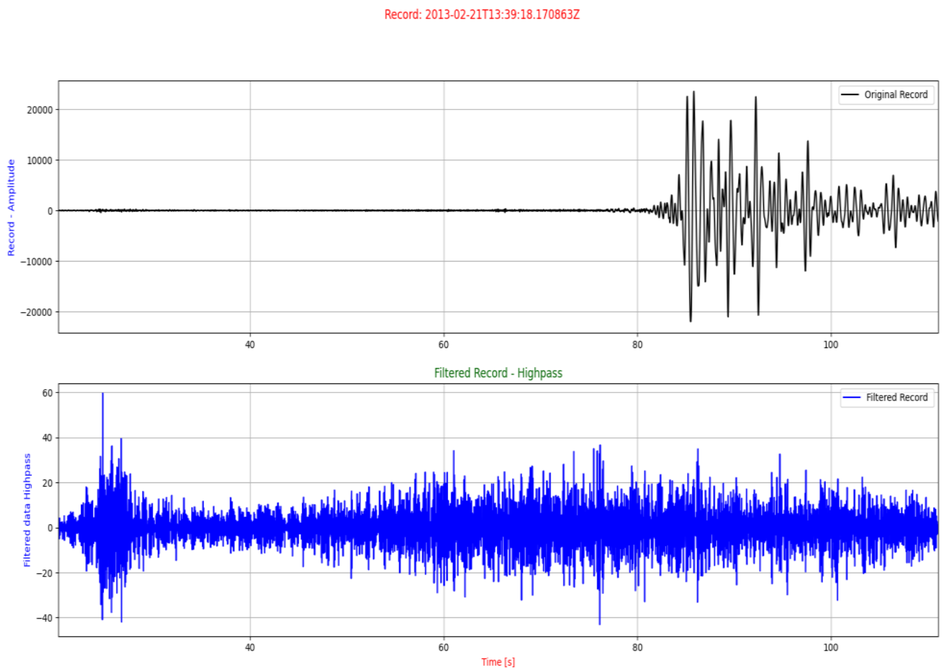

Fig. 56 Example of Zoom on the SAC Record Graph with *Highpass* Filter at 12 Hz and Filter Order 4.

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g) GSE2 Record Graph with Highpass Filter.

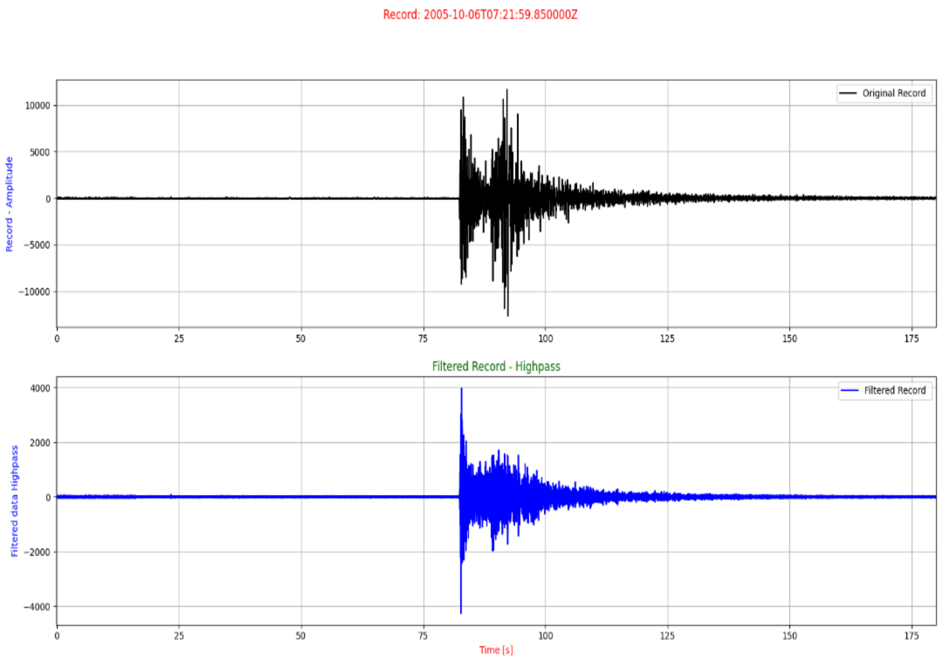

Fig. 57 Example of GSE2 Record Graph with *Highpass* Filter at 12 Hz and Filter Order 4.

h) Zoom of the GSE2 Record Graph with Highpass Filter.

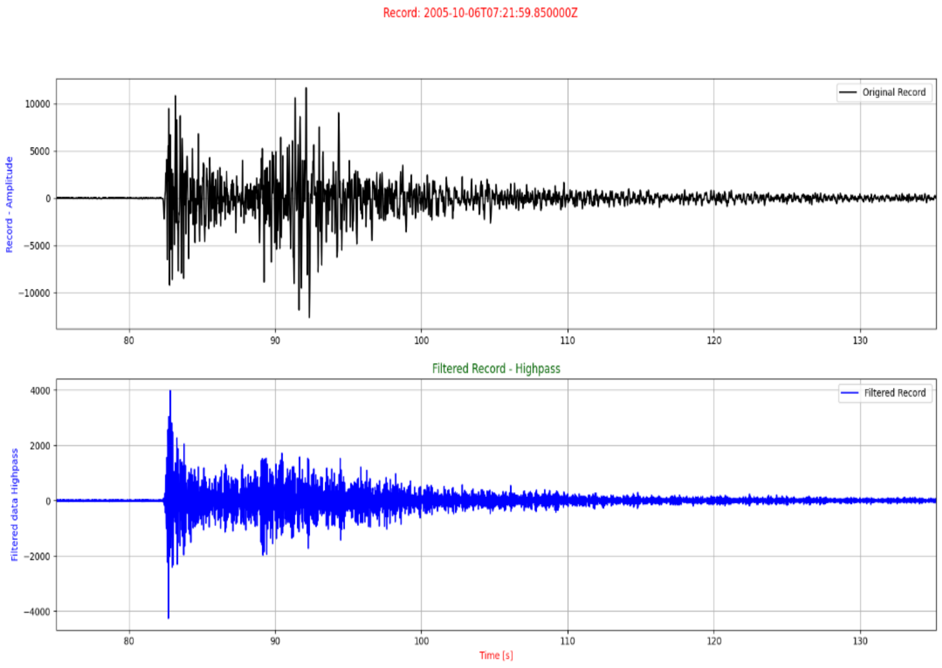

Fig. 58 Example of Zoom on the GSE2 Record Graph with *Highpass* Filter at 12 Hz and Filter Order 4.

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i) SAC Record Graph with Bandpass Filter.

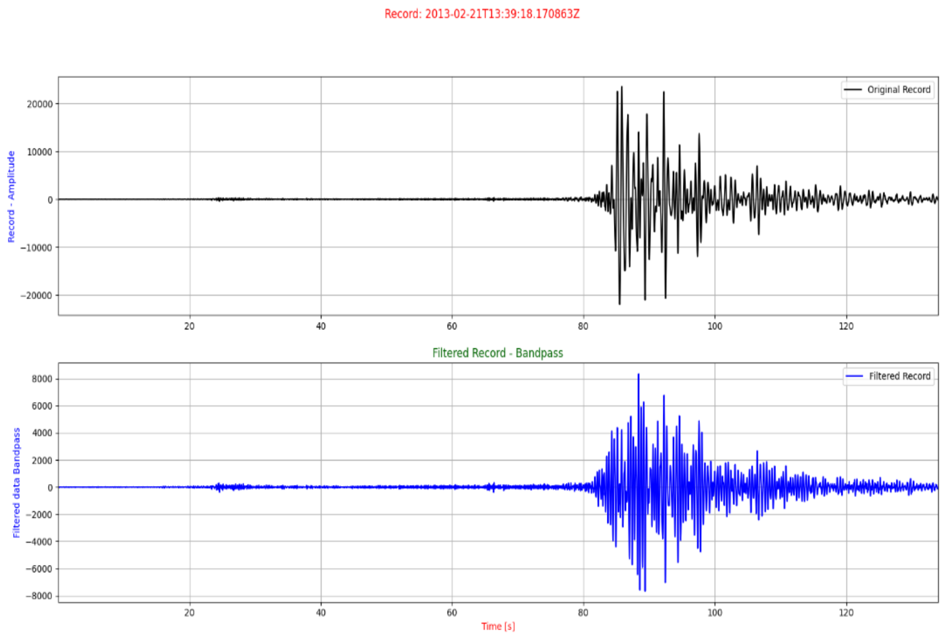

Fig. 59 Example of SAC Record Graph with Bandpass Filter. Minimum Frequency at 0.86 Hz, Maximum Frequency at 3 Hz, and Filter Order 4.

j) Zoom of the SAC Record Graph with Bandpass Filter.

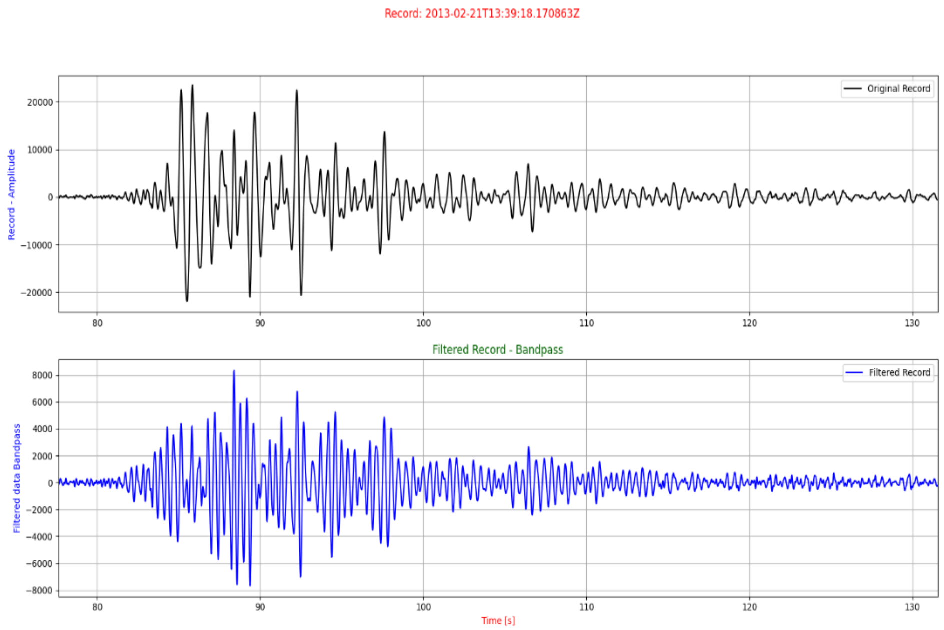

Fig. 60 Example of Zoom on the SAC Record Graph with Bandpass Filter. Minimum Frequency at 0.86 Hz, Maximum Frequency at 3 Hz, and Filter Order 4.

