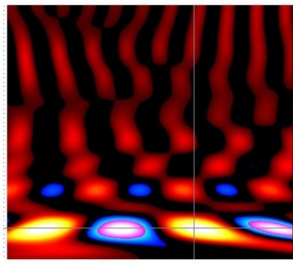
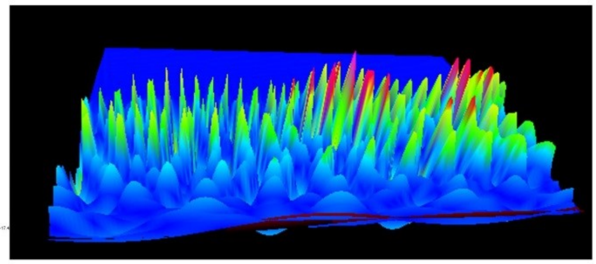
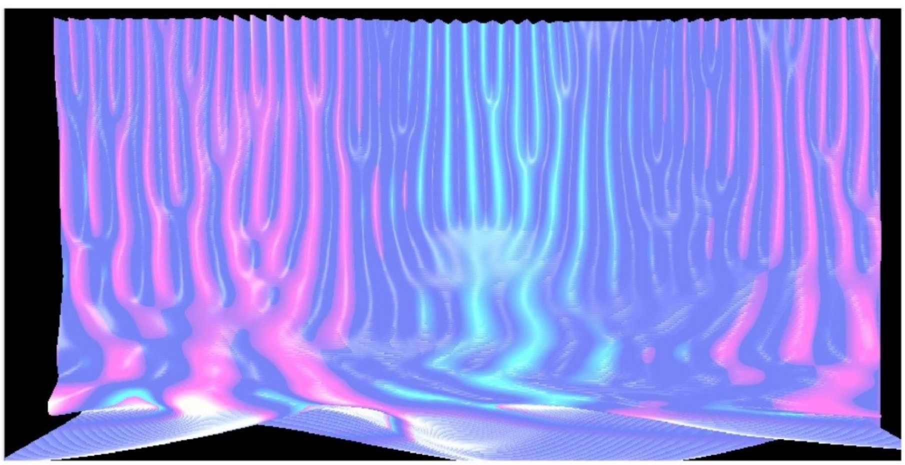
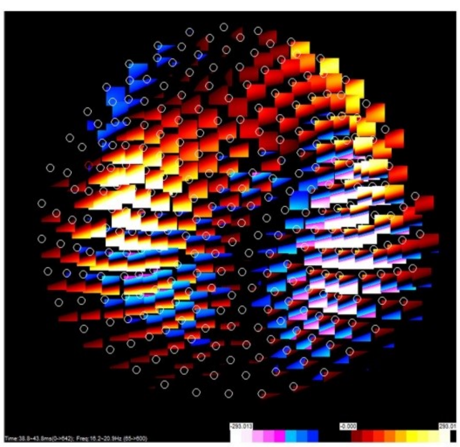
Time-Frequency Analyses

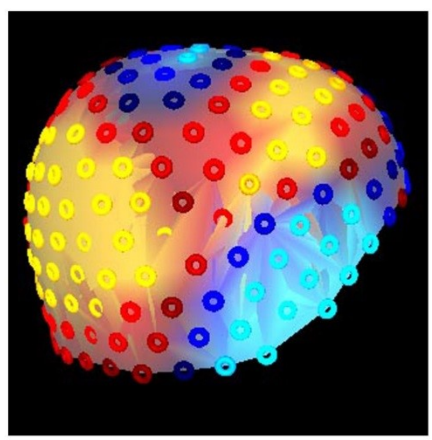
Software Guide (EEG/MEG Data)











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Features and specifications of this software program are subject to change without notice. This manual contains information and images about EEG (electroencephalography) and MEG (magnetoencephalography) time-frequency software and its user interface, GUI and its other signal processing algorithms, publications that may be protected by copyright.

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Thank you.

Contents

Warnings and Cautions

There are many time-frequency analysis algorithms in the program. Each time-frequency algorithm has been designed and tested for specific reasons. In this version of the software, our work focuses on continuous wavelet-transform (CWT) and Gabor transform. To ensure the quality and visibility, all time-frequency algorithms will generate a set of 2D spectrograms and 3D spectrograms. In addition, the spectrograms can be quantitatively measured or quantified with a few clicks.

The time-frequency analysis software does not test if the active and control time windows overlap one another. Meaningful designation of integration time windows is the responsibility of the user. It is strongly recommended that the number of samples integrated into the active and control states are close to equal. Failure to do so will lead to bias in images of difference and ratio.

During time-frequency analysis, the software may overwrite a pre-existing middle data such as old time-frequency data; it is deleted at the beginning of the process and cannot be recovered. It is recommended to save a copy of the important file as a backup.

This program is optimized for the detecting, analyzing and processing high-frequency signals with magnetic and/or electric polarity information. To the best of our knowledge, this is a new area; there are no standardized names, terms or values. For example, spectral data typically represent the spectral power of waveform data. However, in this manual, the “spectrogram” is simply used to as a “place holder” to represent the time-frequency representation of waveform data. The spectrogram may have spectral power, phase, real or imaginary data. In addition, all those type of data may have polarity information attached. The polarity information is important because the time-frequency representations of the EEG/MEG data are also used to localize brain activity/activation.

Preface

This guide describes the operation of EEG/MEG time-frequency analysis. The time-frequency module is one of the core functions in EEG/MEG data analysis. It is used as the primary tool to determine the sinusoidal frequency and phase content of local sections of a signal as it changes over time. The function to be transformed is first multiplied by a Gaussian function, which can be regarded as a window function, and the resulting function is then transformed with a Fourier transform to derive the time-frequency analysis. The window function means that the signal near the time being analyzed will have higher weight. Importantly, the time-frequency analysis module provides graphic user interface (GUI) for access all the functions.

Intended Audience

This guide is intended for persons responsible for analyzing the time-frequency characteristics with EEG and MEG data. This reference is useful to anyone who performs analysis techniques for EEG/MEG data. Operations of time-frequency analysis require some expertise to satisfy requirements of accuracy and fitness for use of the results. Technicians may use the application under review by highly trained analytical staff. The guide assumes the reader is familiar with standard EEG/MEG procedures and is familiar with the Windows operating systems.

There are many EEG/MEG time-frequency algorithms. In this manual, we will discuss the well-tested algorithms that showed promising results in EEG/MEG study.

References

This document assumes familiarity with many terms related to computer operations and physiology. This document also assumes you are familiar with the principles of Fourier transform and the data collection and recording process. It also assumes some knowledge of EEG/MEG analysis. The document uses terms related to computer operations and physiology as well as many acronyms.

Document Structure

Documents are generally provided in both Microsoft Word® format and Adobe® Acrobat® PDF (Portable Document Format). All editions are distributed on Flash Driver, CD or websites with the related software, and include bookmarks and hyperlinks to assist navigating the document. Please feel free to send your critiques, corrections, suggestions and comments to: BrainX@live.com.

Conventions

Numeric: Numeric values are generally presented in decimal but in special circumstances may also be expressed in hexadecimal or binary. Hexadecimal values are shown with a prefix of 0x, in the form 0x3D.

Binary values are shown with a prefix of 0b, in the form 0b00111101. Otherwise, values are presumed decimal.

Units: Units of measure are given in metric. Where measure is provided in imperial units, they are typically shown in parenthesis after the metric units.

A millivolt (mV) is one one-thousandth of a volt (0.001 V or 1 10^{-3}. These units commonly are used in EKG, EMG, and sometimes in EEG. A microvolt (uV) is one one-millionth of a volt (0.000000 V or 1 x 10^{-6}). This is the commonest voltage measure in EEG. A nanovolt (nV) is one-thousandth of one-millionth of a v (0.000000001 V or 1 x 10^{-9}). This measure is used in the specific area of EEG dealing with evoked potentials.

The unit of current is the ampere (A). In EEG, typical smaller amounts are encountered. A milliampere (mA) is one one-thousandth of an ampere (0.001 A or 1 x 10^{-3}). A microamplere (uA) is one one-millionth of an ampere (0.000000 A, or 1 x 10^{-6}).

Magnetic signal strength is given in Teslas (T), the SI unit of flux density (or field intensity) for magnetic fields, also known as the magnetic induction. Typical signal strengths in MEG measurements are in the order of pT (picoteslas = 10^{-12}) or fT (femtoteslas = 10^{-15}).

Changes from Previous Releases

If you used the software before, please read the ReadMeFirst.doc file for late changes that did not make it into this manual and for a list of new functions or options, changes, additions, bug fixes, and known bugs for the application. In comparison with previous version of the software, this version of the software only shows two modules: CWT analysis and Gabor analysis. Many other modules are used only for internal tests. The major reason is that we would like to provide a robust and accurate approach for EEG/MEG data analysis. The discussion of the time-frequency analysis will then focus on CWT and Gabor analyses.

Introduction

This manual describes the various graphical elements that make up time-frequency analysis module and defines the spectrogram data throughout the software applications. There are several ways to perform time-frequency analysis. In this guide, the time-frequency methods will be discussed according to the computing of spectrogram and the visualization of spectral data. The mathematic algorithms will be explained briefly.

Time-frequency analysis is typically applied or used in oscillatory EEG/MEG data. Oscillatory components contained in the ongoing EEG/MEG signals often show power changes relative to experimental events. These signals are not necessarily phase-locked to the event and will not be represented in event related fields and potentials. The goal of the design of the software is to compute and visualize event related changes by calculating time-frequency representations (TFRs) of oscillatory data, phase and power. This will be done using analysis based on wavelets, with some improvements and optimization that allow a better control of time and frequency smoothing.

Major Innovations (Spectrogram vs. Time-Frequency Representations)

The conventional spectrograms (or typically used spectrogram) focus on spectral or the magnitude of spectral data, which typically do not have the magnetic polarity information. This program, however, generates spectral power as well as many other spectral related data. For example, the time-frequency representations generated by this program have the real and imaginary components of the spectral data, which encode the magnetic polarity information.

1) Real Time-Frequency Representation (“Real”): The real components of the time-frequency representations can be displayed independently.
2) Imaginary Time-Frequency Representation (“Img” or “Imag”, which depends on the space of GUI): The imaginary components of the time-frequency representations can be displayed independently.
3) Spectral Power of Time-Frequency Representation (“Power”): Of course, the conventional spectral power is computed by default.
4) Phase of Time-Frequency Representation (“Phase”): The conventional phase of oscillatory signals can be computed by a few mouse clicks.

The spectral power or phase information is typically presented in the same window, which can be computed during time-frequency transform or after the real and imaginary data have been computed.

Menu for Launching Time-Frequency Analysis Windows

The menu for launching time-frequency analysis windows is in the Main Frame of the EEG Studio program, which is under the Spectrum Menu (Figure 1). EEG/MEG data for time-frequency analysis can be raw waveform data and/or pre-processed data. Typically, it will be pre-processed. This manual describes the various graphical elements that make up time-frequency analysis module and defines the spectrogram throughout the software applications.

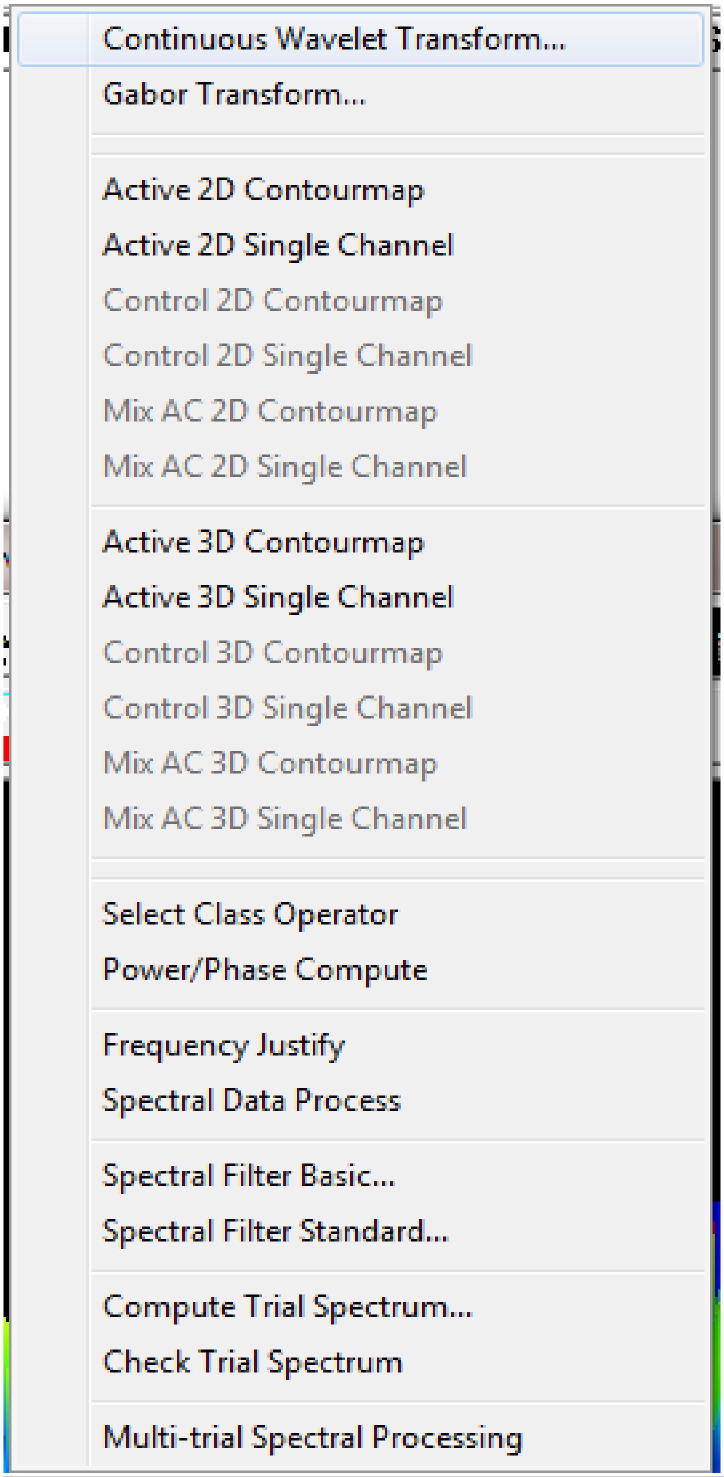

Figure 1. Menu for launching time-frequency analysis Windows.

Continuous Wavelet Transform (CWT)

The “CWT” launches the main window for Continuous Wavelet Transform (CWT) with wave form data and generates spectrograms, which may have multiple time slices. The Window GUI application allows you to configure parameters and processing options for time-frequency transform as well as other kinds of analysis.

Time-frequency analysis is performed after a dataset has been acquired and reviewed. Here is the recommended procedure for a standard analysis using time-frequency analysis programs:

a) Check and verify that you have the correct dataset and trials in the Waveform Viewer (see the EEG Studio Main Frame Guide).
b) If data averaging is necessary or required, do the averring first. Once multiple trials have been averaged successfully, there is at least one averaged trial (“virtual trial”) will be added to the MEG dataset, which is available in the main Frame for waveform viewer.
c) Filtering and/or removing DC-offset is typically required or necessary. If you do think so, apply the filtering/DC-offset to the targeted trial;
d) Check and analyze the EEG/MEG data to determine the interest of time-window. Though there is no standardized way, it is a good idea to use “Overlay” viewer to determine the interest of time-window with all “sensors”.
e) If the time-frequency analysis main window (CWT Settings) has not been launched. Select the desired time-frequency analysis method in the Menu (see “Menu for Launching Time-Frequency Analysis Windows”)
f) During the launching of the window for CWT Settings, the program gets the selected time-window as the Active Window and finds the frequency ranges. The program also checks the integrity and sanity of the data and may report warning/error messages.
g) Use the window for “CWT Settings” to inspect the dataset as well as suitable parameters. If required or necessary, change the data selections.

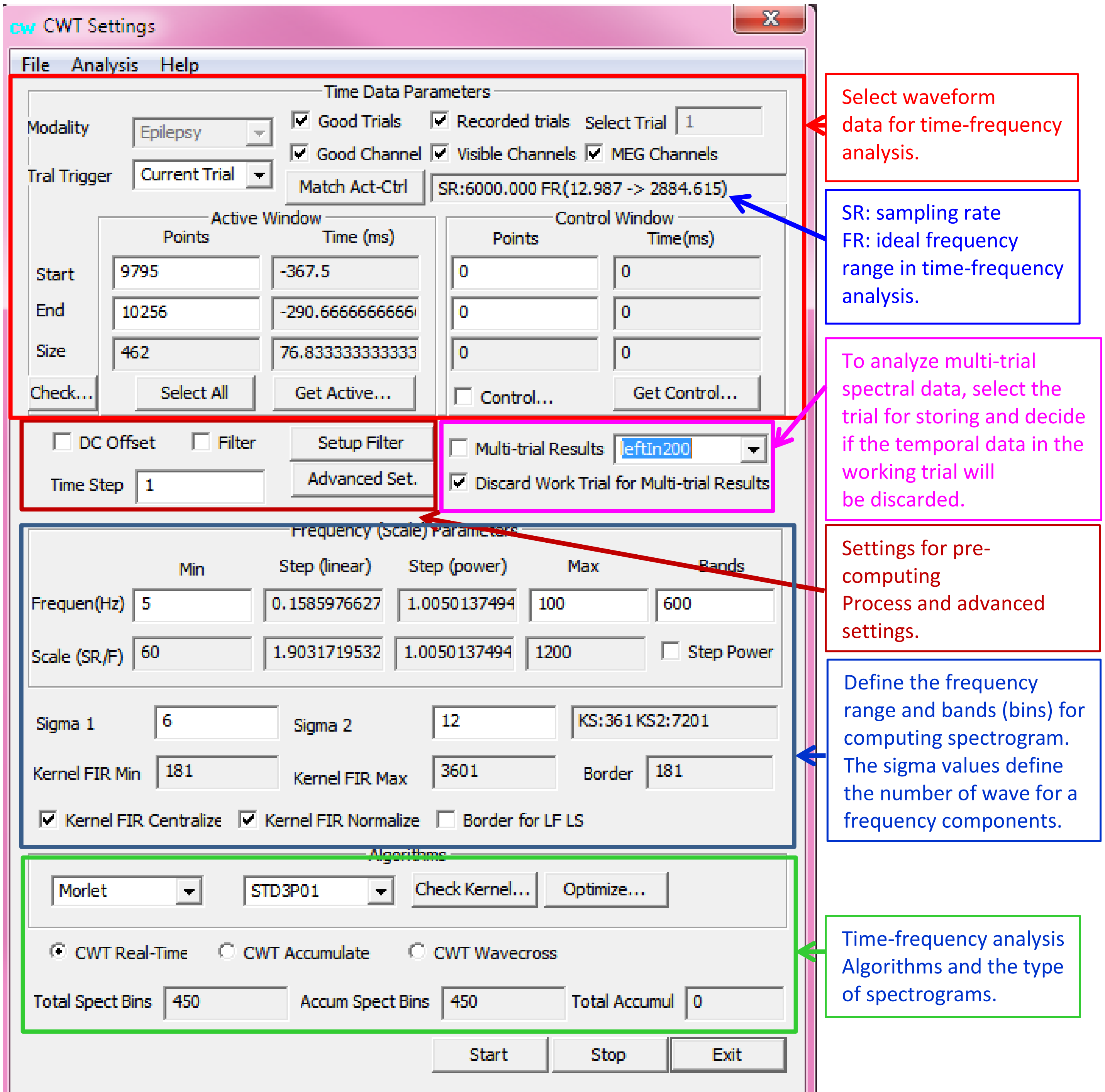

Figure 2. CWT settings for time-frequency analysis.

Main Modules in CWT

The full suite of waveform time-frequency analyses comprises the following components.

- Wave Data Selection
- Pre-analysis data processing
- Size of spectrogram
- Time-frequency analysis mode: real-time (e.g. task-based functional activation) or accumulating (e.g. epileptic activity)
- Time-frequency analysis algorithms
- Parameter checking
- Starting time-frequency analysis scan

Target data (Time windows)

The data selection specifies the trial, channels to be used for time-frequency analyses. The time window parameters specify active- and control-state time windows relative to named triggers or markers or the trial synchronization time point (typically zero). You may use the "Get…" button to get the selection for either active or control time window. You may also change or add the parameters by typing in the edit controls (fields) manually.

Time windows are defined relative to some event in the data — either the beginning of the trial (time zero) or a marker. Triggers (one group of Markers) are added automatically by the Data Acquisition application when the data is acquired. Typical markers are added by the adding Marker programs. They can also be added manually to mark an event of interest using the Selection Mark application.

If you are generating a single-state image, only active-state windows can be defined. If you are generating a dual-state image, both active- and dual-state windows can be defined.

To define a window:

1) Click the "Get Active" or "Get Control" button (Active States or Control States) to get the selection in the waveform viewer window.
2) You may click the "Select All…" to select all data points.
3) To use the control data, you must select "Compute Control" checkbox.
4) The Check Select will check the selection of the data.
5) The Match Act-Ctl (Active-Control) will match the size of the active and control selection so that they have the same length.

Target Frequency Range

The Frequency (Scale) Parameters panel provides options for specifying which frequency ranges to use when computing spectrogram. The "Min" (minimum) and "Max" (maximum) values in the "frequen" (frequency, Hz) group defines the frequency range. The "Bands" specifies the frequency resolution, which define the number of frequency bands or frequency-bins in the spectrogram.

Target Time Slices

The "Total Spect Bins" specifies the total spectral time bins (or slices) in the spectrogram. There are at least three types of spectrograms can be generated.

1) "CWT Real-Time" will generate a spectrogram that keeps all the temporal information by using a sliding window.
2) "CWT Accumulate" will generate a spectrogram that accumulates a long-time window into a short-time window for keeping the frequency information without tracking all the temporal information. This type of spectrogram requires a small amount of memory/hard disk to characterize a huge amount of data.
3) "CWT Wave Cross" will generate a spectrogram that keeps all the temporal information as well as frequency information by using two sigma values.

Dimension of Spectrograms

To generate a spectrogram for each sensor, the parameters in the CWT Settings will be used to compute spectrograms for all sensors. In other words, the region of time window for time-frequency analysis defines the dimensions of all sensors' spectrograms. In other words, the size of the spectrograms in the sensor array is the same and many operations/statistical analysis can be applied to the spectral data.

To define an appropriate size for spectrogram:

1) Ensure the "Bands" and "Spect Bins" are not too big or too small.
2) Although it is possible that the entire data can be used to compute spectrogram with a high frequency resolution, a large spectrogram may take a lot memory.
3) Low-frequency components will significantly increase computation time. If necessary, use "Re-sampling" technique to decrease the computation time (see "EEG Studio Main Frame Guide").
4) The meaning of the "spectrogram" depends on the time-frequency algorithms.

Single-state or Dual-state Spectrograms

The single-state option generates spectrograms based on the active state only (i.e., measurements taken when the brain is being stimulated). The dual-state option generates spectrograms that results from the subtraction of control-state data (measurements taken when no stimulation is applied) from active state data. To generate a dual-state image, you must select both active and control data for time-frequency analysis.

Storage of spectrogram

For spectral data based on one trail, the results are typically stored with that trial. For spectrograms based on multiple trials, the results, which are typically referred as "sum-spectrograms", are stored in a selected trial. It is necessary to define the targeted trial for storing the results before time-frequency analysis.

Running Time-Frequency Transform

Click the "Start" button will start to run the time-frequency transform. Once it is started, the window title bar will show the progress of the time-frequency transformation (see Figure 3).

The time-frequency transform calls several internal dynamically linked libraries to perform a variety of operations. Here are some steps:

1) Check and select the waveform data for time-frequency transform.
2) Perform filtering and removing DC-offset, if necessary.
3) Compute time-frequency coefficients and estimate the necessary memory
4) Transform waveform data for each channel and each trial
5) Compute spectral power or phase if necessary
6) Check the spectral data of the entire sensor array to compute a “global” or “group” spectrogram to describe the characteristic of all sensors
7) As usual, the resulting spectrograms are available to be viewed using Spectral Viewer.

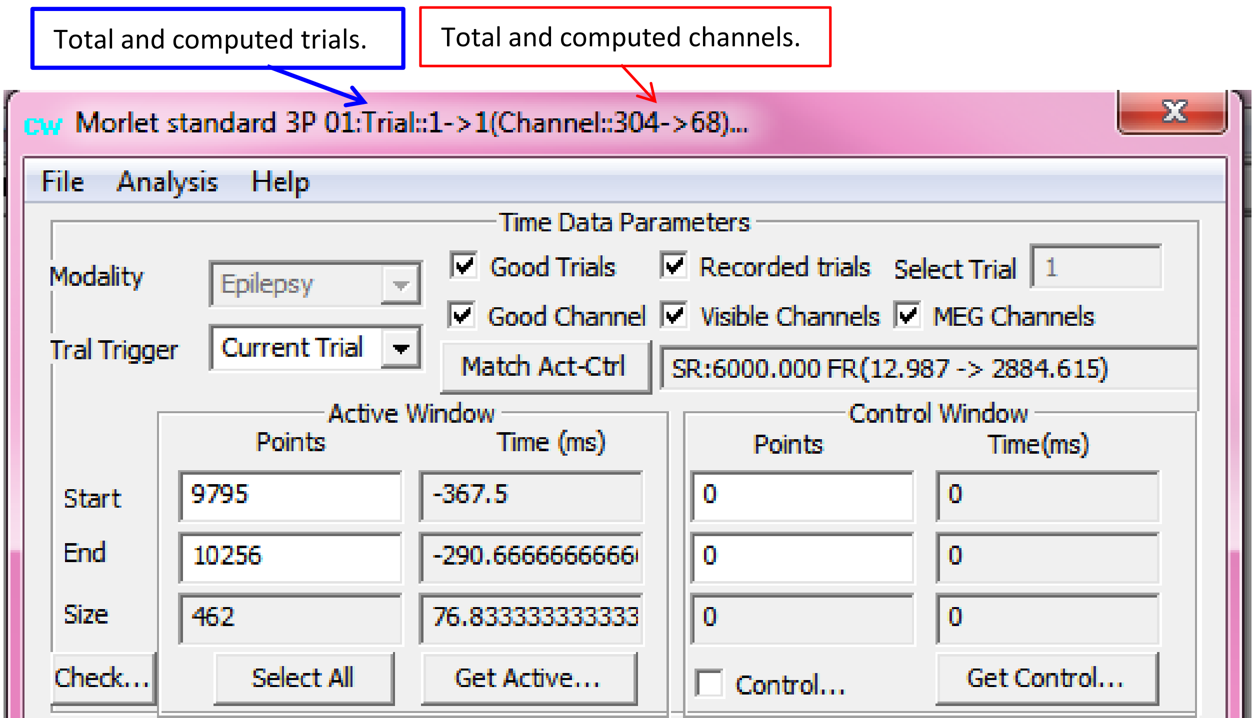

Figure 3. Indication of progress in time-frequency Analysis.

Gabor Transform

The “Gabor Transform” launches the main window for time-frequency transforming with wave form data and generates a spectral image, which may have multiple time slices. The Window GUI application allows you to configure parameters and processing options for time-frequency transforming as well as other kinds of analysis.

Time-frequency analysis is performed after a dataset has been acquired and reviewed. Here is the recommended procedure for a standard analysis using time-frequency analysis programs:

h) Check and verify that you have the correct dataset and trials in the Waveform Viewer (see the EEG Studio Main Frame Guide).
i) If data averaging is necessary or required, do the averring first. Once multiple trials have been averaged successfully, there is at least one averaged trial ("virtual trial") will be added to the MEG dataset, which is available in the main Frame for waveform viewer.
j) Filtering and/or removing DC-offset is typically required or necessary. If you do think so, apply the filtering/DC-offset to the targeted trial;
k) Check and analyze the EEG/MEG data to determine the interest of time-window. Though there is no standardized way, it is a good idea to use "Overlay" viewer to determine the interest of time-window with all "sensors".
l) If the time-frequency analysis main window (CWT Settings) has not been launched. Select the desired time-frequency analysis method in the Menu (see "Menu for Launching Time-Frequency Analysis Windows")
m) During the launching of the window for CWT Settings, the program gets the selected time-window as the Active Window and finds the frequency ranges. The program also checks the integrity and sanity of the data and may report warning/error messages.
n) Use the window for "CWT Settings" to inspect the dataset as well as suitable parameters. If required or necessary, change the data selections.

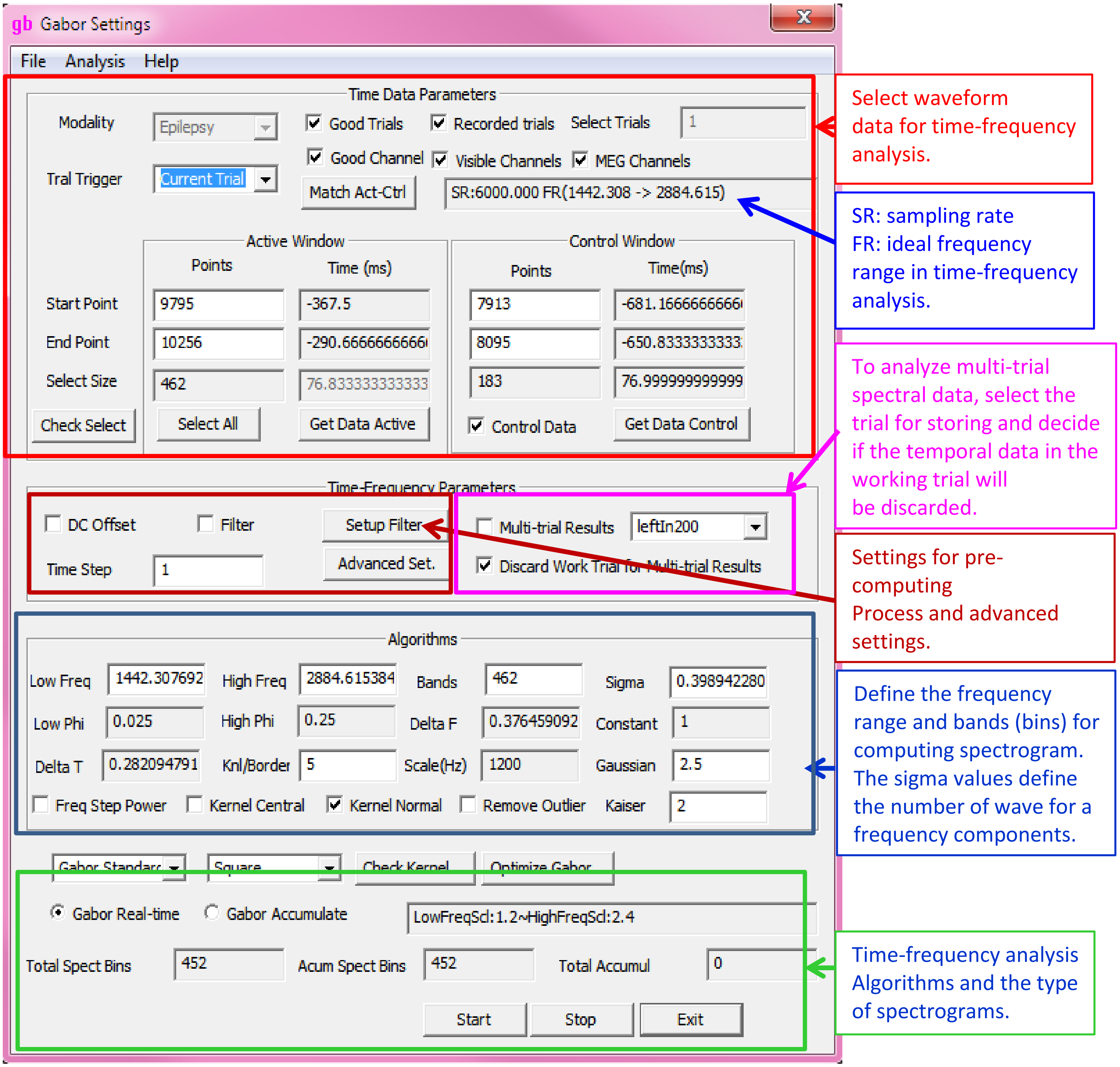

Figure 4. Gabor settings for time-frequency Analysis.