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k) GSE2 Record Graph with Bandpass Filter.

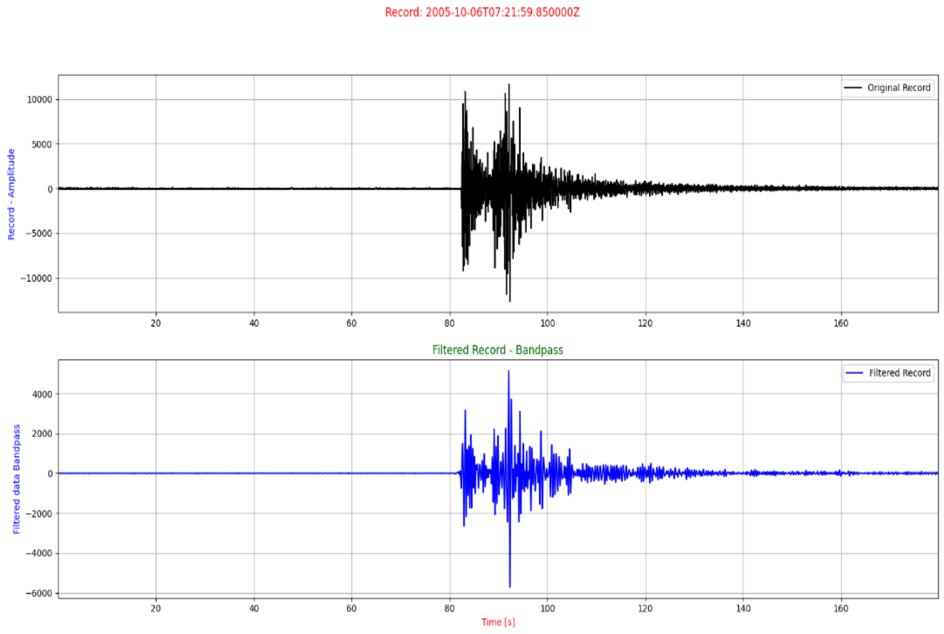

Fig. 61 Example of GSE2 Record Graph with Bandpass Filter. Minimum Frequency at 0.86 Hz, Maximum Frequency at 3 Hz, and Filter Order 4.

l) Zoom of the GSE2 Record Graph with Bandpass Filter.

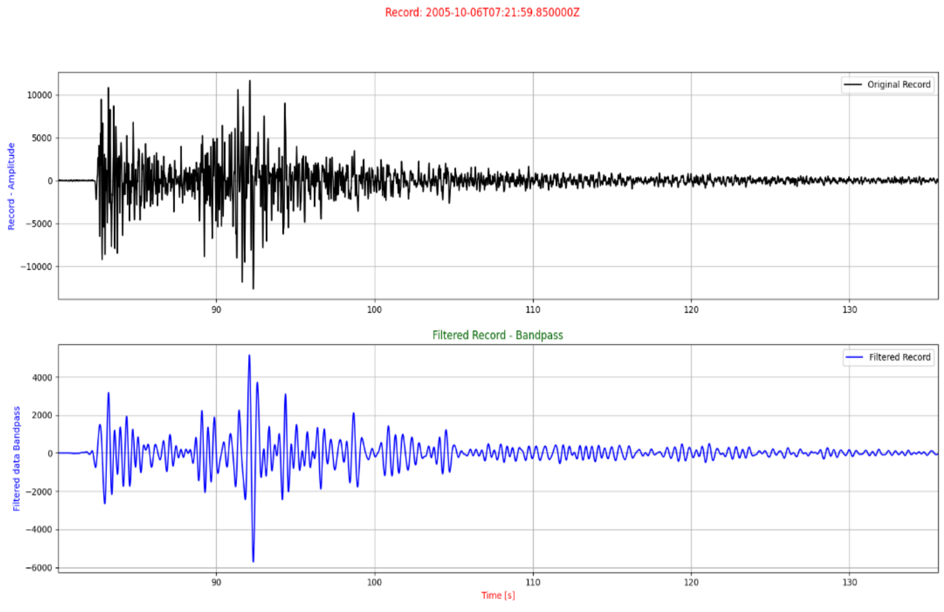

Fig. 62 Example of Zoom on the GSE2 Record Graph with Bandpass Filter. Minimum Frequency at 0.86 Hz, Maximum Frequency at 3 Hz, and Filter Order 4.

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m) SAC Record Graph with Bandstop Filter.

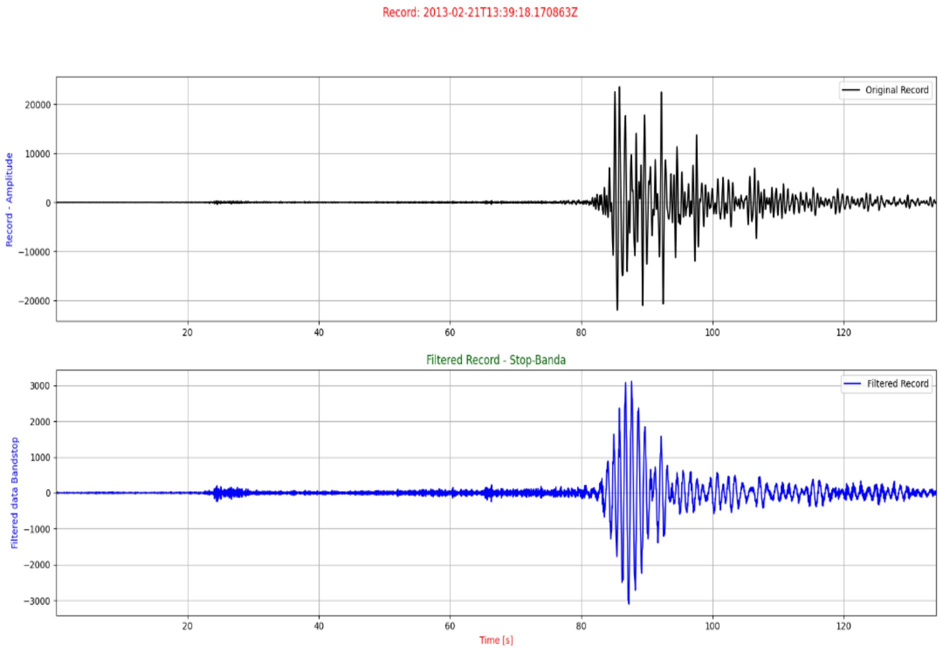

Fig. 63 Example of SAC Record Graph with Bandstop Filter. Minimum Frequency at 1 Hz, Maximum Frequency at 3 Hz, and Filter Order 4.

n) Zoom of the SAC Record Graph with Bandstop Filter.

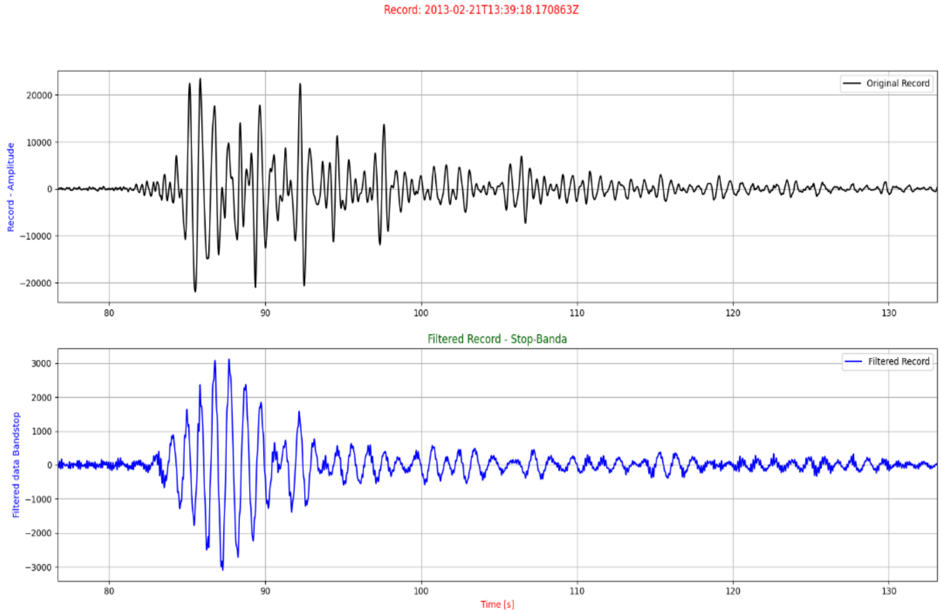

Fig. 64 Example of Zoom on the SAC Record Graph with Bandstop Filter. Minimum Frequency at 1 Hz, Maximum Frequency at 3 Hz, and Filter Order 4.

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o) GSE2 Record Graph with Bandstop Filter.

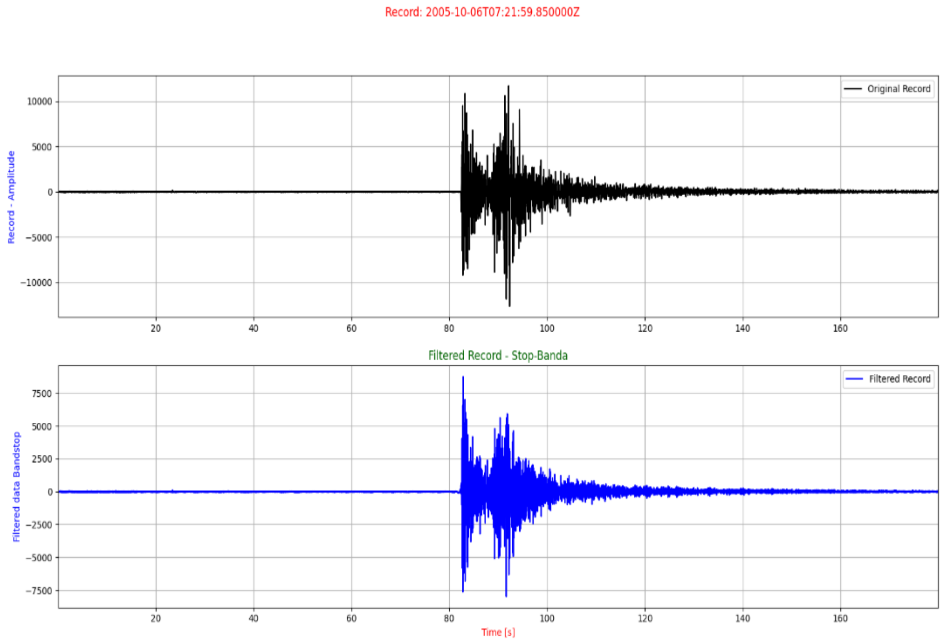

Fig. 65 Example of GSE2 Record Graph with Bandstop Filter. Minimum Frequency at 1 Hz, Maximum Frequency at 6 Hz, and Filter Order 4.

p) Zoom of the GSE2 Record Graph with Bandstop Filter.

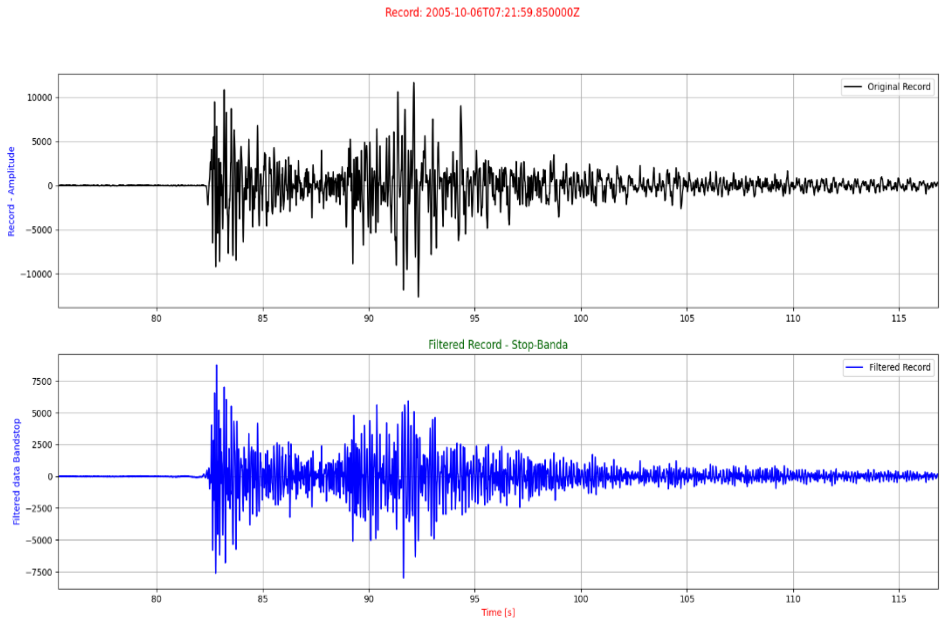

Fig. 66 Example of Zoom on the GSE2 Record Graph with Bandstop Filter. Minimum Frequency at 1 Hz, Maximum Frequency at 6 Hz, and Filter Order 4.

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5.2.- Spectral Analysis Graphs and Their Zooms.

Next, examples of records for each type of spectral analysis will be presented. For simplicity, the SAC format will be used in all examples.

a) SAC Record Graph with Fourier Transform Spectrum in the Frequency Domain.

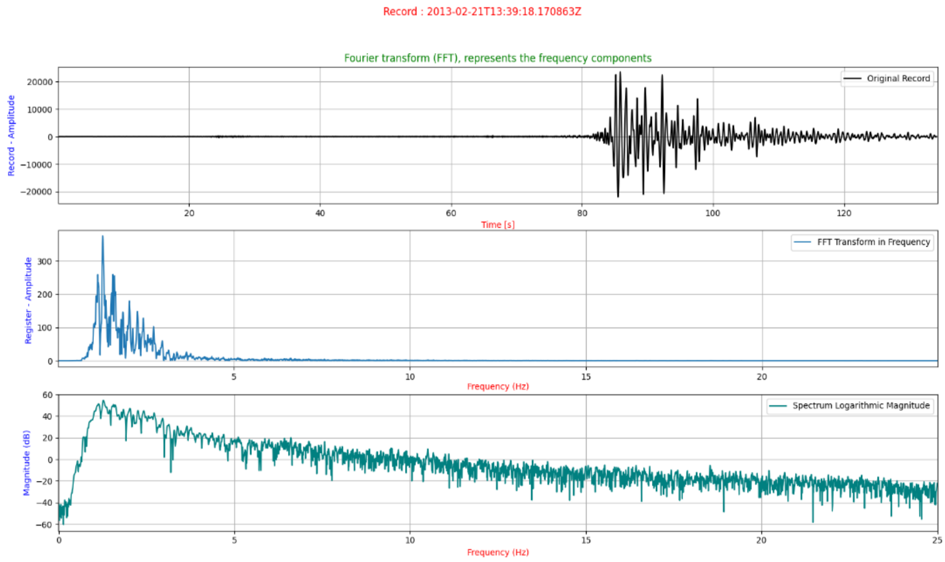

Fig. 67 SAC Record Graph with the Fourier Transform Spectrum in the Frequency Domain.

b) Zoom on the SAC Record Graph at 5 Hz. Fourier Transform Spectrum in the Frequency Domain. Each graph must be zoomed in individually, as the automatic zoom mode is disabled.

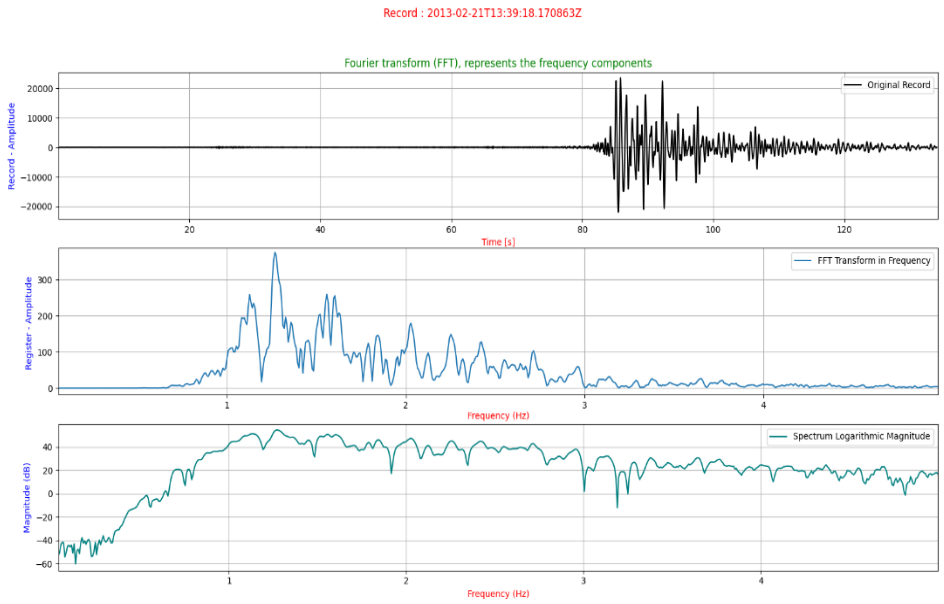

Fig. 68 Zoom on the SAC Record Graph at 5 Hz, with the Fourier Transform Spectrum in the Frequency Domain.

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c) SAC Record Graph with the Magnitude Phase of the Frequency Spectrum.

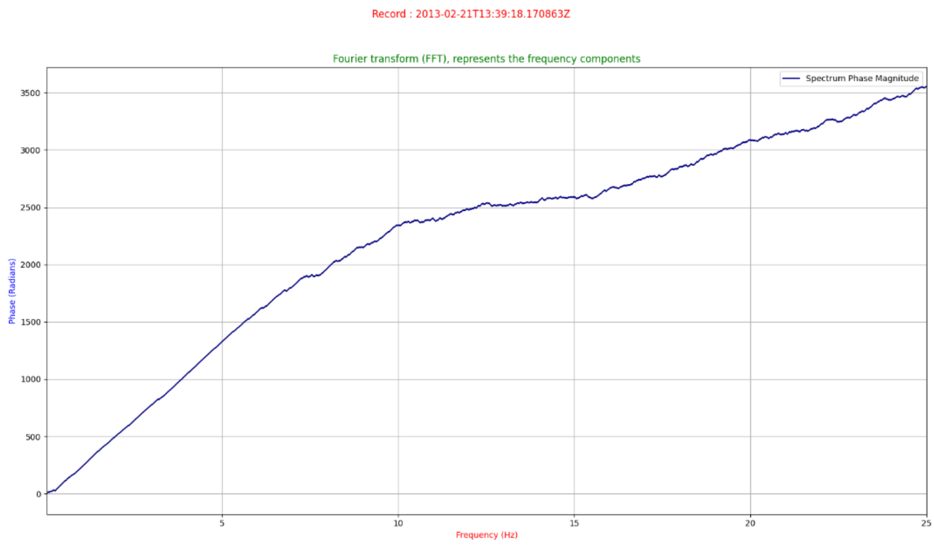

Fig. 69 Gráfica del registro SAC, con el espectro de la Transformada de Fourier (Magnitud en Fase).

d) SAC Record Graph of the Spectrogram using Fast Fourier Transform (FFT).

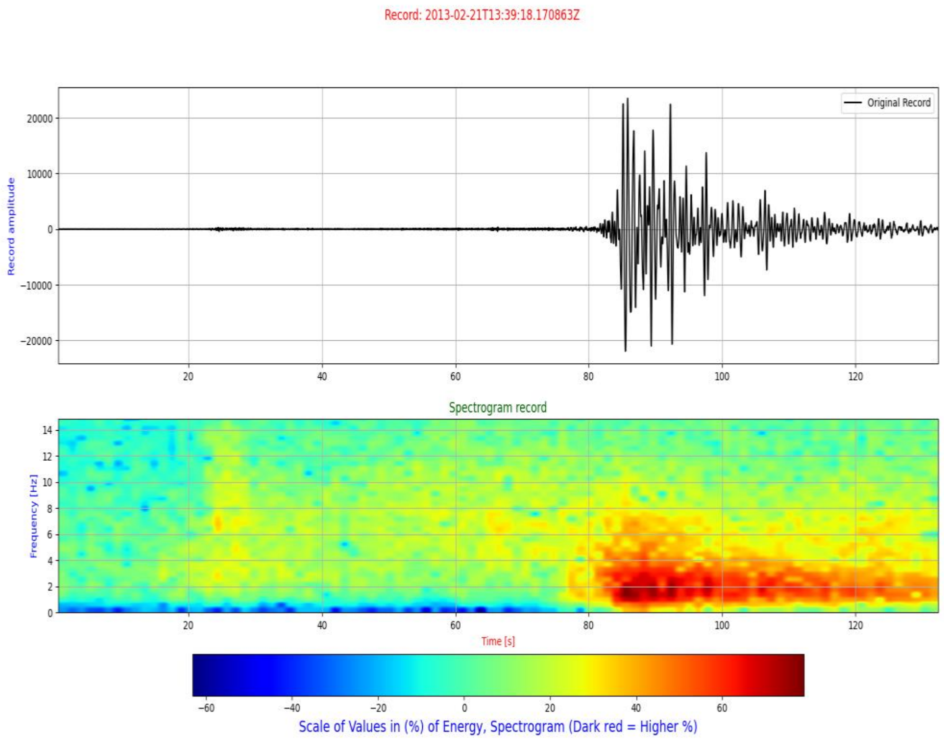

Fig. 70 SAC Record Graph with Spectrogram using Fourier Transform, 128 FFT, 50 Fs, and 0 Overlap.