Main Module in Gabor Transform

The full suite of time-frequency transformation contains the following components.

- Wave Data Selection
- Pre-analysis data processing
- Size of spectrogram

- Time-frequency analysis mode: real-time (e.g. task-based functional activation) or accumulating (e.g. epileptic activity)
- Time-frequency analysis algorithms
- Parameter checking
- Starting time-frequency transforming

Target data (Time windows)

The data selection specifies the trial, channels to be used for time-frequency analysis. The time window parameters specify active- and control-state time windows relative to named triggers or markers or the trial synchronization time point (typically zero). You may use the “Get…” button to get the selection for either active or control time window. You may also change or add the parameters by typing in the edit controls (fields) manually.

Time windows are defined relative to some event in the data — either the beginning of the trial (time zero) or a marker. Triggers (one group of Markers) are added automatically by the Data Acquisition application when the data is acquired. Typical markers are added by the adding Marker programs. They can also be added manually to mark an event of interest using the Selection Mark application.

If you are generating a single-state image, only active-state windows can be defined. If you are generating a dual-state image, both active- and dual-state windows can be defined.

To define a window:

1) Click the “Get Active” or “Get Control” button (Active States or Control States) to get the selection in the waveform viewer window.
2) You may click the “Select All…” to select all data points.
3) To use the control data, you must select “Compute Control” checkbox.
4) The Check Select will check the selection of the data.
5) The Match Act-Ctl (Active – Control) will match the size of the active and control selection so that they have the same length.

Target Frequency Range

The Frequency Parameters panel provides options for specifying which frequency ranges to use when computing spectrogram. The “Low Freq” (Low Frequency) and “High Freq” (High Frequency) values defines the frequency range. The “Bands” specifies the frequency resolution, which define the number of frequency bands or frequency-bins in the spectrogram.

Target Time Slices

The “Total Spect Bins” specifies the total spectral time-bins (or slices) in the spectrogram. There are at least two types of spectrograms can be generated.

1) “Gabor Real-Time” will generate a spectrogram that keeps all the temporal information by using a sliding window.

2) "Gabor Accumulate" will generate a spectrogram that accumulates a long-time window into a short-time window for keeping the frequency information without tracking all the temporal information. This type of spectrogram requires a small amount of memory/hard disk to characterize a huge amount of data. Noteworthy, "Acum Spect Bins" is always smaller or equal to "Total Spect Bins".

Dimension of Spectrograms

To generate a spectrogram for each sensor, the parameters in the CWT Settings will be used to compute spectrograms for all sensors. In other words, the region of time window for time-frequency analysis defines the dimensions of all sensors' spectrograms. In other words, the size of the spectrograms in the sensor array is the same and many operations/statistical analysis can be applied to the spectral data.

To define an appropriate size for spectrogram:

1) Ensure the "Bands" and "Spect Bins" are not too big or too small.
2) Although it is possible that the entire data can be used to compute spectrogram with a high frequency resolution, a large spectrogram may take a lot memory.
3) Low-frequency components will significantly increase computation time. If necessary, use "Re-sampling" technique to decrease the computation time (see "EEG Studio Main Frame Guide").
4) The meaning of the "spectrogram" depends on the time-frequency algorithms.

Single-state or Dual-state Spectrograms

The single-state option generates spectrograms based on the active state only (i.e., measurements taken when the brain is being stimulated). The dual-state option generates spectrograms that results from the subtraction of control-state data (measurements taken when no stimulation is applied) from active state data. To generate a dual-state image, you must select both active and control data for time-frequency analysis.

Storage of spectrogram

For spectrogram based on one trial (or one epoch), the results are typically stored with that trial. For spectrograms based on multiple trials, the results, which are typically referred as "sum-spectrograms", are stored in a selected trial. It is necessary to define the targeted trial for storing the results before time-frequency analysis.

Running Time-Frequency Transform

Click the "Start" button will start to run the time-frequency transform. Once it is started, the window title bar will show the progress of the time-frequency transformation (see Figure 3).

The time-frequency transform calls several internal dynamically linked libraries to perform a variety of operations. Here are some steps:

1) Check and select the waveform data for time-frequency transform.

2) Perform filtering and removing DC-offset, if necessary.
3) Compute time-frequency coefficients and estimate the necessary memory
4) Transform waveform data for each channel and each trial
5) Compute spectral power or phase if necessary
6) Check the spectral data of the entire sensor array to compute a “global” or “group” spectrogram to describe the characteristic of all sensors
7) As usual, the resulting spectrograms are available to be viewed using Spectral Viewer.

Visualization of Spectral Data

Spectral data can be visualized in both 2D and 3D. In either 2D or 3D visualization, time-frequency representation of EEG/MEG data can be plotted as plate view and topographic (contour map) view. The plate view is designed for viewing a spectrogram for one sensor at once. The topographic view is designed for view a group of sensors with topographic information for a specified time- and frequency interval. Spectral data can also be displayed as parallel strips. Of note, there are many ways of graphically representing the data: 1) time-frequency plots of all channels, in a quasi-topographical layout is named “Spectral Contour map”, 2) time-frequency plot of an individual channel as “single channel viewer”, 3) topographical 2-D map of the time-frequency changes in a specified time-frequency interval according name orders. The visualization of the spectral data varies slightly among the versions of the software.

There are three ways of graphically representing the data: 2) time-frequency plot of an individual channel, 3) topographical 2D map of the power changes in a specified time-frequency interval.

Launching Spectral Viewers (Viewers for Time-Frequency Representations)

Since this program computes not only the conventional spectrogram, but also polarity spectrogram or the time-frequency representations of oscillatory signals or EEG/MEG data, the data visualization windows may be different from the conventional spectral viewers.

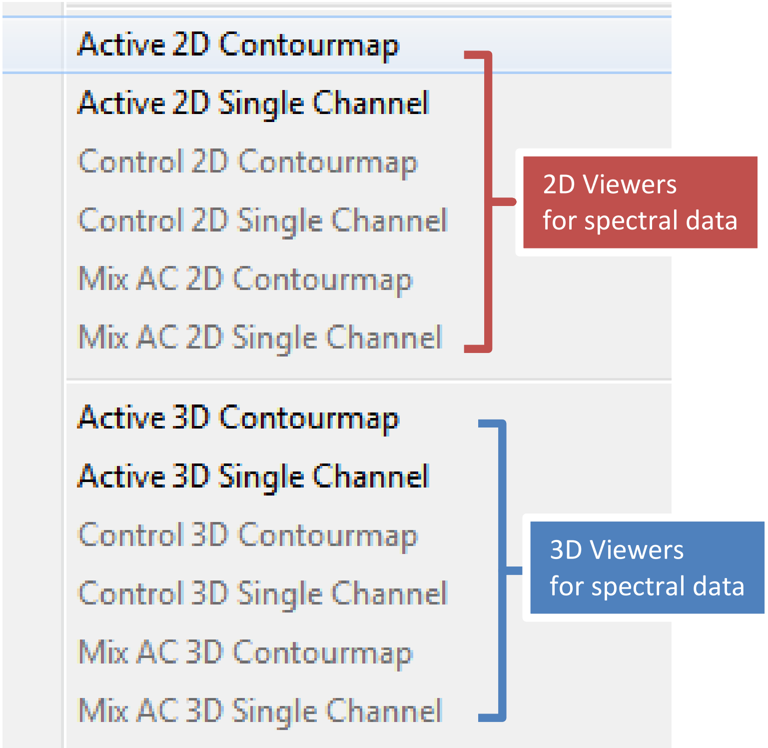

Figure 5. Launching Spectral Viewer from the Menu in the Main Frame.

Importantly, this program provides three classes of 2D viewers and three classes of 3D Viewers. Each class includes a "Contour Map Viewer" and a "Single Channel Viewer". For example, 2D viewers include: (1) Active 2D Contour map; (2) Active 2D Single Channel;(3) Control 2D Contour Map; (4) Control 2D Single Channel; (5) Mix AC 2D Contour Map; (6) Mix AC 2D Single Channel.
Please see the "Classification of Spectral Data" for detailed explanation about Active, Control and Mix AC data.

2D Time-Frequency Contour map (Topographic Time-Frequency Representations)

2D spectral contour maps (topographic spectrogram) are commonly used to analyze the spatial distribution of EEG/MEG data in a specified time-frequency ranges. In this program, one patch (or square block) shows the spectrogram from on sensor. One circle is typically used to represent the sensor location. This is kind of time-frequency plots of all channels, in a quasi-topographical layout in a specified time-frequency interval.

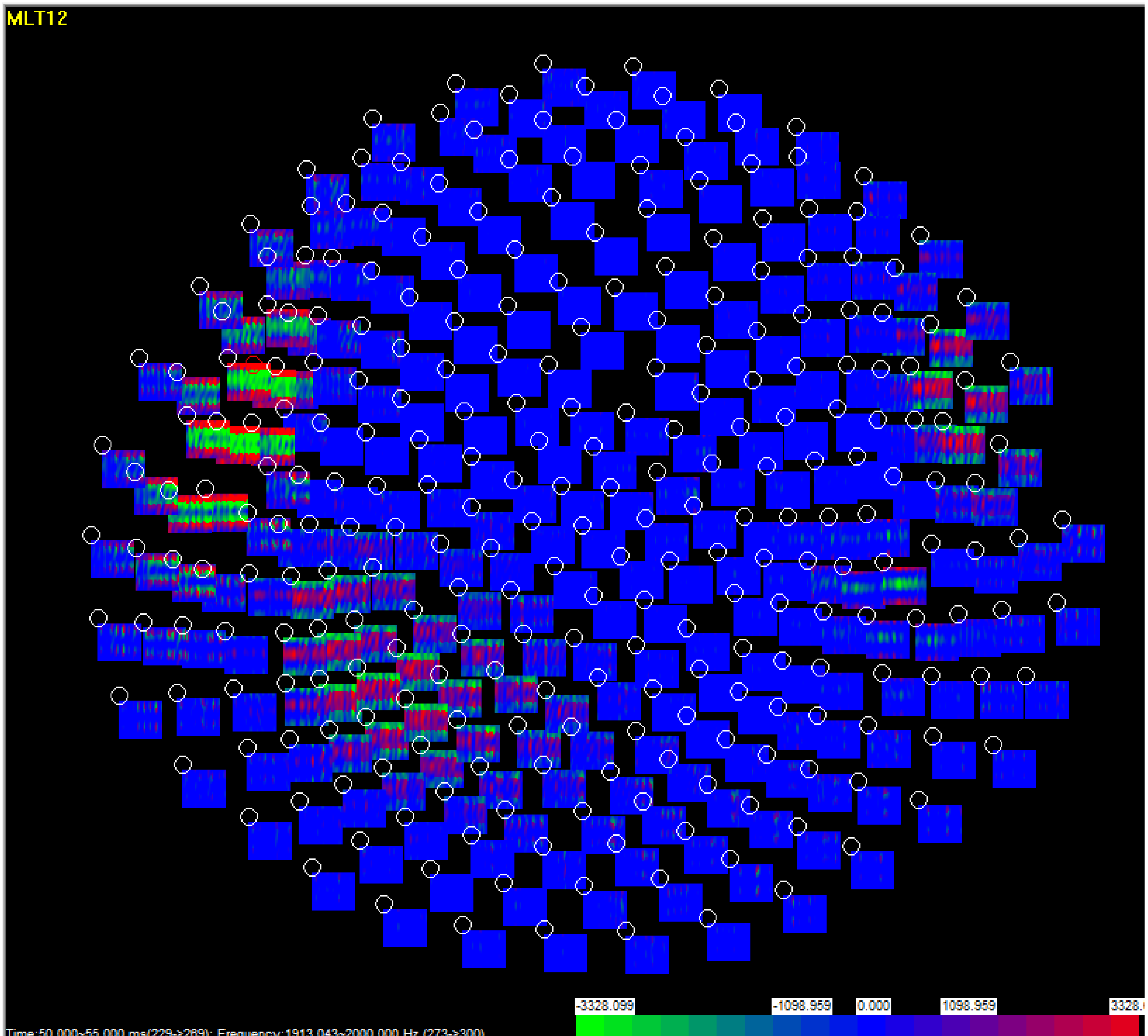

Figure 6. Visualization of time-frequency representation of MEG data with spectral contour map (topographic spectrogram). In this type of “spectral contour map”, each small circle represents a sensor. Each square patch (rectangle) represents a spectrogram from one sensor.

Display controls for 2D Contour Map

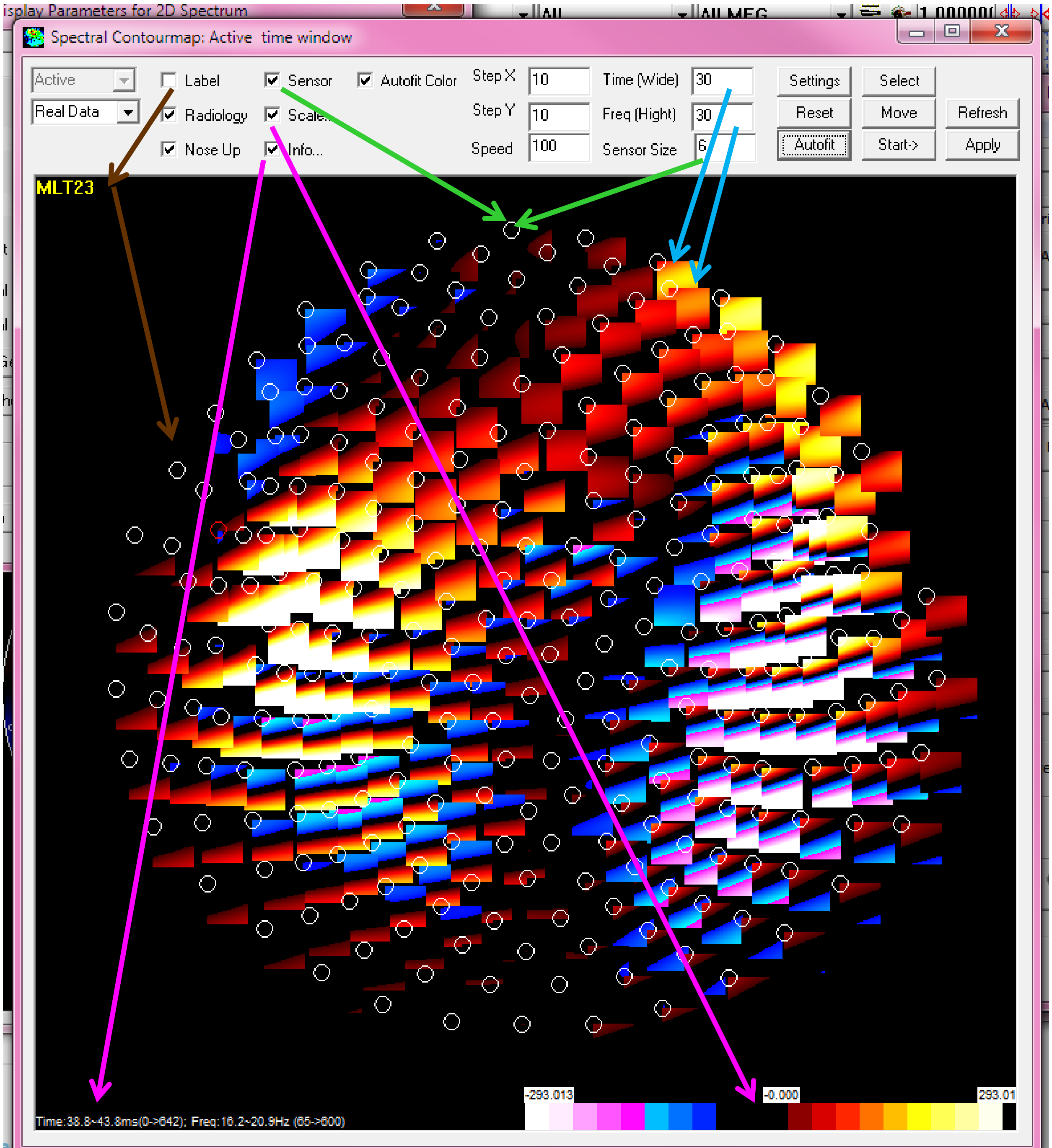

Figure 7. Controls for 2D contour map (topographic spectrogram).