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e) SAC Record Graph of the Spectrogram with Included Bandpass Filter.

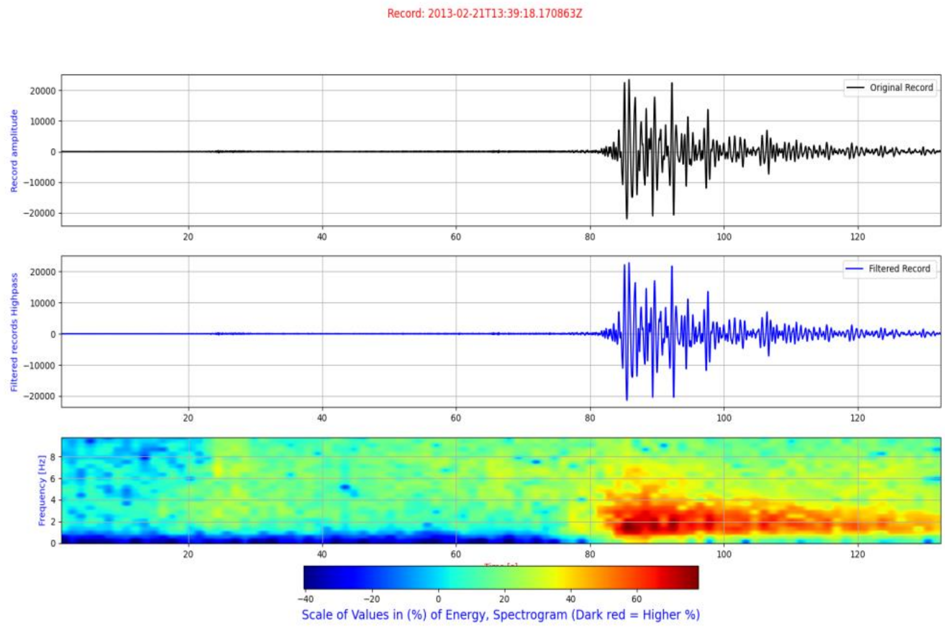

Fig. 71 SAC Record Graph with Spectrogram and Included Bandpass Filter (0.86 – 15 Hz), 128 FFT, 50 Fs, 0 Overlap, and Filter Order 4.

f) SAC Record Graph of the Envelope of the Filtered Signal using a Lowpass Filter.

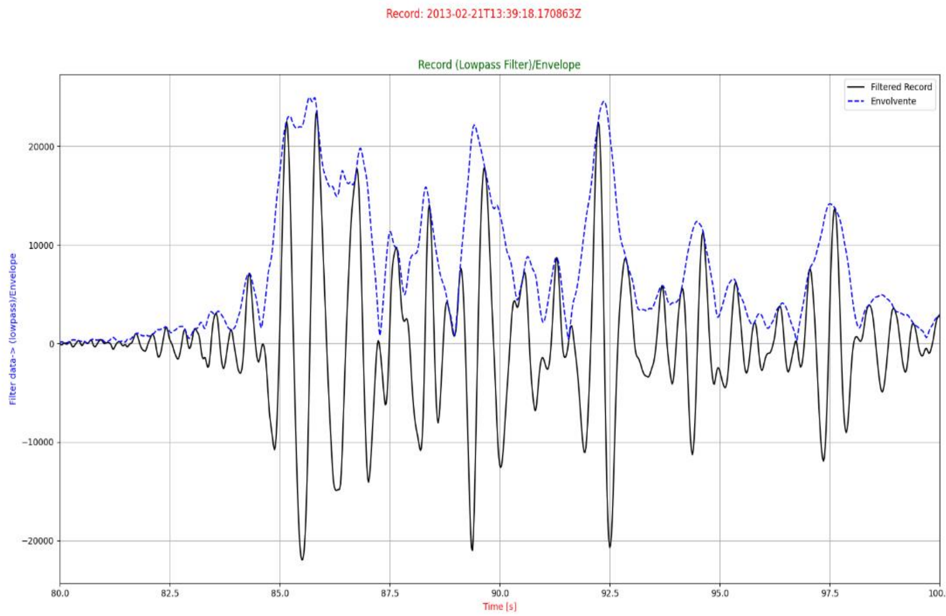

Fig. 72 Graph of the Envelope of the SAC Record, Lowpass Filter at 0.86 Hz, Cut Time: Min 80 s, Max 100 s, and Filter Order 4.

g) SAC Record Graph of Power Spectral Density using the Welch Method with Hanning Window -> "Hann".

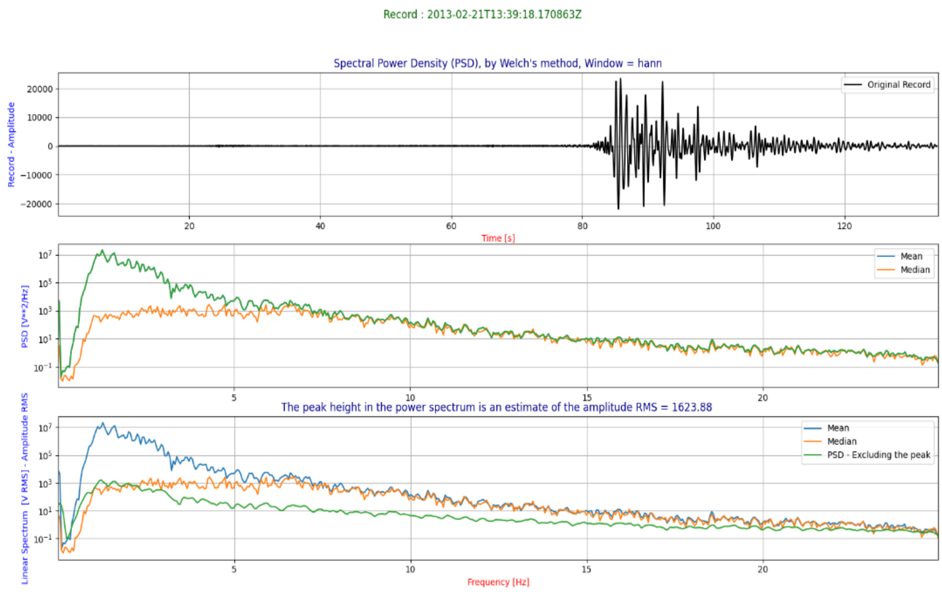

Fig. 73 SAC Record Graph of Power Spectral Density via Welch Method with Hanning Window "Hann".

h) Graphs of an MSEED record of the six types of Periodogram, with ZOOM.

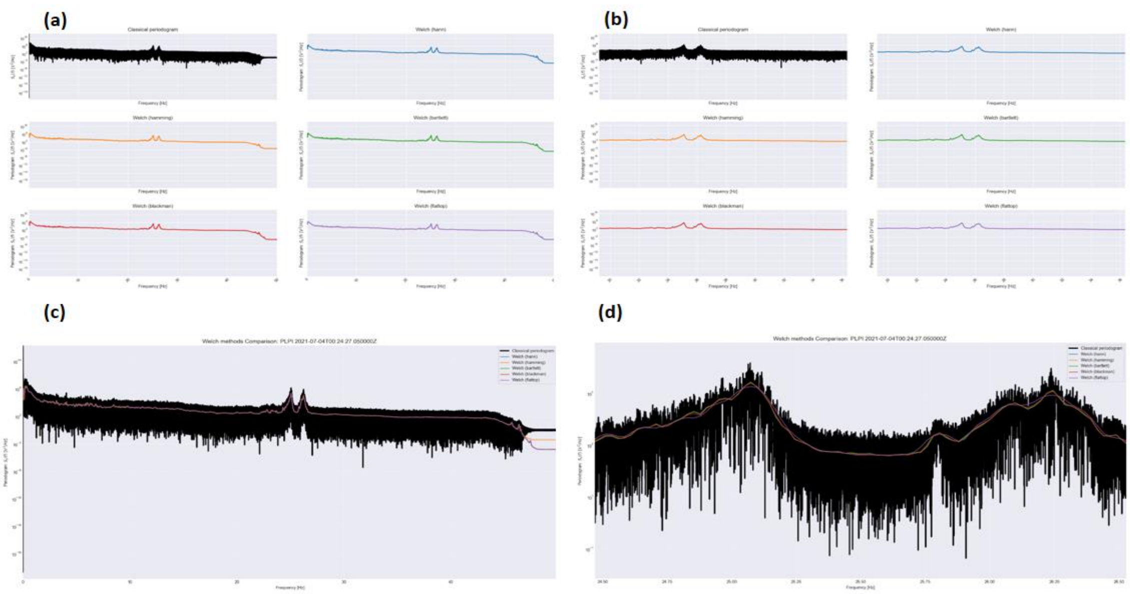

Fig. 74 Graphs of the Periodograms of an MSEED record; a) Classical, Welch with “Hann” window, Welch with “Hamming” window, Welch with “Barlet” window, Welch with “Backman” window, Welch with “flattop” window b) Zoom (20-36 Hz), c) Comparison of six types, d) Zoom comparison of six types (24.50 – 26.25 Hz)

i) Graph of the SAC record from the Continuous Wavelet Transform (CWT).