The 2D Contour Map Viewer or Topographic Viewer provides a set of options and controls for appropriately displaying the spectral data in all sensors or a group of selected sensors. All the options and the controls are on the top of the window (or Dialog). The Dialog provides a lot of flexibility and power for you to control the display. The “Controls for Contour Map” shows the details about the display items and their controls.

Operations in 2D Contour Map

The 2D Single Channel Viewer provides a set of options and controls for appropriately displaying the spectral data. All the options and the controls are on the top of the window (or Dialog). The Dialog provides a lot of flexibility and power for you to control the display. The following figure shows the details about the display items and their controls.

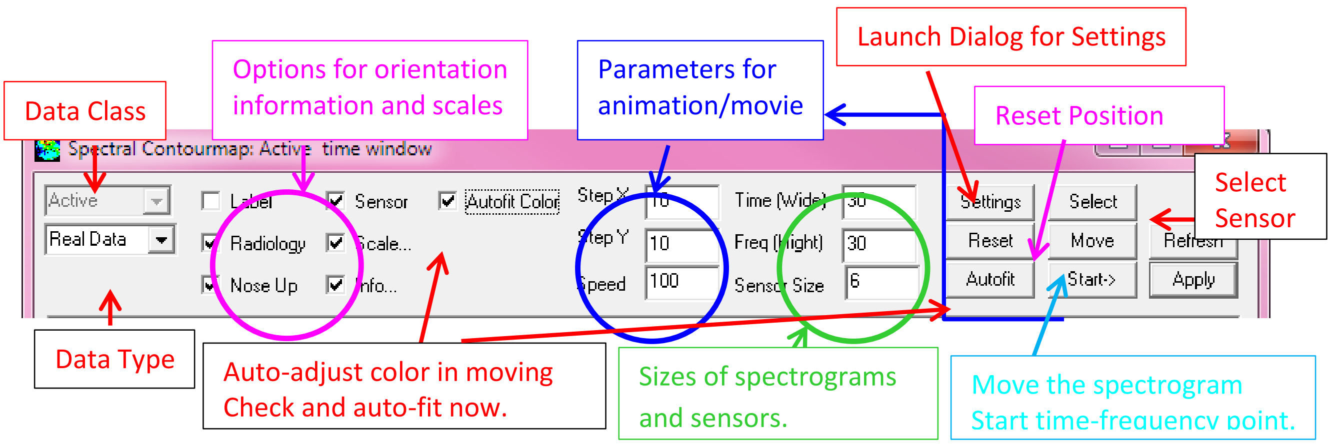

Figure 8. Controls and options in Spectral Viewer for one sensor or the summation of a group of sensors.

2D Time-Frequency Plate (Time-Frequency representation for one sensor)

2D spectrogram for single channel, which is typically showed as a plate, is commonly used to analyze the spectral values in a specified time-frequency ranges. In this program, one plate shows the spectrogram from on sensor.

It has to be emphasized that a spectrogram can be computed from a group of sensor. A summation (e.g. mean values, maximum values and minimum values of a group of sensor can be showed in the 2D Time-Frequency Plate by selecting it in the combo box.

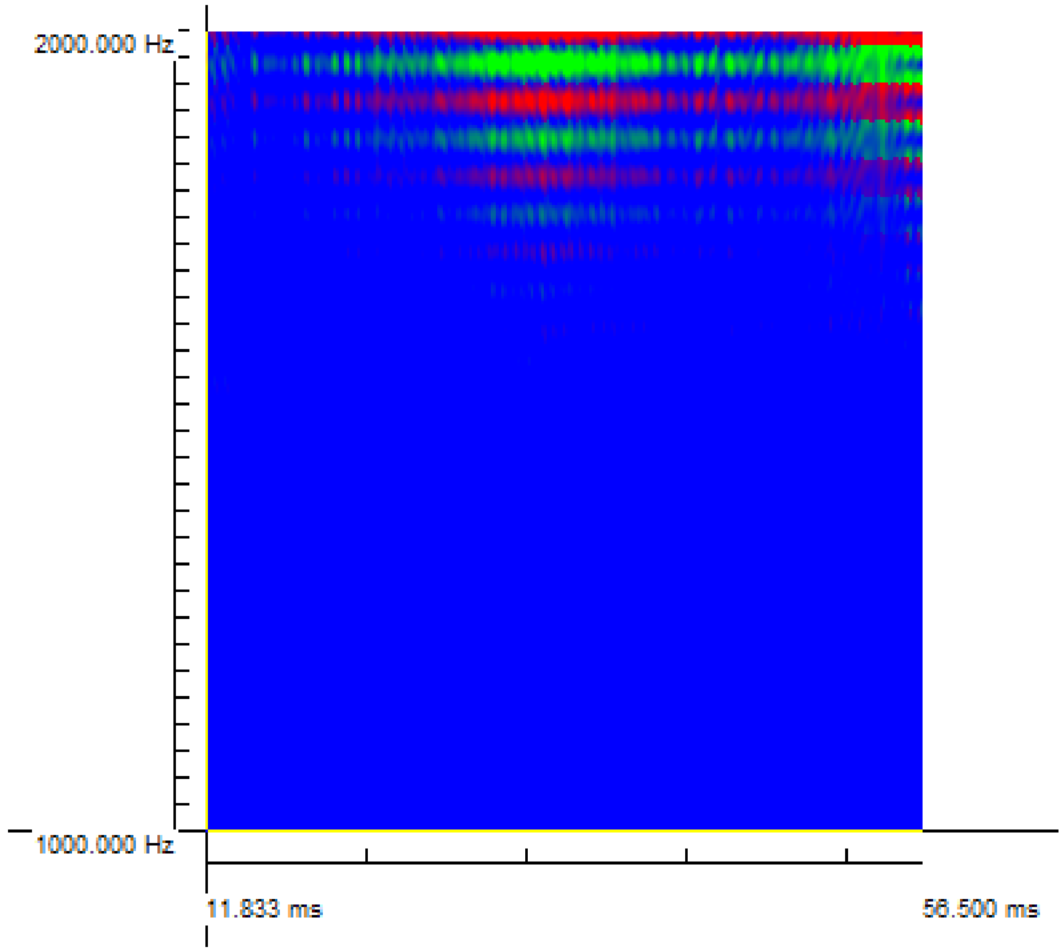

Figure 9. Visualization of the time-frequency representation for single sensor in 2D.

Display Controls for 2D Single Channel Viewer

The 2D Single Channel Viewer provides a set of options and controls for appropriately displaying the spectral data. All the options and the controls are on the top of the window (or Dialog). The Dialog provides a lot of flexibility and power for you to control the display. The following figure shows the details about the display items and their controls.

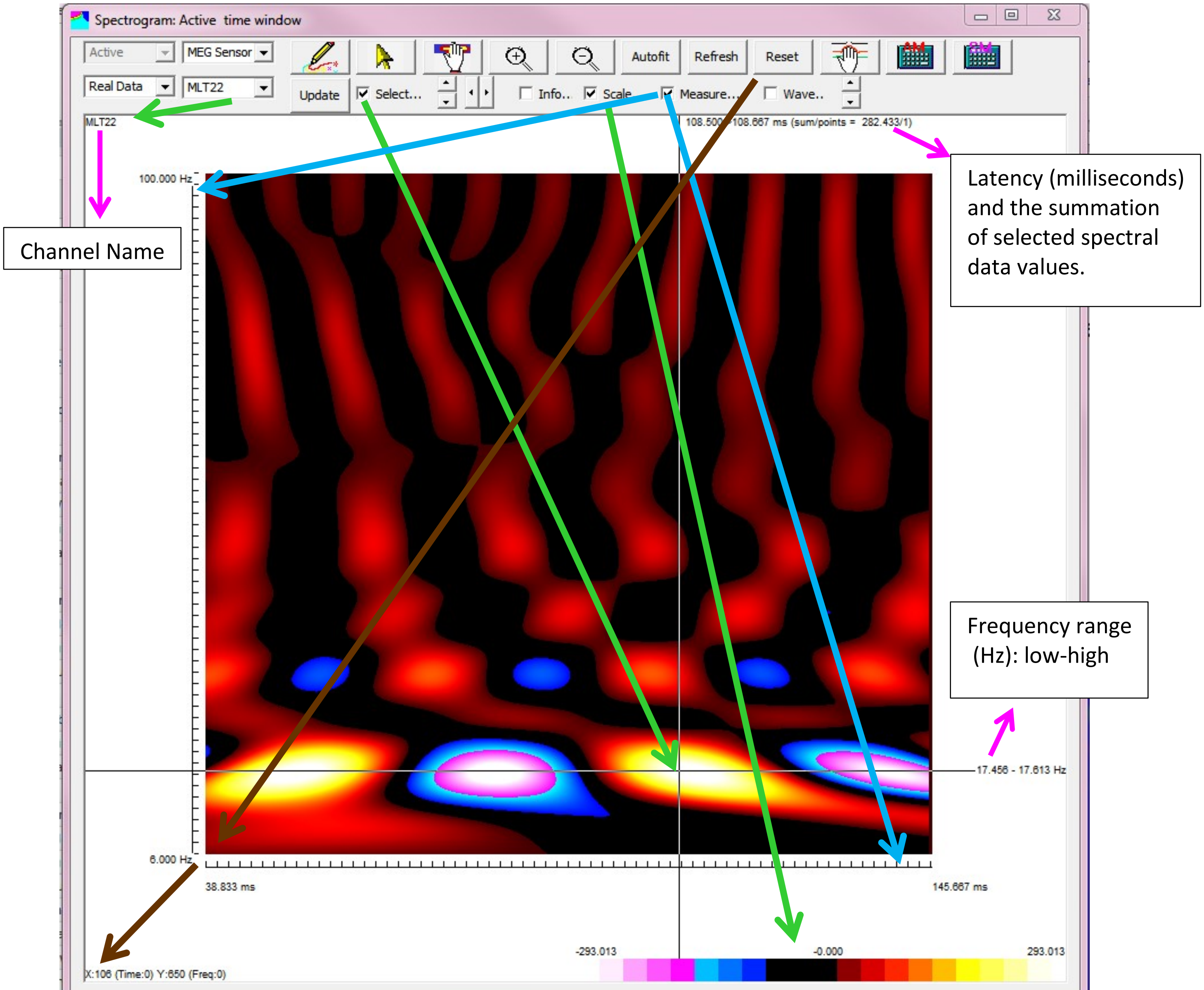

Figure 10. The options and controls of 2D Spectral Viewer for Single Channel or a summation of spectrograms from a group of sensors. If the summation of spectrograms is from all sensors within a MEG dewar or a EEG array, the summation is also called global spectrogram.

Operations in 2D Single Channel Viewer

The 2D Single Channel Viewer also provides a set of tools to operate and analyze the time-frequency representations of oscillatory data. To measure the latency, frequency and spectral values, please make sure that the "Select" and the "Measure…" check boxes are checked. The select lines will show the location of the measuring point or area.

If the spectrogram is computed with waveform data from one sensor, the waveform can also be displayed with the matched time-window by checking the "Wave…" check box. Of course, the waveforms can be moved up-down, left-right to give a best display for both spectrogram and waveforms.

The easiest way to find a suitable display is to click "Autofit" and "Reset" Buttons if the spectrogram appears unfavorable.

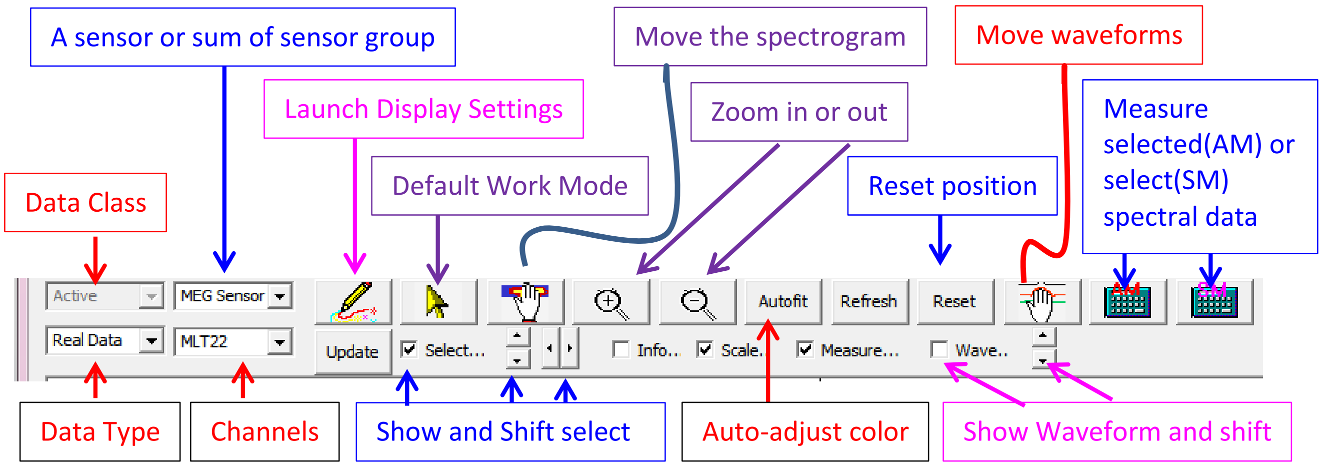

Figure 11. Controls and options in Spectral Viewer for one sensor or the summation of a group of sensors.

Global and group spectrogram in 2D Viewer

The 2D Single Channel Viewer can also be used to visualize and analyze the summation of spectrograms computed from a group of sensors. If the group sensors are the entire sensor array (or MEG dewar), the summation of the spectrograms is also called global spectrogram. The summation of group spectrograms can be described as a few sub-types:

1) Group Mean
2) Group Min (minimum, negative)
3) Group Max (maximum, positive)
4) Averaged Positive (magnetic goes out/in)
5) Averaged Negative (magnetic goes in/out)
6) Root-Mean-Square (RMS)

To view the summation type of spectrogram, select and specify it from the corresponding Combo box as following figure. Specifically, to view spectrogram from a specific sensor:

(1) select "MEG Sensor";
(2)select the sensor you like to analyze.

You may use the "Up" and "Down" Arrow keys to flip all spectrogram quickly.

It is important to point it out that spectral data type "Power/Phase) can be re-compute with real/imaginary data with a variety of settings as many times as you like.