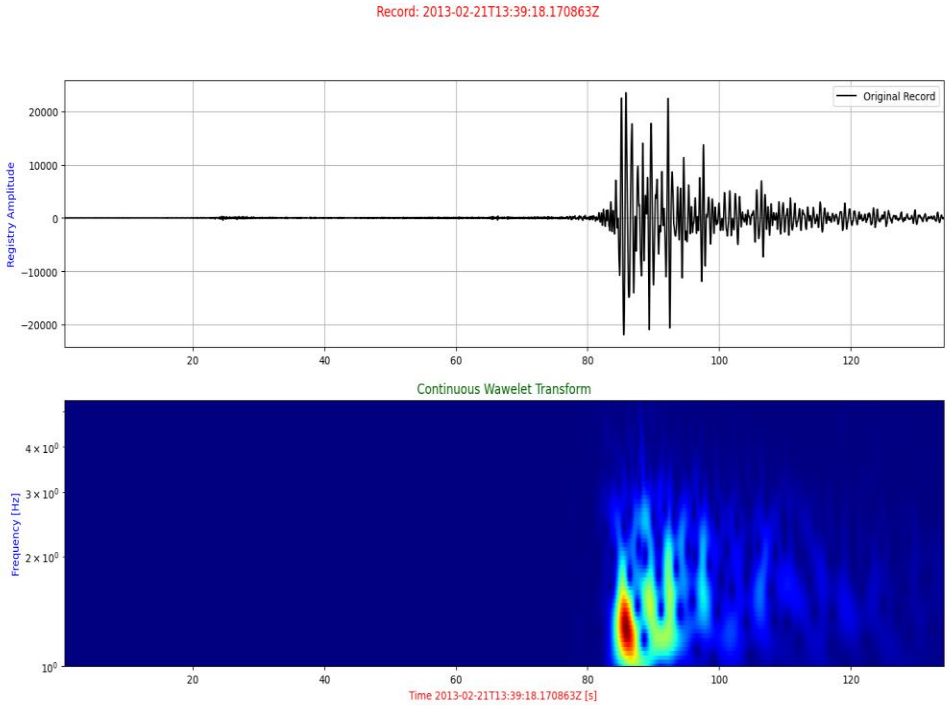

Fig. 75 Graph of the SAC record from the Continuous Wavelet Transform (CWT) with a minimum frequency of 1 Hz and a maximum frequency of 15 Hz.

j) A Zoom of the Graph of the SAC record from the Continuous Wavelet Transform (CWT) is observed. In this type of graph, the Zoom is automatically applied to the two sections when one of them is selected.

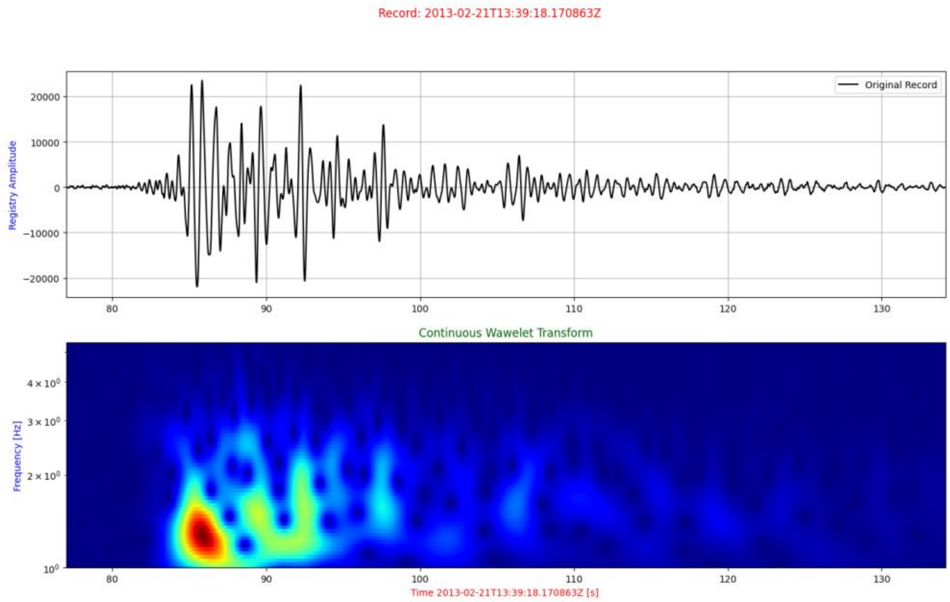

Fig. 76 Zoom of the Graph of the GSE2 record from the Continuous Wavelet Transform (CWT).

k) Graph of the Analysis of the Discrete Coefficients at 5 levels (approximation and detail) from the Wavelet Transform of a SAC record (for this example, the "**coif17**" type has been selected). Additionally, a graph of the original record is presented.

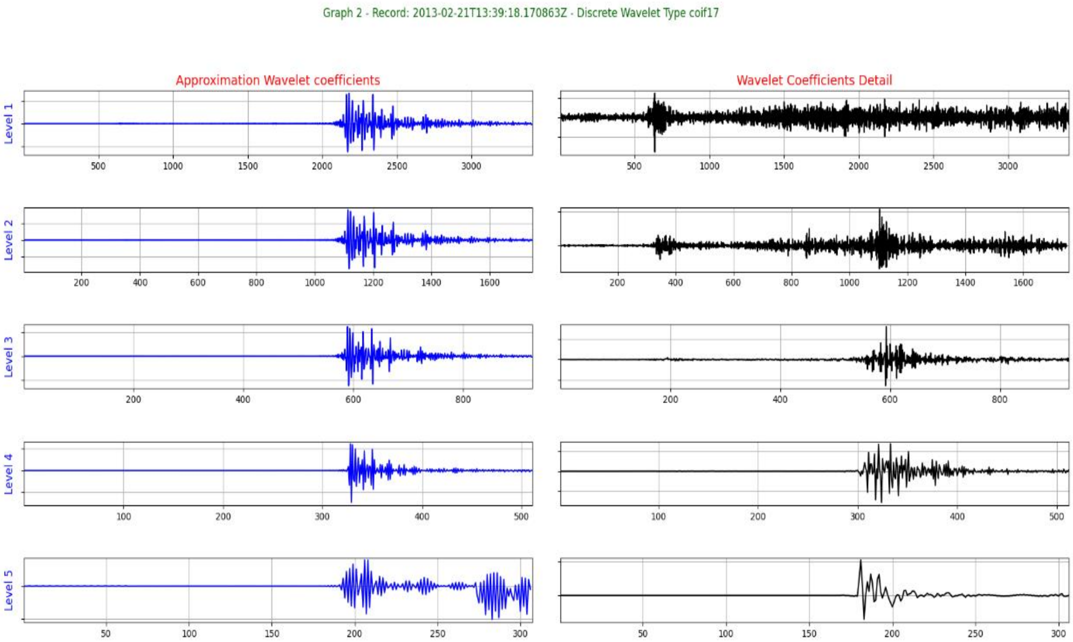

Fig. 77 Graph of the SAC record, with discrete wavelet coefficients of the "coif17" type.

l) Graph of the original signal from the analysis of the Discrete Coefficients at 5 levels (approximation and detail).

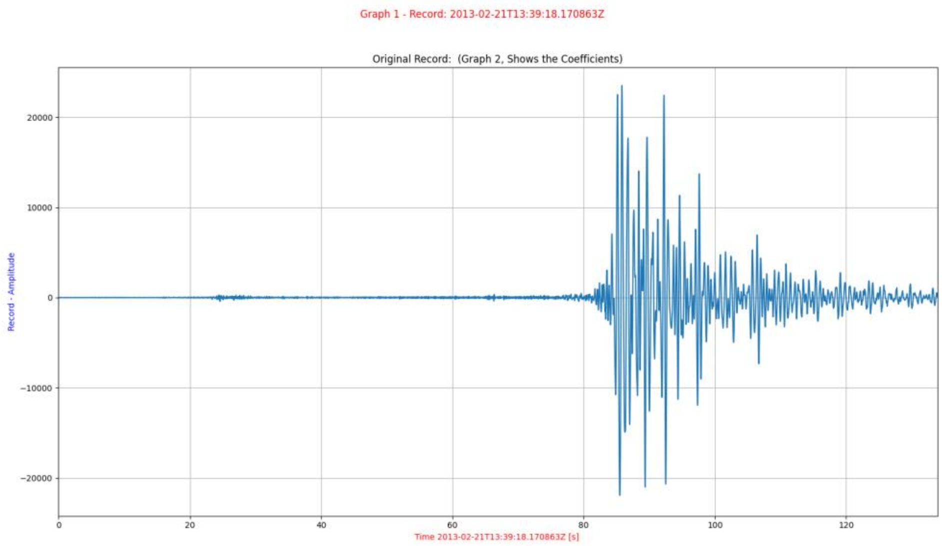

Fig. 78 Graph of the original signal from the SAC record, with discrete wavelet coefficients of the “coif17” type.

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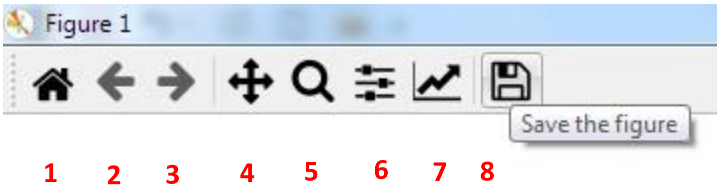
6.- Toolbar of Graphs (Matplotlib Library).

In the construction of graphs, the *Matplotlib* library's graph screen has a set of very useful tools that allow you to visualize, edit, and save graphs in various formats. At the top of the Matplotlib graph screen that appears when a graph is created, there is a toolbar similar to the following:



From left to right, the icons representing the actions to be performed are:

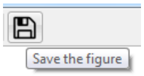
1. Reset original view: Restores all graphs to the initial state.
2. Back to previous view: Preview of the selected graph.
3. Forward to next view: Forward view of the next image.
4. Left button pans, Right button zooms, x/y fixes axis, CTRL fixes aspect. Moves the graph and axes left or right, zooms in or out, fixes the x/y axis, and fixes the aspect with CTRL.
5. Zoom to rectangle: Through a rectangle, zooms in on the selected graph.
6. Configure subplots: Configuration of subplots (Borders and spacings).
7. Edit axis, curve and image parameters: Editing the parameters of the graph. Select the axes or graph and edit elements such as title, coordinates (X, Y), and curve parameters (lines, markers) in styles, colors, and size.
8. Save the figure: Saves the graph in several formats.

This document does not delve into each of them; it only highlights the use of those that are generally more commonly used, such as (1, 2, 5, 7, and 8).

In the above graphs, the use of the zoom tool (5) has been observed. Tools 2 and 3 allow zooming in or out individually for each graph. Option 1 allows restoring all elements or subplots of the graph to their initial values (*each individual graph or part of the window*). As for option 8, it allows saving the graph in various formats. The rest are straightforward, and it is up to the user to explore each of them. Now, the processes for "***editing***" and "***saving*** or ***storing***" the graphs (*Numbers 7 and 8*) are detailed below.

6.1.- *Saving Graphs.*

The process of saving graphs is very simple. Click on the icon of tool number 8 (Save the figure).