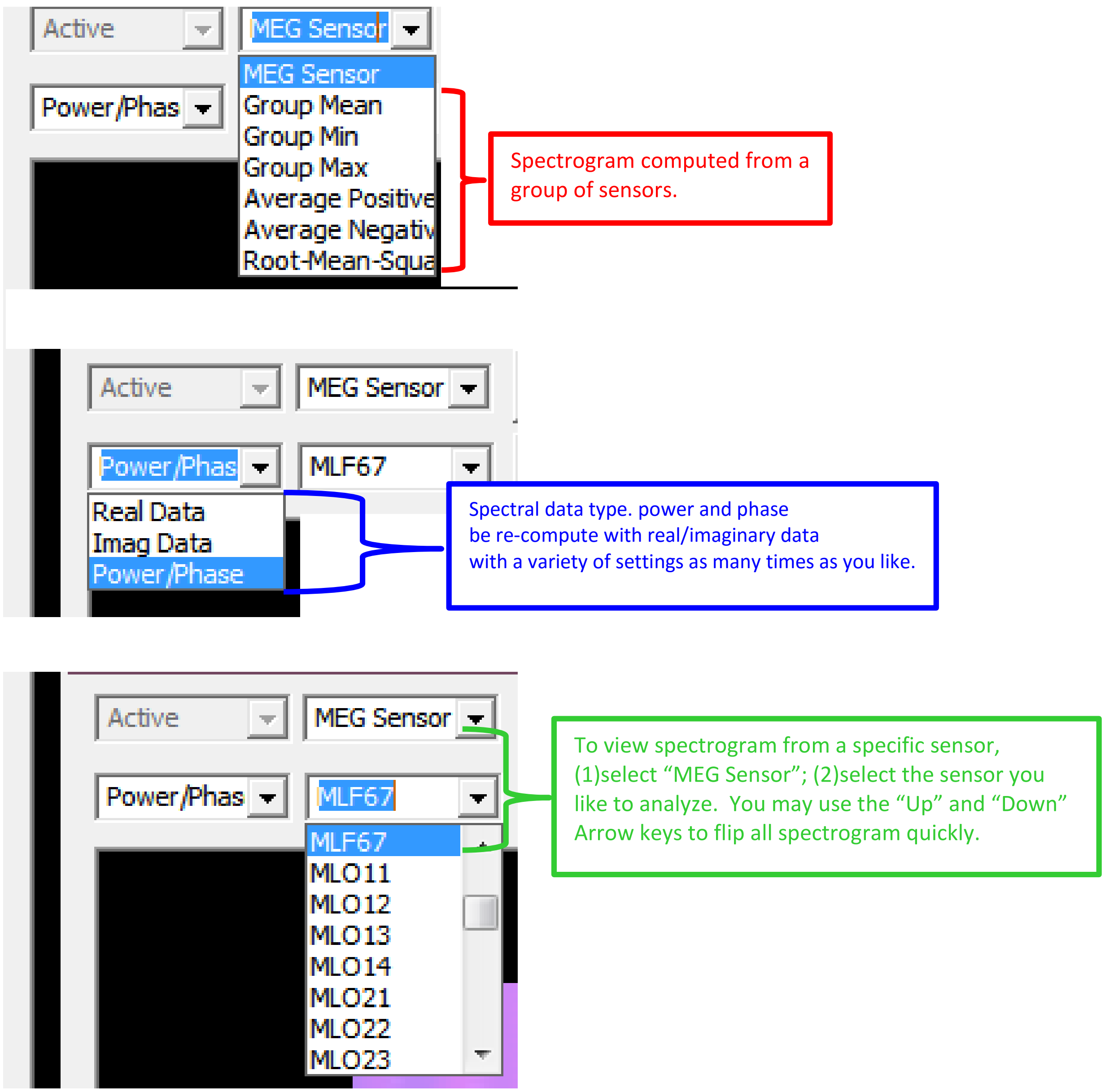

Figure 12. Controls and options in Spectral Viewer for one sensor or the summation of a group of sensors.

2D View Parameters for Displaying Spectral Data

The spectral values may vary among algorithms for time-frequency transforms. To appropriately display spectrum, the ranges of low and high limits of the spectral data are important. To enable users to easily and appropriately adjust the parameters, a window (dialog) has been designed to visually set or change the parameters.

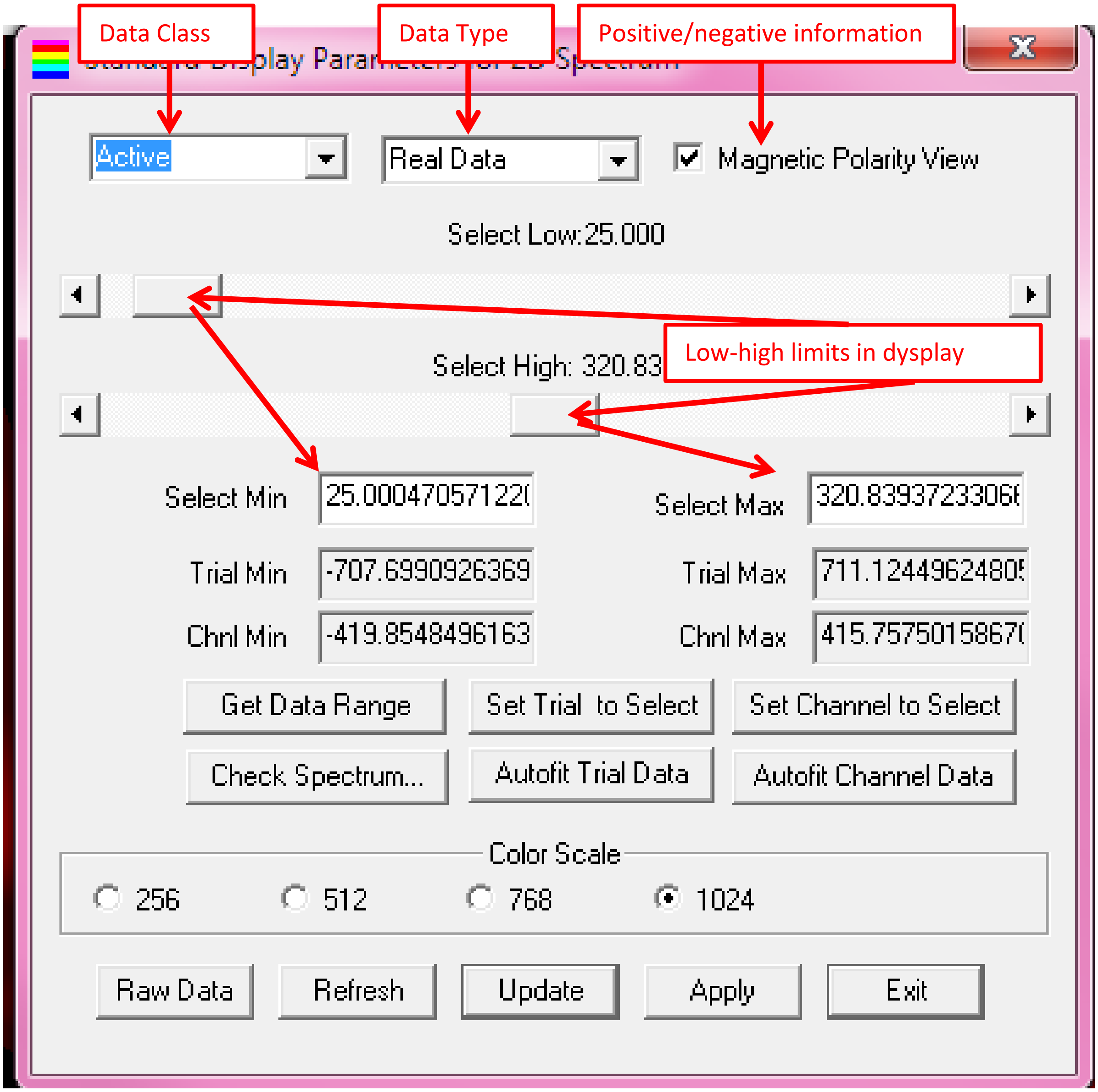

Figure 13. Standard Display Parameters for 2D Spectrogram.

In the Standard Display Parameters for 2D Spectrum, there are two combo boxes, which enable you to check and get the data range of a specified data class and type. Consequently, the data display can be precisely controlled and presented.

The low and high limits of the display values are absolute values. If there are negative values, the values will be judged in absolute values. If "Magnetic Polarity View" is checked, the magnetic/electric polarity information will be displayed by using two color coding systems, one for negative numbers and one for positive numbers.

1) Visible range of spectral values: The “Select Low” and “Select High” can be adjusted with the horizontal scroll bars. If you know the exact values (very common for experienced researchers/clinicians), you may directly input the values in the “Select Min” and “Select Max” edit fields. The selected values define and specify the data range for spectral display.
2) The range of spectral data in the current trial: The “Trial Min” and “Trial Max” show the range of spectral data in the current trial that is shown in the Spectral Contour Map and Topographic Viewer. You may click the “Get Data Range” to retrieve the data ranges. The range of spectral data in the current trail is very important for Spectral Contour map.
3) The range of spectral data in the current channel (sensor): The “Chnl Min” and “Chnl Max” show the range of spectral data in the current channel that is shown in the single channel viewer. You may click the “Get Data Range” to retrieve the data ranges. The range of spectral data in the current trail is very important for spectrogram for single channel.
4) Set Trial and Channel to Select: The “Set Trial to Select” and “Set Channel to Select” get the trial and channel data and transfer the ranges to the selected minimum (low) and maximum (high). The two functions enable you to view the full range of data in either Spectral Contour Map or Spectral Single Channel Viewer easily.
5) Check Spectrum function: the “Check Spectrum” function checks the integrity and sanity of the spectral data in the entire trails, e.g. the data range and the size and errors.
6) Automatically fit Trial Data and Channel data: the “Autofit Trial Data” and “Autofit Channel Data” compute or retrieve the data range and automatically define the range for appropriate showing according to the default settings. This function is based on experience with thousands of MEG datasets (http://clinicaltrials.gov/show/NCT00600717).
7) Color Scale and Color Coding: There are at least 4 groups of color scale (256, 512, 768 and 1024) for coding the spectrograms. Of note, the color scale will change the dysplay of the data, it does not change the data. Therefore, you are free to try all the color scales and find the best to meet your taste and requirements.
8) Raw data: If you did anything wrong that may change the data, you may click the “Raw data” to get the original data that are typically stored during time-frequency transforms.
9) Refresh: the “Refresh” button updates all viewers.
10) Other buttons are self-explainable.

3D Time-Frequency Contour Map

3D spectral contour maps (topographic spectrogram) are commonly used to analyze the spatial distribution of EEG/MEG data in a specified time-frequency ranges. In this program, the magnitude of spectrogram from a sensor is color coded and displayed on the sensor. A sensor can be showed as a torus, cube or ball. In this manual, we typically use a torus to represent a 3D sensor, which has the location as well as orientation. This is kind of time-frequency plots of all channels, in a quasi-topographical layout in a specified time-frequency interval.

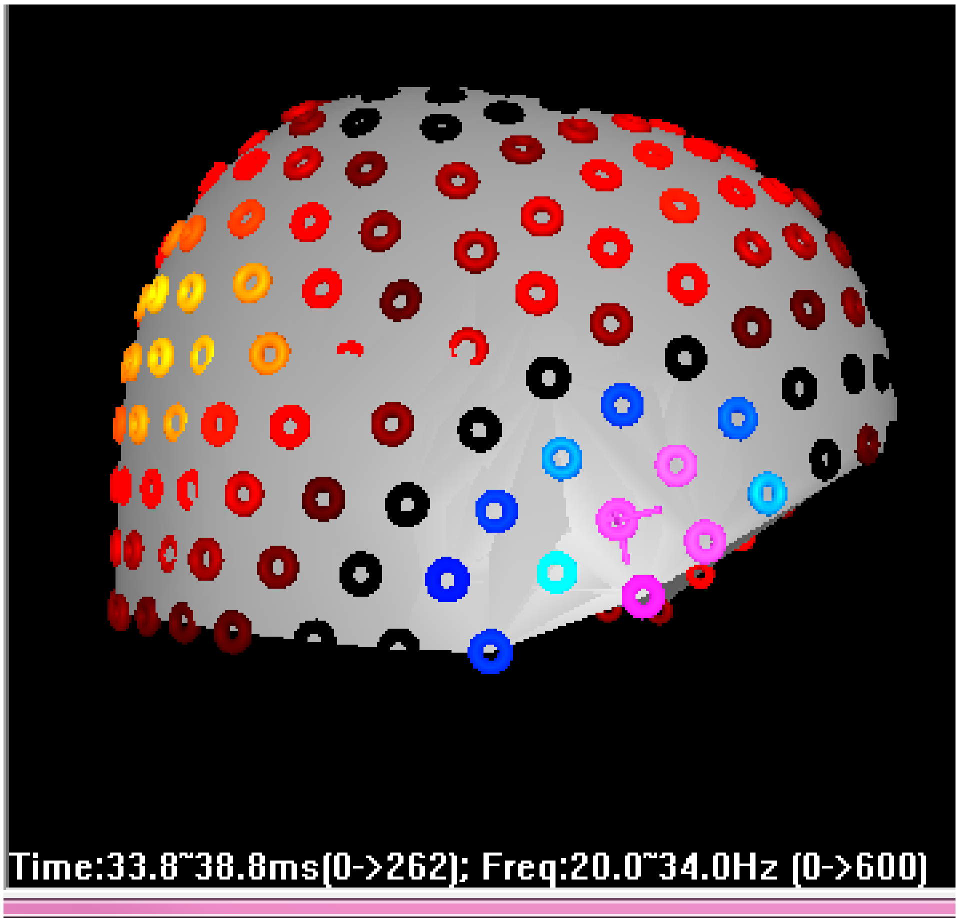

Figure 14. Visualization of time-frequency representation of MEG data with 3D spectral contour map (3D topographic spectrogram). In this type of "spectral contour map", each small torus represents a sensor. The magnitude of the spectrogram at a selected time-frequency range is color-coded in each sensor.

Display controls for 3D Contour Map

The 3D Contour Map Viewer or Topographic Viewer provides a set of options and controls for appropriately displaying the spectral data in all sensors or a group of selected sensors. All the options and the controls are on the top of the window (or Dialog). The Dialog provides a lot of flexibility and power for you to control the display. The "Controls for Contour Map" shows the details about the display items and their controls.

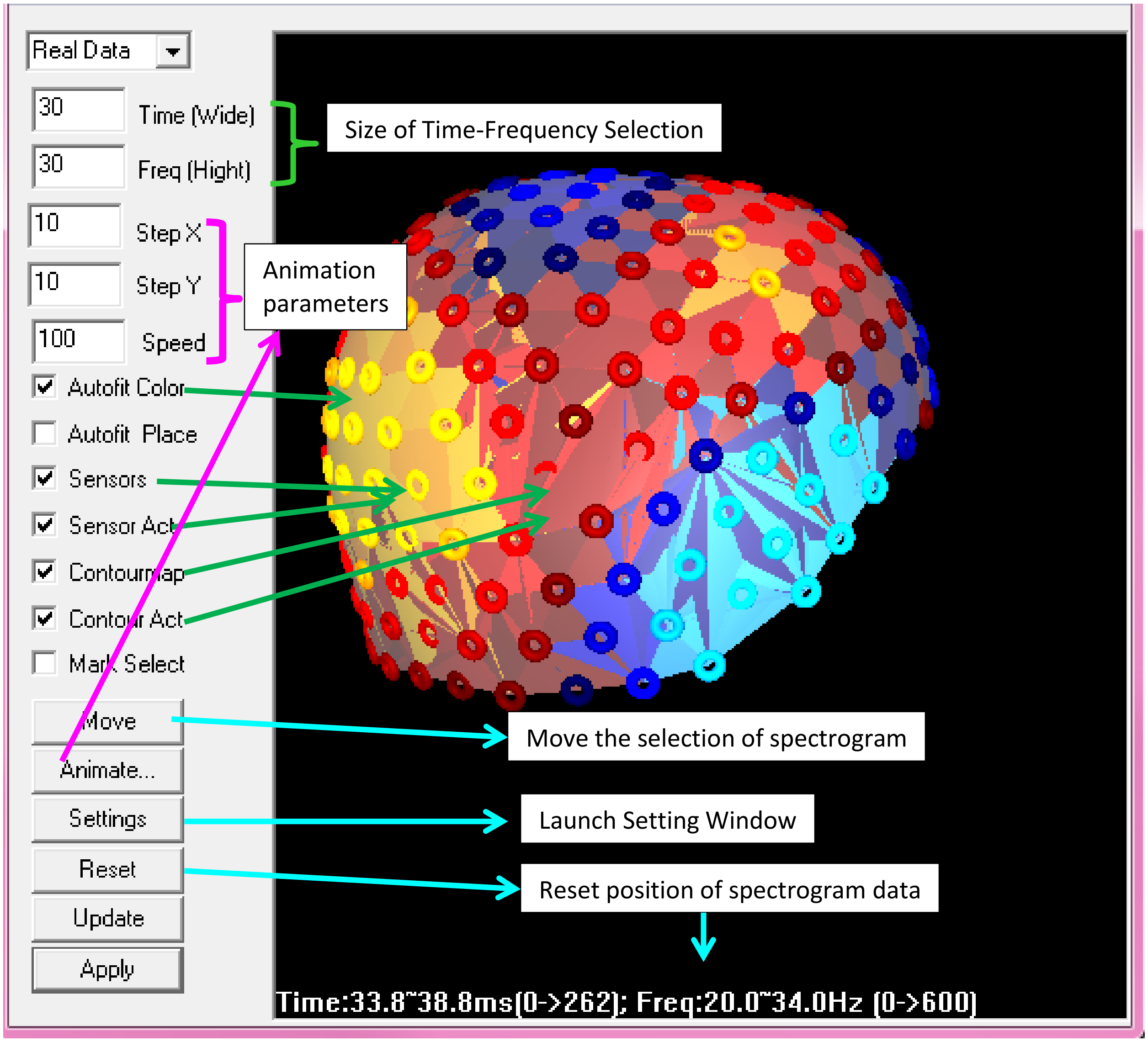

Figure 15. Controls for 3D contour map (topographic spectrogram).

Menu in 3D Contour Map

The Menu in 3D Single Channel Viewer provides a set of options and controls for appropriately displaying the spectral data. The options and the controls change the “working mode”, which is indicated by the cursor. Once the “working mode” is set, press-the left mouse button and move the mouse will change the display. In this manner, it provides a dynamic visual feedback and has a lot of flexibility for you to control the display. The following figure shows the details about the display items and their controls.

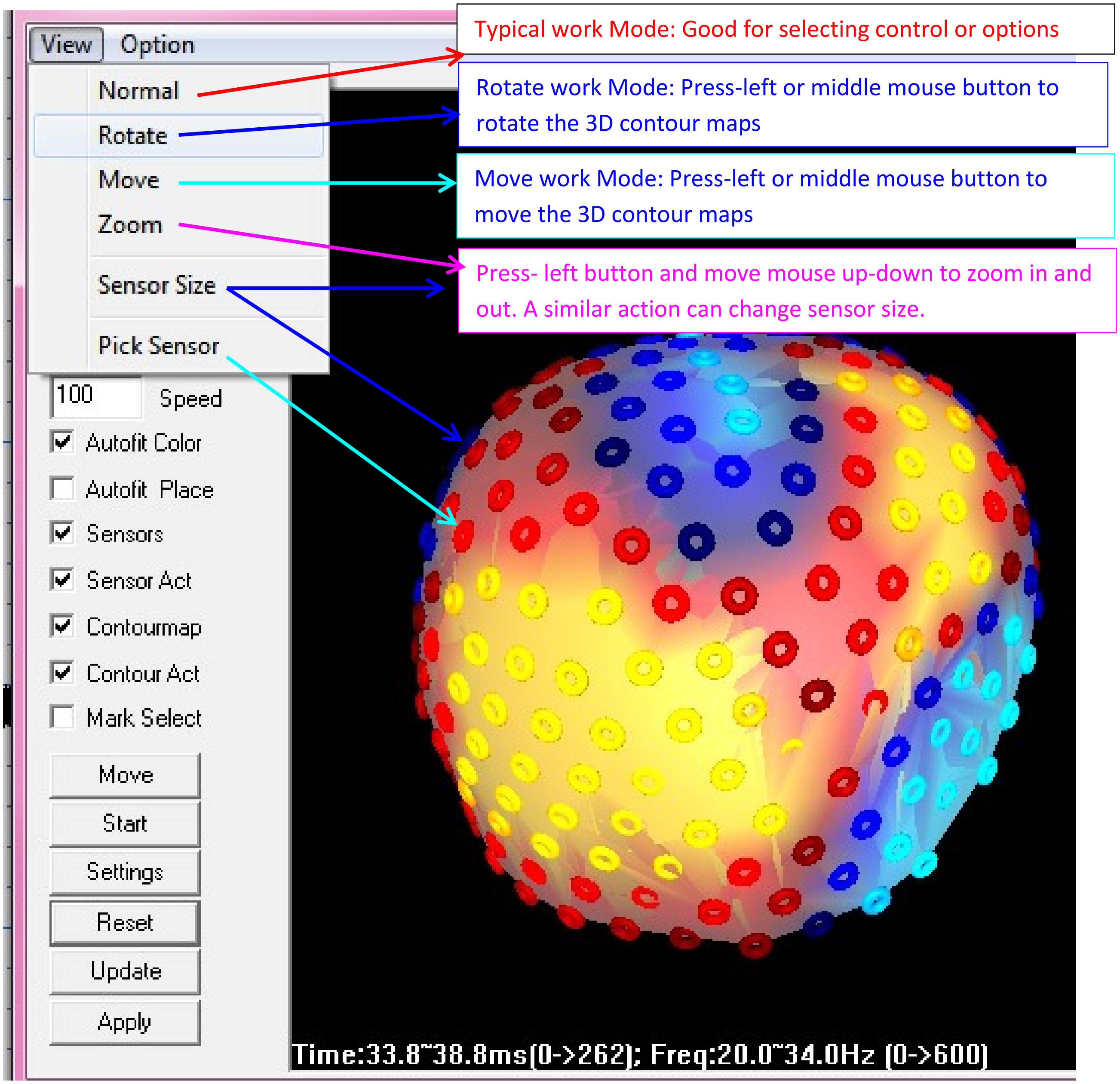

Figure 16. Menu for 3D contour map (topographic spectrogram).

3D Time-Frequency Plate (Time-Frequency representation for one sensor)

3D spectrogram for single channel, which is typically showed as a 3D plate with peaks and troughs, is commonly used to analyze the spectral values in a specified time-frequency ranges. In this program, one plate shows the spectrogram from on sensor.

It has to be emphasized that a spectrogram can be computed from a group of sensor. A summation (e.g. mean values, maximum values and minimum values of a group of sensor can be showed in the 2D Time-Frequency Plate by selecting it in the combo box.

Figure 17. Visualization of the time-frequency representation for one sensor in 3D.

Display Controls for 3D Single Channel Viewer

The 3D Single Channel Viewer provides a set of options and controls for appropriately displaying the spectral data. All the options and the controls are on the top of the window (or Dialog). The Dialog provides a lot of flexibility and power for you to control the display. The following figure shows the details about the display items and their controls.

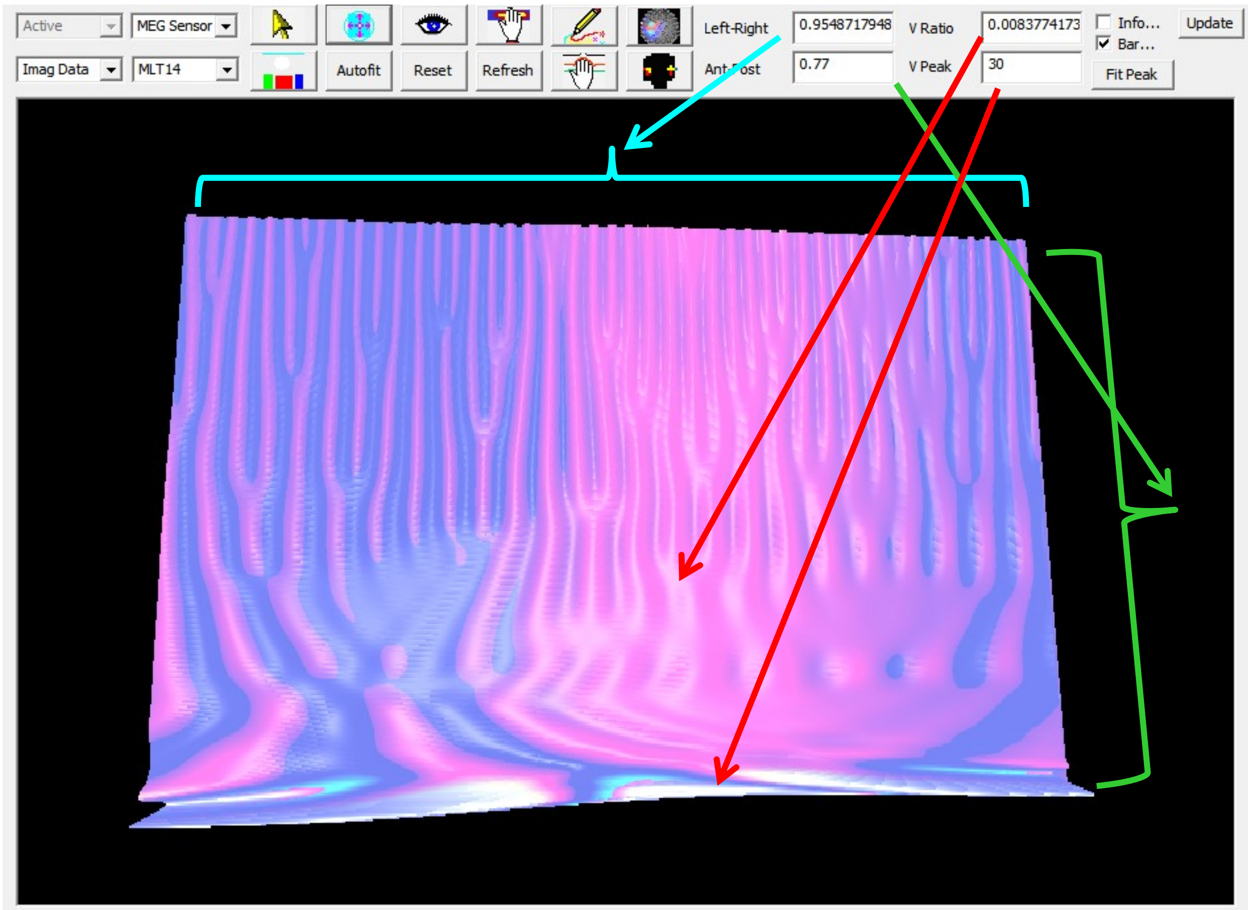

Figure 18. The options and controls of 3D Spectral Viewer for Single Channel or a summation of a group of sensors. If the summation of spectrograms is from all sensors within a MEG dewar or a EEG array, the summation is also called global spectrogram.

Operations in 3D Single Channel Viewer

The 3D Single Channel Viewer also provides a set of tools to operate and analyze the time-frequency representations of oscillatory data. To analyze the latency, frequency and spectral values, please make sure that the parameters are appropriate used.

If the range of the spectral data is very large, please try to use the “Rotate” and “Zoom” to adjust the position and depth for viewing.

The easiest way to find a suitable display is to click, “Reset”, “Autofit” and “Fit Peak” Buttons if the spectrogram appears unfavorable.

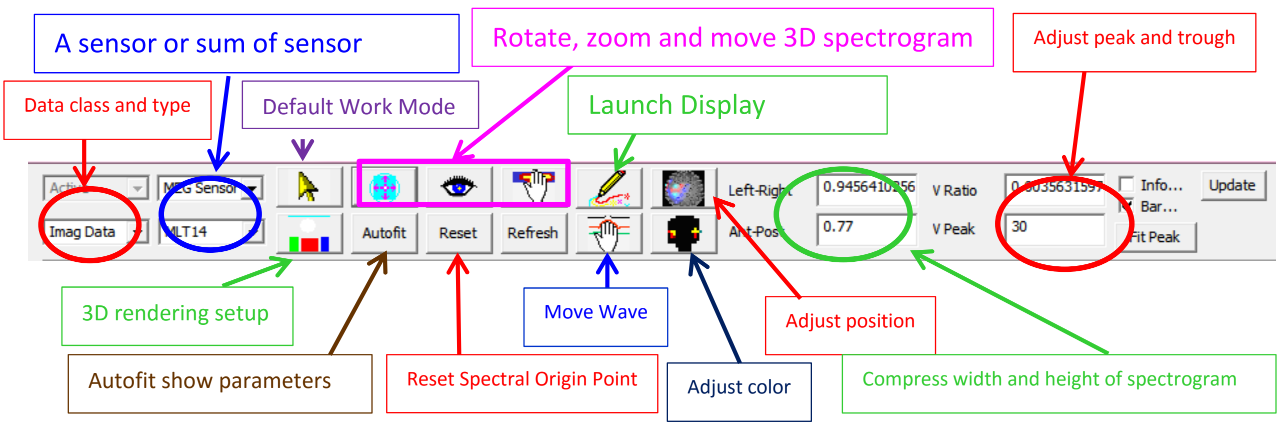

Figure 19. Controls and options in Spectral Viewer for one sensor or the summation of a group of sensors.

Global and group spectrogram in 3D Viewer

The 3D Single Channel Viewer can also be used to visualize and analyze the summation of spectrograms computed from a group of sensors. If the group sensors are the entire sensor array (or MEG dewar), the summation of the spectrograms is also called global spectrogram. The summation of group spectrograms can be described as a few sub-types:

1) Group Mean
2) Group Min (minimum, negative)
3) Group Max (maximum, positive)
4) Averaged Positive (magnetic goes out/in)
5) Averaged Negative (magnetic goes in/out)
6) Root-Mean-Square (RMS)

To view the summation type of spectrogram, select and specify it from the corresponding Combo box as following figure. Specifically, to view spectrogram from a specific sensor:

(1)select “MEG Sensor”;

(2)select the sensor you like to analyze.

You may use the “Up” and “Down” Arrow keys to flip all spectrogram quickly.

It is important to point it out that spectral data type “Power/Phase) can be re-compute with real/imaginary data with a variety of settings as many times as you like.