This opens an explorer window, similar to 

those in Windows (depending on the language or system used), where you can select the folder or directory where the graph will be saved.

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Additionally, provide a name and select the desired format type. This can be done at the bottom of the explorer window (red circle in the image), where various format types available for saving are selected. The screen resembles the following.

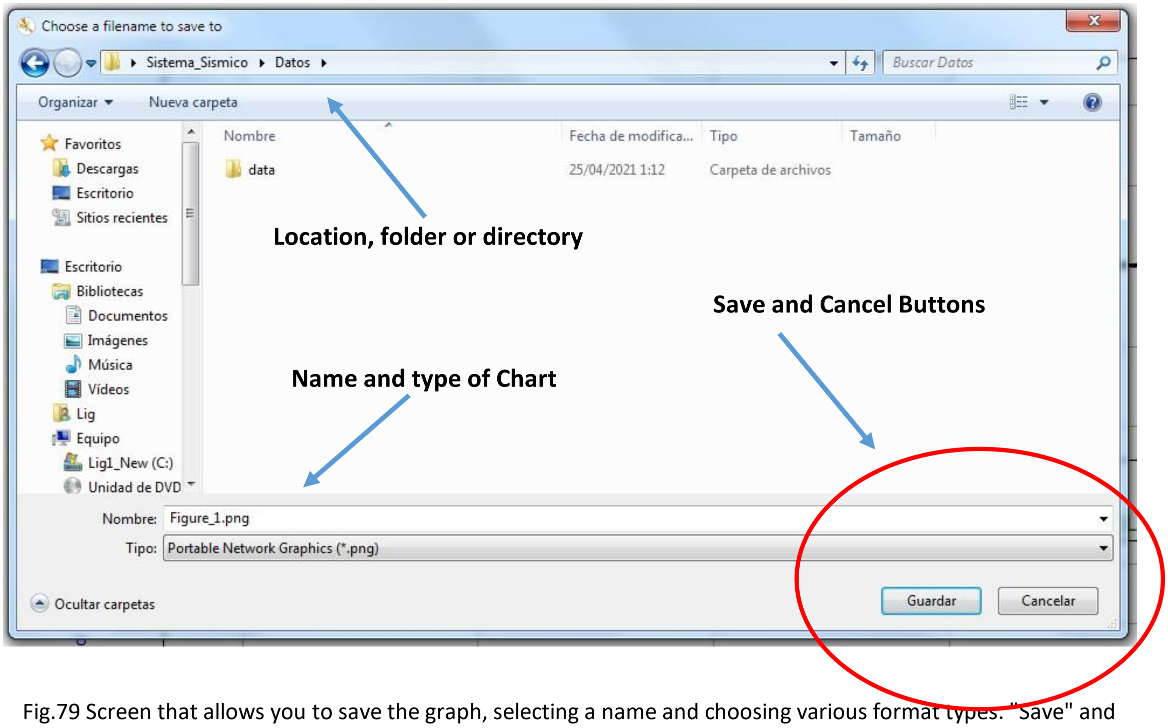


Fig.79 Screen that allows you to save the graph, selecting a name and choosing various format types. "Save" and "Cancel" buttons are provided to complete or cancel the process.

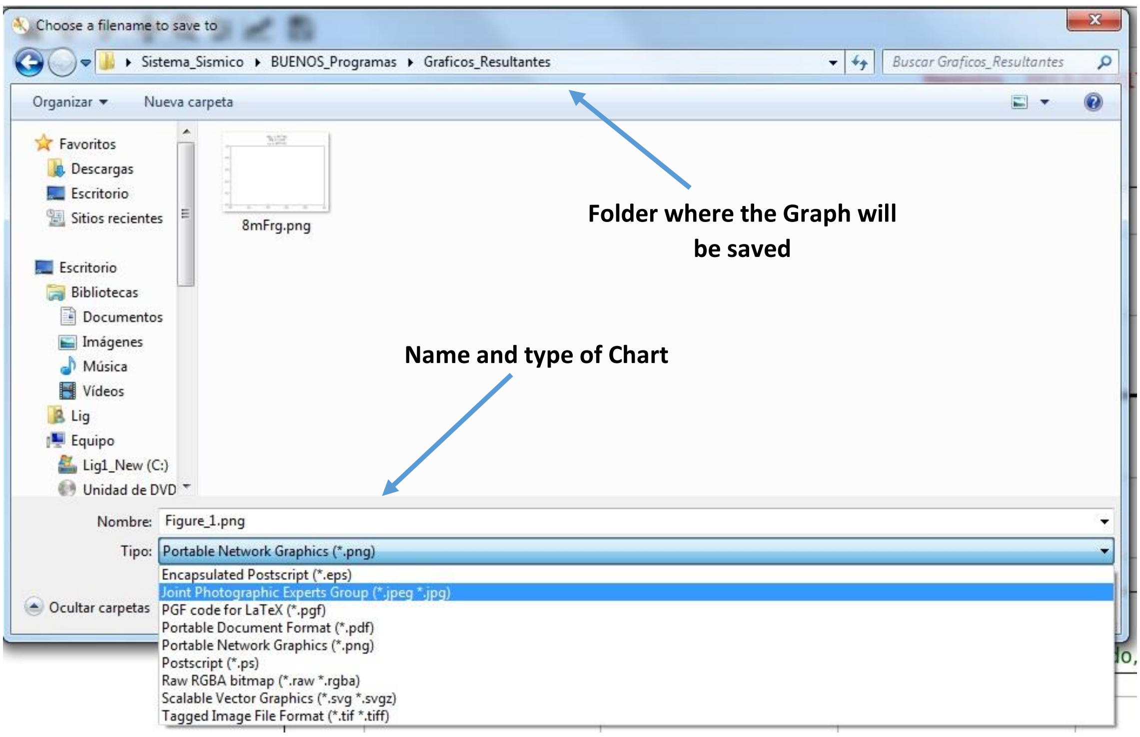


Fig. 80 Screen where you can see the types of formats available to save the graph.

The previous figure shows a list of the available file formats, the following image presents this list in more detail:

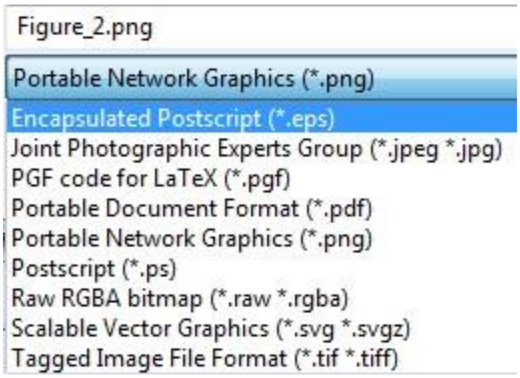
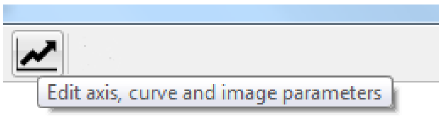


Fig. 81 List of available formats for saving the graph generated by the analysis.

Once you have selected both the name and the desired file format, and the location of the folder or directory where the graph will be saved, click the "*Save*" button (*See Fig. 85*), and the graph will be stored and available for further use as needed.

6.2.- Editing Axes and Images in Graphs

Through the "Edit" button, point 7 (*See page 66*) of the graph toolbar (*Edit axis, curve and image parameters*), it is possible to edit or modify the parameters of the axes, images, and curves of the graphs.



For example, to modify the parameters of the image of a spectrogram, click on this command button. A "*Customize*" dialog box appears, indicating which of the "*axes*" in the graph areas you want to edit or modify. After selecting, click the "OK" button. This dialog box is similar to the following:

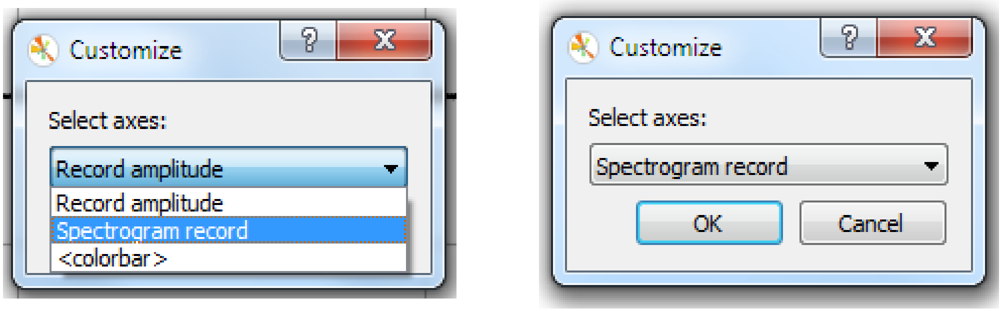


Fig. 82 Customize dialog box, the spectrogram axis has been selected.

Once the desired axis is selected, and the "OK" button is clicked, a new window with the options in the figure is presented. Here, various values of the selected axis are edited, in this case, the spectrogram (*Axes and Images*). The dialog box is as follows:

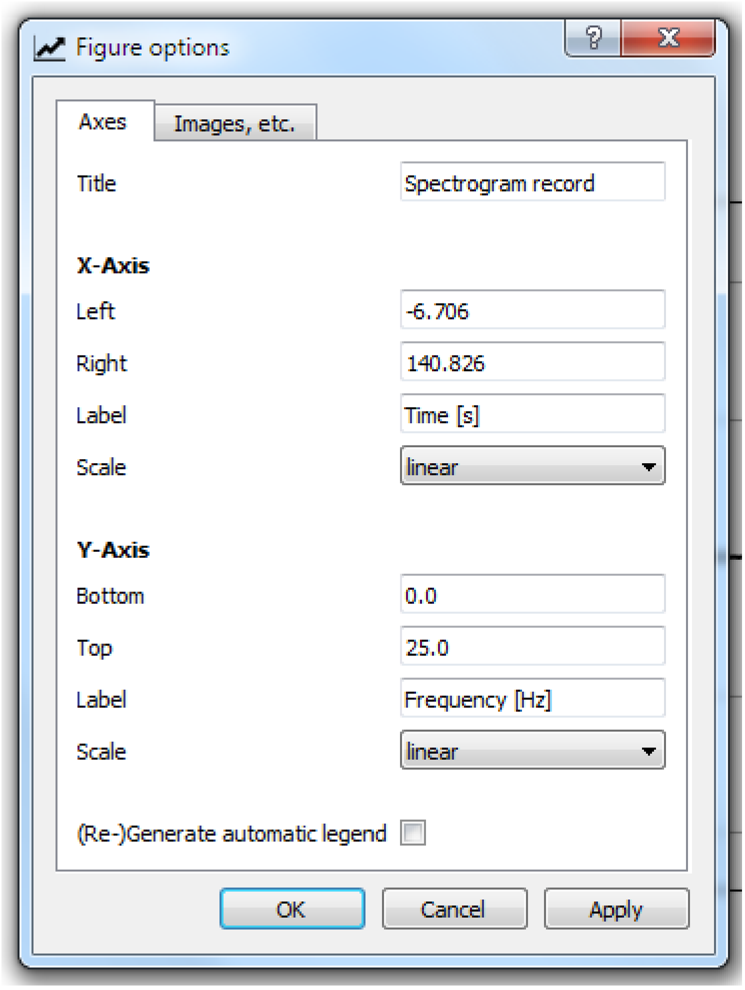


Fig. 83 Dialog box for editing options for the title and axes of the figure.

In this "*Axes*" section, as you can see, you can edit or modify the values or parameters of the title and the "X" and "Y" axes of the graph. For our example, we want to modify the image, so we will select the tab indicating this option. The image presented is as follows:

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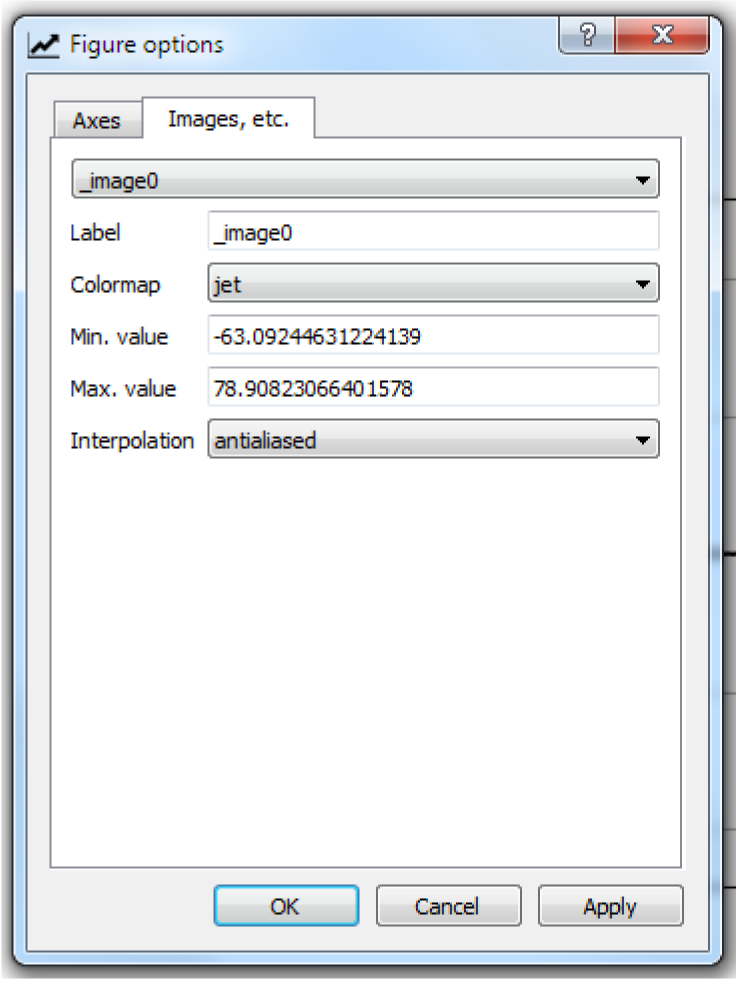

Fig. 84 Dialog box for editing options for image parameters

As seen in the image, various parameters can be modified, including labels, the color map or "*Colormap*", used in the spectrogram, minimum and maximum values, and interpolation. The default value for the "*Colormap*" is set to "**jet**". The minimum and maximum values for this color map and the interpolation used are assigned by default to the image, but they can be modified according to the operator's interest.

The list of editable parameter values for both "*Colormap*" and "*Interpolation*" is presented in the figure on the next page.

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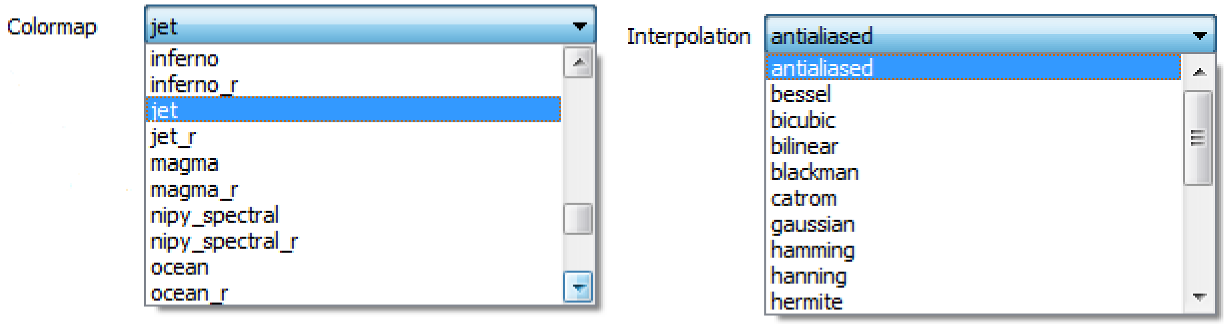

Fig. 85 Dialog boxes for editing some of the parameters of "*Colormap*" and "*Interpolation*" to select in the graph.

CONCLUSION: As demonstrated throughout the development of this work, both this module and the rest of the system have been designed and developed as a comprehensive set of computer tools for complex processes involving the calculation and analysis of seismic-volcanic signals. These tools allow for easy understanding, use, and access by the user, even without advanced computer knowledge. They feature user-friendly and straightforward interfaces that provide reliable technological assistance for observatories and researchers in the analysis of seismic records. Like each of the modules that make up this system, the current version (1.1), an improvement over the initial version 1.0, consists of a single module. It includes a series of filter analyses and spectral analyses most commonly used in the study of general seismic-volcanic records. Additionally, future versions can incorporate various modules with different types of analyses, offering added value to the process of researching, studying, and analyzing seismic-volcanic signals.

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END of the document.

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Granada, Spain – 2023

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APPENDIX A

A1.- Installation of Python and Additional Libraries

A1.1. Package Content.

The main folder "***Analysis_System_1***", It contains two folders with the programs (codes and interfaces in English and documentation in Spanish and English), organized as follows:

a) Folder **"Reliable_set_tools_system_1"**: (*seismic analysis system assembly*). This folder must be copied to "*My Documents*". Contains the following elements:

   a. Subfolder: "***Images***" " Images necessary for program interfaces.

   b. Program: ***Menu.py***. Startup program, presentation and calling of individual modules.

   c. Program: Analysis_System_1.py. Main program for spectral analysis and filtering. (*current program, plus the rest of the modules*).

   d. Program: class_canvas1.py. Support program, which creates the initial canvas for the main interface.

b) Folders (*Document_ES and Document_EN, depending on the language; English or Spanish*). For *English* "***Document_EN***": It consists of the following items:

   a. User Manual for the module: "***1_Manual_Analysis_System_EN.pdf***" in PDF, written in English, with the necessary documentation for the use of the system interfaces. In turn, the rest of the manuals for the other modules (1-10) that make up the system are found.

   b. "***Initials Requirements.txt***" file. File containing the libraries needed to be installed on Windows through "Pip", once Python is installed.

   c. File "***README.txt***": File with general instructions for system installation.

   d. File "**Set_tools_System_1_1.bat**", batch processing executable file. It must be copied to the desktop, from there by right clicking "run as administrator", it will start the system by calling the main menu. The file will automatically search for the startup program (**Menu.py**) that is located in the "**Set_tools_System_1_1**" folder that has been previously copied to "**My Documents**" and will start Python, executing said program.

The system has all the elements (*programs and interfaces*) in English, except for the user manual, which is written in both Spanish and English. To install on Windows, two main actions should be taken after downloading and extracting the ". Rar" files. The first is to copy the entire folder (a) to the "*My Documents*" folder on the PC.

a) From the main folder (**Analysis_System_1**), copy the subfolder "**Document_EN**" to "**My Documents**" in Windows.

b) Copy the file "**Set_tools_System_1_1.bat**", from the "(Document/Document_ES or Document_EN)", depending on the version (Spanish or English), to the Windows desktop.

This ensures the proper use of the program. Now, we will proceed with the installation of the Python language and additional Python libraries on Windows.

A1.2.- Installing Python on Windows.

Python is an interpreted, multi-platform, and multiparadigm programming language (*it works on various operating systems, including Windows, Linux, and Mac*), utilizing two or more programming paradigms within a program-object-oriented, reflective, imperative, and functional.

In addition, Python can be enriched by a large number of programming modules, libraries, packages, or libraries installed through its package manager, "**Pip**." On Linux, the Python program and its manager "**Pip**" are installed together with the operating system. In Windows systems, however, where Python is not a native language, it is necessary to install this language beforehand by downloading the appropriate version from the Python distribution website at the following address: https://www.python.org/downloads/

On the website, the correct version should be selected based on the type of operating system on the computer, including whether it is 32 or 64 bits.

To be installed on both 32 and 64-bit systems, it is essential to note that this document and the software were created with the version available at that time, which was "Python 3.8.6", and many more versions have emerged since then. A more modern and adaptable version to the software (recommended) is "Python 10.10".

Users need to check if more advanced versions do not interfere with some of the installed libraries, such as "*Obspy*," for example. This is because everything related to Linux systems is constantly changing with updates that Python and Linux-based systems make. It is advisable to visit the website and download the most stable or tested updated version of Python that works well with this software.

Once downloaded, run it as an administrator (*right-click and "run as administrator"*), and the software installation wizard will guide you through the necessary steps (*just follow the instructions*).

The process takes only a few minutes. It is "recommended" to indicate during the process, when asked, to include an access path in the system's "**Path**" so that Python can be accessed from any location in Windows. If this is not done during the installation process, it must be done manually by modifying the environment variables (more complicated) to include the path from where Python is installed. This will not be necessary (*if indicated at the beginning*) through the installation wizard.

A1.3.- Installation of Additional Libraries.

The next step is to ensure that Python and its file manager or package manager (**Pip**) have been installed correctly. "**Pip**" (*file and library manager*) is crucial because it allows the installation of additional libraries that Python needs to run the created programs. To do this, open the Windows console window, or "*CMD*." The CMD, or command prompt, is a command-line interpreter.