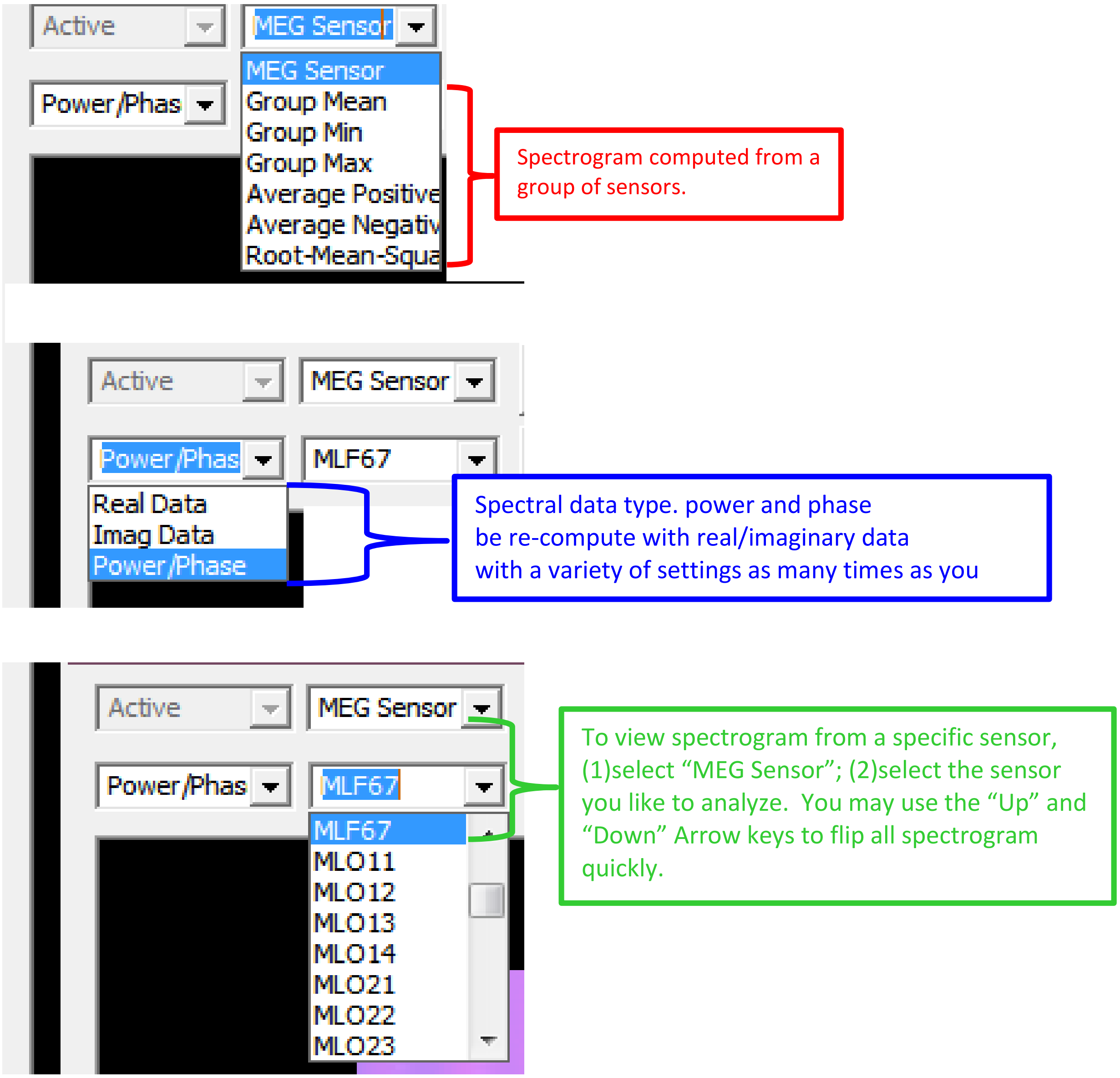

Figure 20. Controls and options in Spectral Viewer for one sensor or the summation of a group of sensors.

3D View Parameters for Displaying Spectral Data

The spectral values may vary among algorithms for time-frequency transforms. To appropriately display spectrum, the ranges of low and high limits of the spectral data are important. To enable users to easily and appropriately adjust the parameters, a window (dialog) has been designed to visually set or change the parameters.

In the Standard Display Parameters for 3D Spectrum, there are two combo boxes, which enable you to check and get the data range of a specified data class and type. Consequently, the data display can be precisely controlled and presented.

The low and high limits of the display values are absolute values. If there are negative values, the values will be judged in absolute values. If "Magnetic Polarity View" is checked, the magnetic/electric polarity information will be displayed by using two color coding systems, one for negative numbers and one for positive numbers.

1) Visible range of spectral values: The "Select Low" and "Select High" can be adjusted with the horizontal scroll bars. If you know the exact values (very common for experienced researchers/clinicians), you may directly input the values in the "Select Min" and "Select Max" edit fields. The selected values define and specify the data range for spectral display.
2) The range of spectral data in the current trial: The "Trial Min" and "Trial Max" show the range of spectral data in the current trial that is shown in the Spectral Contour Map and Topographic Viewer. You may click the "Get Data Range" to retrieve the data ranges. The range of spectral data in the current trail is very important for Spectral Contour map.
3) The range of spectral data in the current channel (sensor): The "Chnl Min" and "Chnl Max" show the range of spectral data in the current channel that is shown in the single channel viewer. You may click the "Get Data Range" to retrieve the data ranges. The range of spectral data in the current trail is very important for spectrogram for single channel.
4) Set Trial and Channel to Select: The "Set Trial to Select" and "Set Channel to Select" get the trial and channel data and transfer the ranges to the selected minimum (low) and maximum (high). The two functions enable you to view the full range of data in either Spectral Contour Map or Spectral Single Channel Viewer easily.
5) Check Spectrum function: the "Check Spectrum" function checks the integrity and sanity of the spectral data in the entire trails, e.g. the data range and the size and errors.
6) Automatically fit Trial Data and Channel data: the "Autofit Trial Data" and "Autofit Channel Data" compute or retrieve the data range and automatically define the range for appropriate showing according to the default settings. This function is based on experience with thousands of MEG datasets (http://clinicaltrials.gov/show/NCT00600717).
7) Color Scale and Color Coding: There are at least 4 groups of color scale (256, 512, 768 and 1024) for coding the spectrograms. Of note, the color scale will change the display of the

data, it does not change the data. Therefore, you are free to try all the color scales and find the best to meet your taste and requirements.

8) Raw data: If you did anything wrong that may change the data, you may click the "Raw data" to get the original data that are typically stored during time-frequency transforms.
9) Refresh: the "Refresh" button updates all viewers.
10) Other buttons are self-explainable.

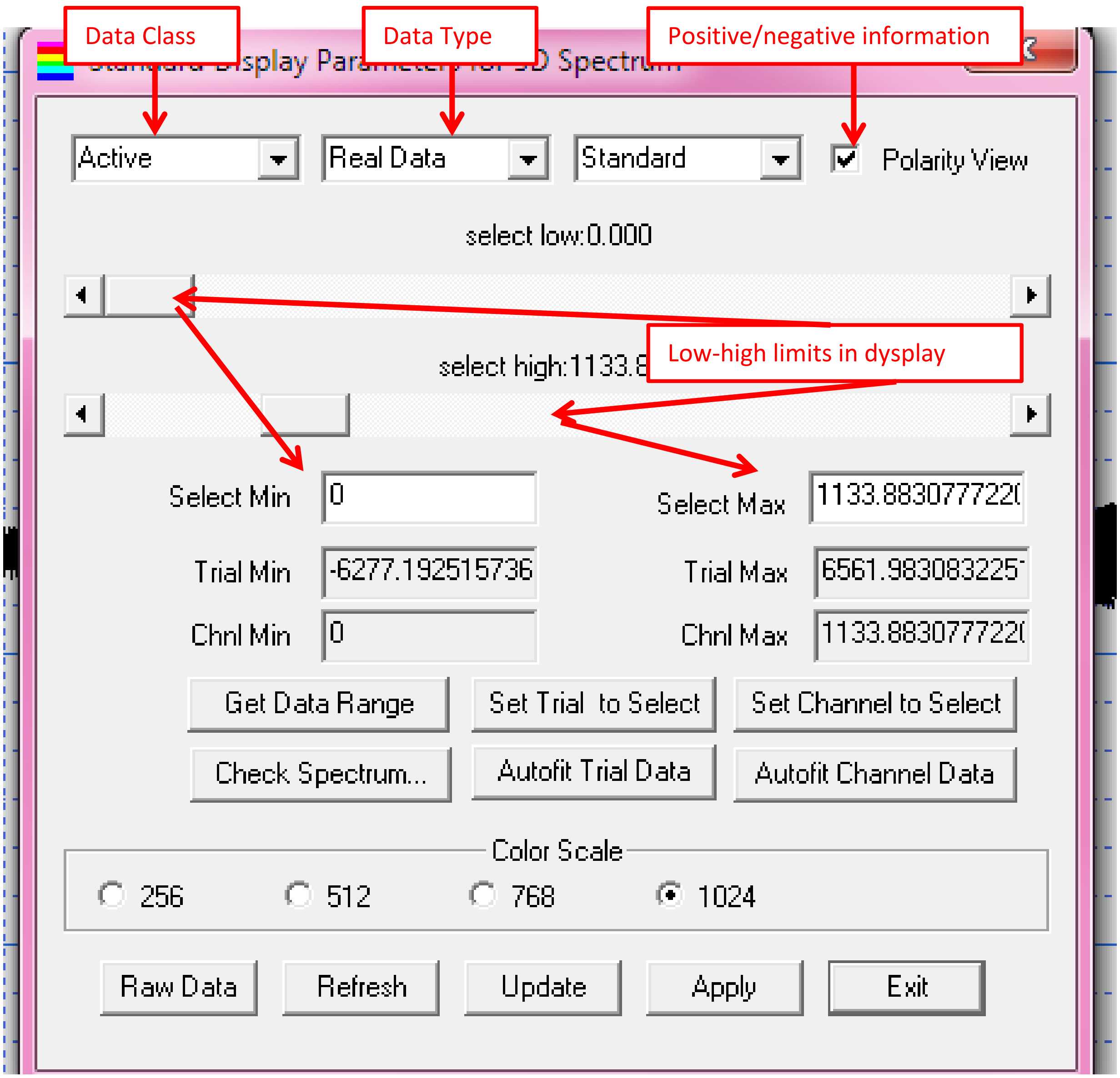

Figure 21. Standard Display Parameters for 3D Spectrogram.

3D Rendering for Spectral Data

This software has a powerful 3D rendering engine which supports both Direct3D and OpenGL. To appropriately display spectrum in 3D, several windows (dialogs) have been designed to enable you to adjust the 3D images.

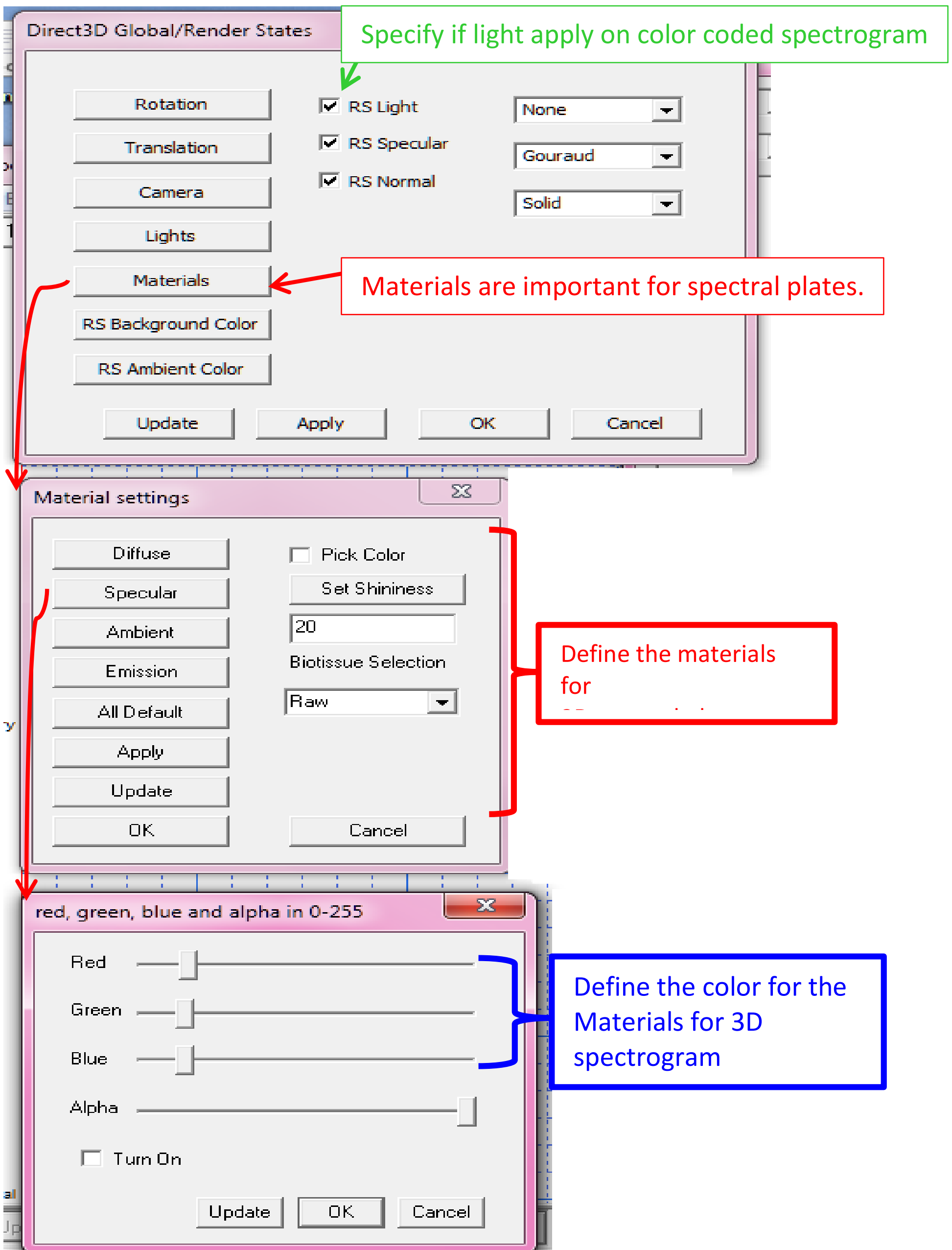

Figure 22. Settings for 3D Rendering of Spectrogram.

Normalization of Spectral Data

To better characterize EEG/MEG data, normalization of spectral data with respect to a baseline interval can be performed. There are several possibilities for normalizing: (a) subtracting, for each frequency, the average magnitude (or power) in a baseline interval from all other magnitude values. This gives, for each frequency, the absolute change in magnitude with respect to the baseline interval. (b) expressing, for each frequency, the raw power values as the relative increase or decrease with respect to the power in the baseline interval. This means active period/baseline. Note that the relative baseline is expressed as a ratio (i.e. no change is represented by 1).

Classification of Spectral data (Active, Control and Mixer of Active-Control)

To maximize the usability of spectral data and to provide the most flexible ways for users to explore the data, this program provides a data manager to deal with three classes of spectral data: Active state, Control State and Mixer of Active-Control. You can combine the various visualization options/functions interactively to explore your data and perform a set of post-transforming processes.

1) Active data typically represent the spectral data acquired during an active task
2) Control data typically represent the spectral data acquired during a resting state, which is not involved in responding to the task.
3) Mixer of Active-Control (or Mix AC or Results of Act-Ctl) represents the results of an operation applied to active and control data. We use those kinds of awkward names because there are no standardized names. We have to follow the rules in each journal, which may represent reviewers' consideration.

For example, (1) subtracting, for each frequency, the average power in a baseline interval from all other power values. This gives, for each frequency, the absolute change in power with respect to the baseline interval. (b) dividing, for each frequency, the raw power values as the relative increase or decrease with respect to the power in the baseline interval. This means active period/control period. Of note, the mixer of active-control may be the results of active data subtracted/divided by control data.

Spectral Class Operation

Spectral data can be classified to three: Active, Control and the combination of Active-Control. The combination of the active and control spectral data can be computed in a variety of ways. For example, (1) subtracting, for each frequency, the average power in a baseline interval from all other power values. This gives, for each frequency, the absolute change in power with respect to the baseline interval. (b) dividing, for each frequency, the raw power values as the relative increase or decrease with respect to the power in the baseline interval. This means active period/control period. Of note, the mixer of active-control may be the results of active data subtracted/divided by control data. To facilitate the spectral class operation, a dialog has been designed to provide GUI for such kind of operations.