Accessing the CMD is possible by typing, searching for the Windows logo key (a window), located between the "Ctrl" and "Alt" keys at the bottom left of the keyboard. Pressing this key, plus (+) the letter "**R**" key, will open a "Run" program window, similar to the following.

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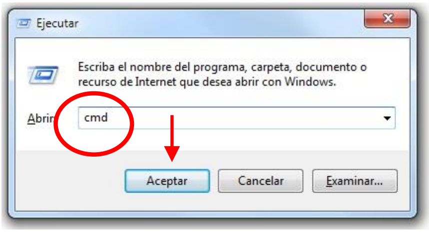

Fig. A1 Screen run in Windows. In the red circle, type "cmd" and click "OK."

As seen in the figure above, type "cmd," click "OK," which will open the Windows command prompt window.

Another way to do this is at the bottom of the desktop, in (W7) or next to (W10) the Windows "Start" button. There is the search section, indicated by the magnifying glass icon. This indicates a search for programs, similar to the following.

Fig. A2 Windows Program Search Screen.

In the box that says "Search programs and files" (Windows 7) or "*Type here to search*" (Windows 10), type "cmd" as well. This action or the previous one will bring up the Windows command prompt (CMD), similar to the following (W7).

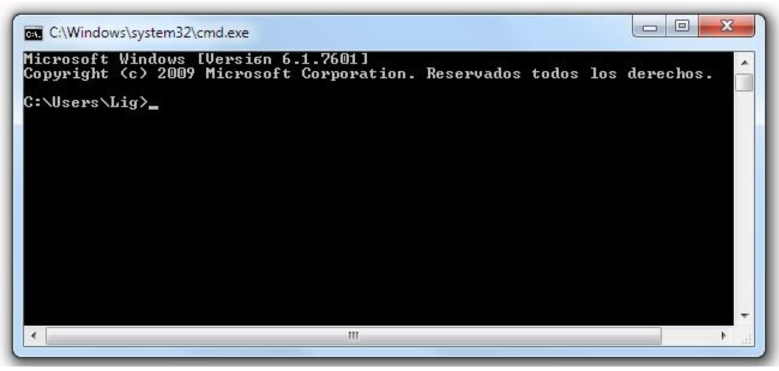

Fig. A3 Windows 7 Command Prompt (CMD) Screen.

The same applies to versions: Windows 10 (W10) or Windows 11 (W11).

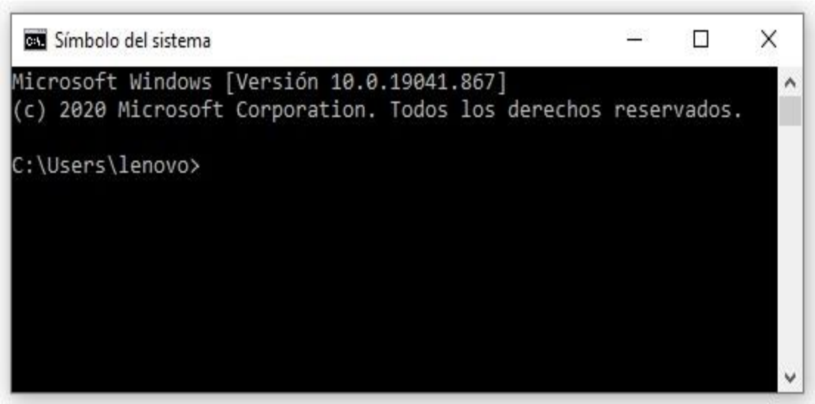

Fig. A4 Command Prompt (CMD) Screen in Windows 10.

Once on this screen, to verify that both Python and its package manager "**pip**" have been installed correctly, type the following commands: **Python -V**, and to check "**pip**," type: **pip -V**. This is shown in the following figure.

Fig. A5 CMD Screen, indicating Python and pip versions in Windows.

The output of typing "-V" in Python indicates invoking the installed version. In this case, it can be seen that it is "3.8.6" (*The library set is compatible with 3.10.10 version*). This has been possible from any location in the system because the Python script has been installed, remember, in the "**path**" or route found in the system's environment variables. Also, after typing "pip -V", it can be seen that the Pip version is "*20.2.1*." At this point, it is recommended to update this version since, by default, "Pip" is installed along with "Python", but it does not install the latest or most up-to-date version. To do this, in the CMD window or console, type the following command (*Windows/Linux*): On Windows, type "python," and on Linux, type "python3".

Windows: > python –m pip install –upgrade pip | Linux: $ sudo python3 –m pip install –upgrade pip

This indicates that "Pip" will be updated to its most recent version (*On Linux, as a "superuser," i.e., with "**sudo**" at the beginning*). It is shown in the following screen.

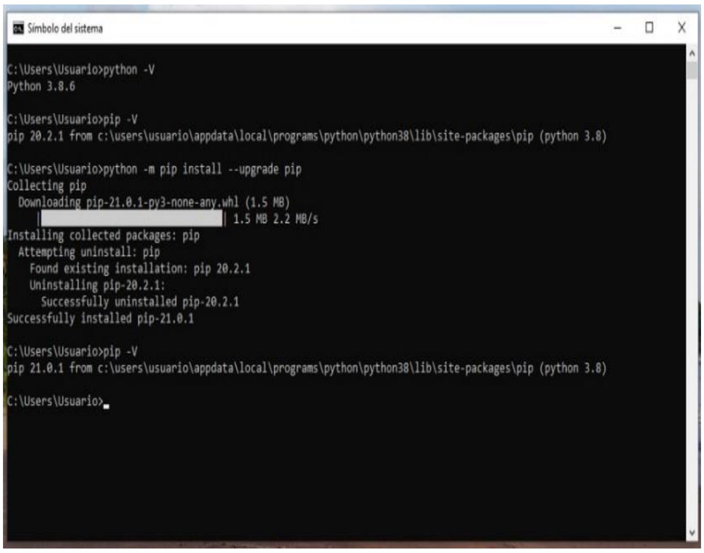

Fig. A6 Screen showing the update and verification of the new version of pip in Windows.

As can be seen, when typing again (**pip -V**), once Pip is updated, the version is 21.0.1. With this, Python and Pip are already installed and updated. Pip, as mentioned, is very important because with this manager, all the necessary libraries and packages are installed so that Python applications can be executed correctly and without errors. To use the system, you must proceed to install the necessary packages or libraries through Pip.

Next, we will proceed to explain how, in a simple and completely automatic way, the most commonly used and general libraries that Python needs will be installed on the system. Libraries such as, for example, "*obspy*," which is the open-source library or software based on Python for processing seismological data. Also, "***matplotlib***," which is a library for generating graphics from data contained in lists or arrays in Python and its mathematical extension "***NumPy***," among others, which the system needs for its execution (*See Annex B*).

A1.4 Automatic Installation of Libraries on Windows and Linux from PIP

The advantage of having already installed and updated Pip in Windows is that you can install all the libraries that Python needs to run the system.

Additionally, in the "***Document***" folder, the "***Readme.txt***" file contains instructions for this installation. So the user only needs to follow the instructions, and the necessary packages will be installed on the computer (PC) automatically by "***Pip***", both on Windows and Linux. The required libraries are in the file called "***Initial_requirements.txt***", included in the "***Document***" folder of the downloaded installation files and in **Annex B**.

In a Windows Command Prompt (**Cmd**) window, actions are taken for each of the commands indicated in the file, following the instructions. The installation should not present problems on Windows and Linux systems. If any library encounters an error during installation (*shown in red in CMD*), you should consult the documentation for that library or check if the correct or recommended version of Python is being installed (*version 3.8.6 and/or 3.10.10*). The installation on Linux systems (*See README.txt*) is similar and simpler. Copy the main folder to the desktop, the personal folder, etc. From that location, open a command prompt, and simply type:

"***$ python3 Menu.py***" to start the system.

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APPENDIX B:

INSTALL PYTHON LIBRARIES FOR THE PROPER FUNCTIONING OF THE SYSTEM.

1.- **PIP**: The **Pip** (*Preferred Installer Program*) is the package or package management manager used to install and manage software packages written in Python. When installing Python, Pip is installed by default. To check the version of Python or PIP, type the following in a console or CMD:

python - V / pip – And to see the list of installed pip packages: -> pip list

Usually, you need to update the version of pip with which Python is installed. For this, type the following command in the command prompt (CMD). In Linux and Mac systems, "**sudo**" is placed at the beginning to indicate super-user permissions.

Python –m pip install - - upgrade pip / (LINUX) -> sudo python –m pip install - - upgrade pip

Once downloaded and installed, you can check the version again with the first command, and you will see that the version has changed and been updated. Now that pip is updated, we will proceed to install the necessary packages for Python to work correctly with the applications.

2.- .- **PyQt Installation**: This is a Python binding for the Qt library written in the C++ language. It is used for creating and using graphical user interfaces (GUI) in Python. Type the following in the command prompt (CMD).

pip install PyQt5 / (LINUX & Mac) -> sudo python install PyQt5

3.- **Matplotlib library Installation**. Matplotlib is the library that allows the creation and visualization of graphics. Type the following:

pip install matplotlib / (LINUX & Mac) -> sudo python install matplotlib

4.- Install the **Obspy** library. This library is for handling seismic signals. Type the following:

pip install obspy / (LINUX & Mac) -> sudo python install obspy

5.- Install **Thinter**: Thinter is a graphical user interface (GUI). Type the following:

pip install tk / (LINUX & Mac) -> sudo python install tk

6.- Install **quantecon**: This library is used for spectrum estimation, Periodogram, Fourier transform. Type the following:

pip install - - upgrade quantecon / (LINUX & Mac) -> sudo python install - - upgrade quantecon

7.- Update a library for **matplotlib**. To avoid problems with graphics, install the following:

pip install msvc-runtime / (LINUX & Mac) -> sudo python install msvc-runtime

8.- Install **easygui** for the graphical interface:

pip install easygui / (LINUX & Mac) -> sudo python install easygui

9 Install **PyWavelets** for CWT handling.

pip install PyWavelets / (LINUX & Mac) -> sudo python install PyWavelets

10.- Install **plotly** for handling and assisting with graphics along with Matplotlib.

pip install plotly / (LINUX & Mac) -> sudo python install plotly

11.- Install "**pyaudio**", for audio management. Python bindings for PortAudio v19, the cross-platform audio I/O library

python -m pip install pyaudio / (LINUX & Mac) -> sudo apt-get install python3-pyaudio

Finally, type "pip list" to see the installed libraries. Optionally, you can create a file called "***requirements.txt***" that will contain all the libraries that the PC will use. The "***requirements.txt***" file must be in the current directory. The instruction to do this is as follows:

pip freeze > requirements.txt