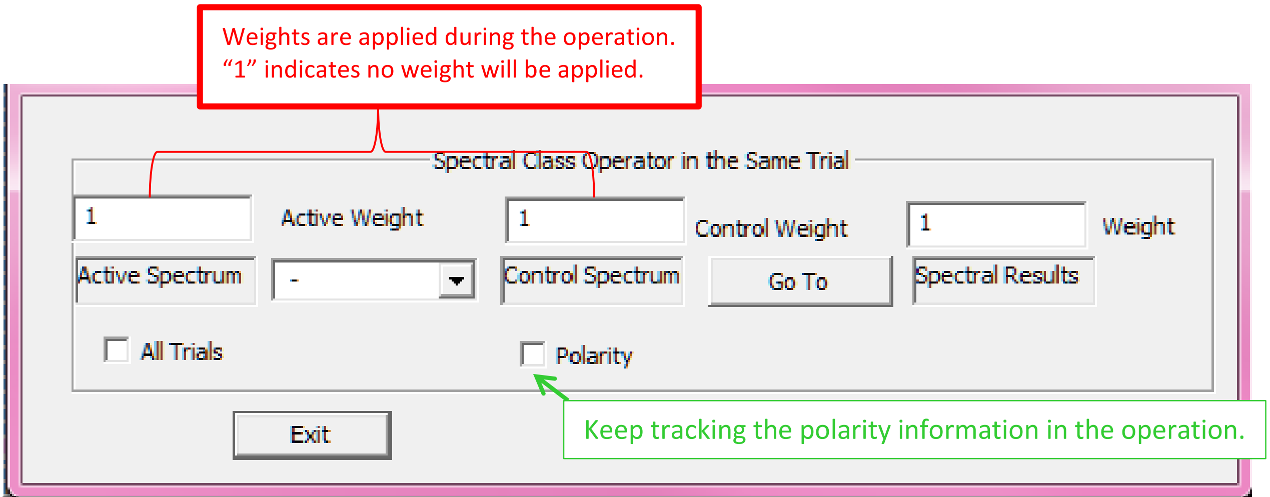

Figure 23. Spectral Class Operator in the Same Trial. The active spectrum is typically used to represent brain activation while the control spectrum is typically used to represent baseline or background activity. A submission of the two class will produce a resulting spectrum which gives, for each frequency, the absolute change with respect to the baseline interval.

Power/Phase Compute

Spectrogram typically represents the spectral power (magnitude of spectral data) of waveform data. However, in this manual, the “spectrogram” is simply used to as a “place holder” to represent the time-frequency representation of waveform data. The spectrogram may have spectral power, phase, real data, and imaginary data.

In this program, the spectral power or magnitude of spectral data may have polarity information. Those information may be used in source localization and determine the source orientation.

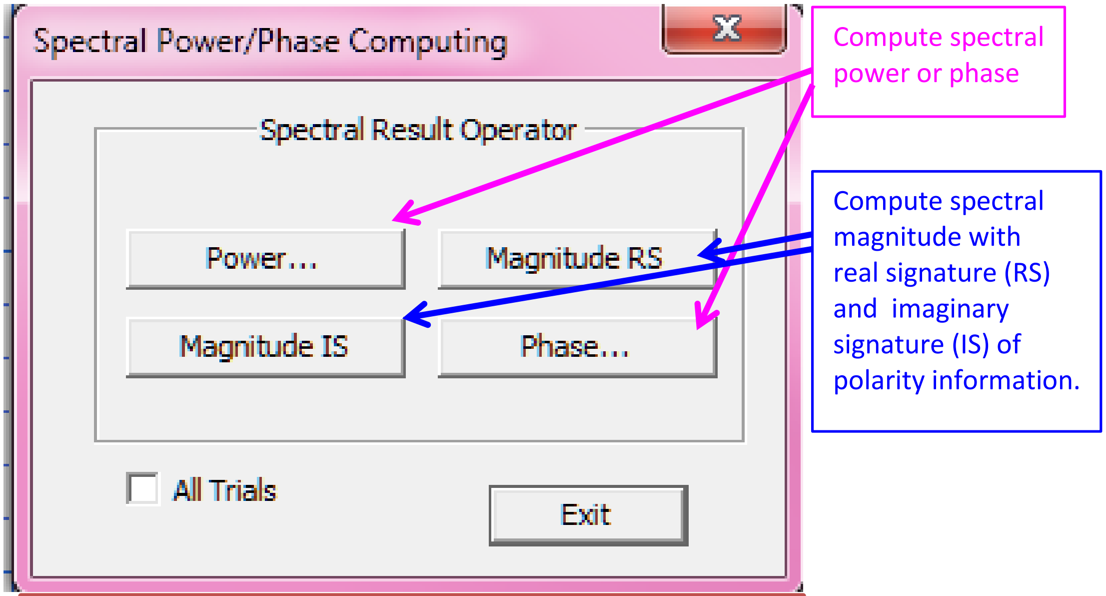

Figure 24. Settings for computing spectral power, phase, magnitude with polarity information.

Frequency Justify

Low-frequency neuromagnetic or neuroelectric signals are typically much stronger than that of the high-frequency signals. To detect high-frequency neuromagnetic or electric signals, this program designed a few functions to highlight the high-frequency signals. Frequency justification is designed to enhance high-frequency signals while minimize low-frequency signals. The main purpose is to magnify high-frequency signals so that those high-frequency signals would not be overshadowed by low-frequency signals.

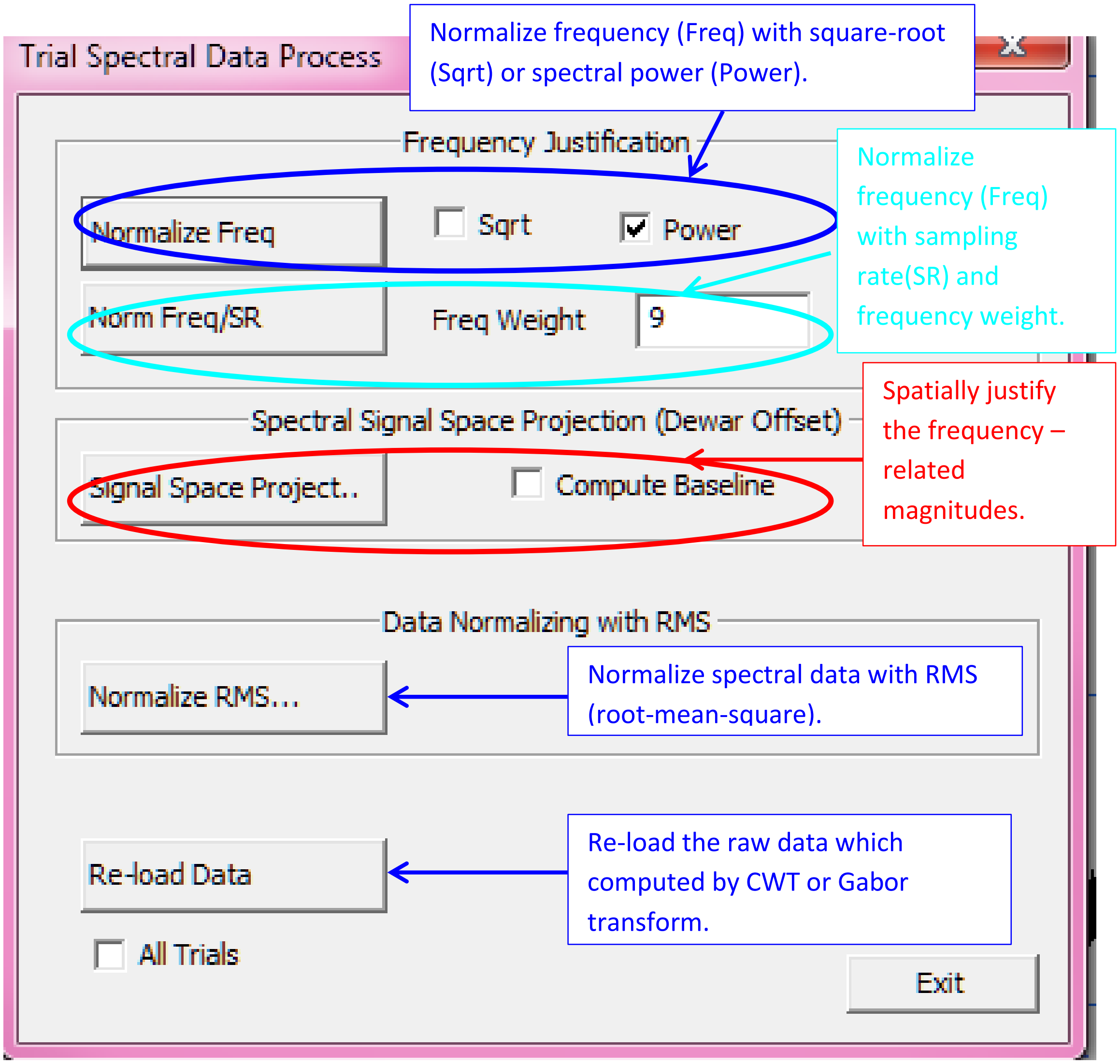

Figure 25. Trial spectral data processing.

Spectral Signal Space Projection

In comparison with simulated data, real EEG and MEG data contain additive correlated noise generated by environmental and “background physiological sources”. Those noises may be spatially outside of the brain or spatially different from the “sources” we are interested in. To suppress this type of spatially coded noise, source estimation is often performed with spatial whitening based on a measured or estimated noise covariance matrix. However, artifacts that span relatively small noise subspaces, such as cardiac, ocular, and muscle artifacts, are often explicitly removed by a variety of denoising methods (e.g., signal space projection) before source imaging. In this program, we developed a few new approaches, one of them is the spectral signal space projection algorithm, in which time-frequency (TF)-specific spatial projectors are designed and applied to the noisy TF-transformed data, and whitened source estimation is performed in the TF domain. According to our MEG data, the majority of strong environmental noise is in low frequency. System noise can either very low (DC-shift) and very high. The method provided in the program can be used to derive spectral variants of all linear time domain whitened source estimation algorithms. The denoised sensor and source time series can be obtained by the corresponding inverse TF-transform.

Spectral Data Edit

Analysis of spectral data that arise as signals often requires a standardization step so that information extracted from biologically equivalent signals can be quantified for comparison across classes. Differences in high-frequency noise and/or local background can arise from variabilities due to instrumentation or conditions during data collection. This program have designed some common ways in which such variation can be adjusted or edited for and introduces a generalization of the popular "standard normal variate" transformation. Based on a wavelet and Gabor decomposition this generalization provides increased flexibility for normalizing spectral data affected by local background noise. For example, if you know that “60 Hz” or “50 Hz” are power-line noise, you may simply cut them off with the spectral data edit function.

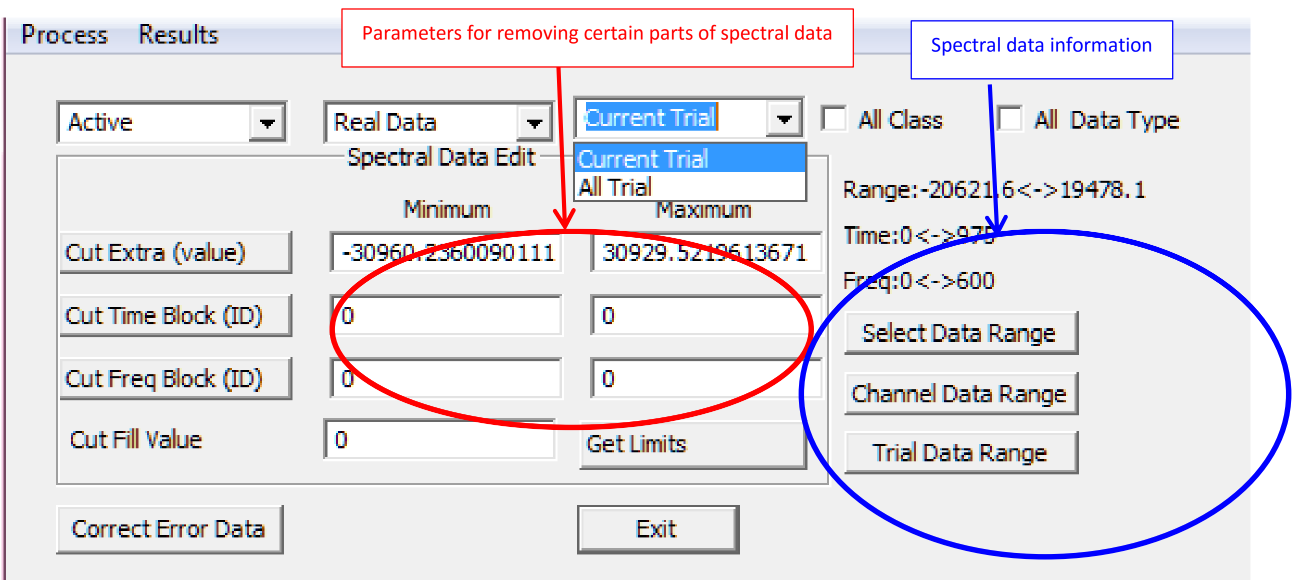

Figure.26. Spectral data edit and analysis.

Spectral Filter Basic

The spectral filter basic is designed for experienced users only because time-frequency analysis is assumed that the data have already been appropriately filtered. Consequently, this function can be easily misused.

Spectral Filter Standard

The spectral filter standard is designed for experienced users only because time-frequency analysis is assumed that the data have already been appropriately filtered. Consequently, this function can be easily misused.

Compute Trial (or Group) Spectrum

This function is designed for computing the summation of all sensors in a trial or a group of sensors in the trial. It is important to point it out that, this function is assuming that the spectral data for the sensors that you plan to analyze have been computed appropriate. Otherwise, please go to "Continuous Wavelet Transform (CWT)" and "Gabor Transform" sections to see how the spectrogram can be computed.

The summation of group spectrograms can be described as a few sub-types:

1) Group Mean
2) Group Min (minimum, negative)
3) Group Max (maximum, positive)
4) Averaged Positive (magnetic goes out/in)
5) Averaged Negative (magnetic goes in/out)
6) Root-Mean-Square (RMS)

The definition of sensor group can be done with the "Channel Selection" window (dialog). If you like to compute a summation of a small group of sensors, you may turn all other sensors to "Non-visible" or bad by using one of the following ways:

1) Click the channel in Waveform Viewer in the Main Frame (Column View Mode), then press the right mouse button to show Pop-up Menu, and select "Hide Channel" or "Good Channel".
2) Launch the Waveform Channel Selection window (see Main Frame Guide for details), select the channels in the "Included Channels" list, and then click "<-" arrow to move the channel you do not like to use to "Excluded Channels" list.
3) In the Main Frame (see Main Frame Guide for details), select a group of channels in the channel group combo box (by default, it is "All MEG"). The build-in groups are:
    - All MEG
    - Left
    - Right
    - Midline
    - Frontal
    - Central
    - Parietal
    - Occipital
    - Temporal

Once the channel group has been defined, make sure to check the option for the Channel Selection for computing for trial spectral data.

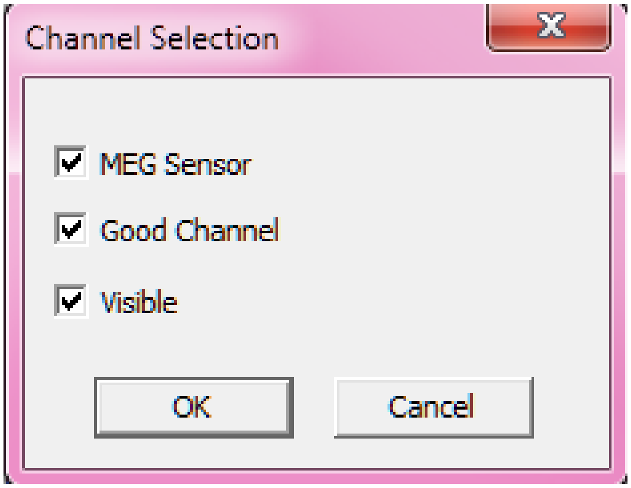

Figure 27. Channel Selection for computing the summation of sensors in a trial. If all unchecked, all sensors with spectral data will be used to compute the spectral summation.

Check Trial (or Group) Spectrum

This function is designed to check the integrity and sanity of spectral data in all channels. It will return how many channels have spectral data. In addition, it will find the ranges of spectral data (minimum, maximum and the mean of the spectral data).

Multi-Trial Spectral Processing

EEG/MEG data are typically acquired in multiple trials for functional study. Multiple Trial spectral data can be further processed by Multi-Trail Spectral Processing function. One of the major applications of multi-trial spectral processing is to accumulate spectral data from multiple trials to one trial. The results may reveal the time-frequency locked signals.

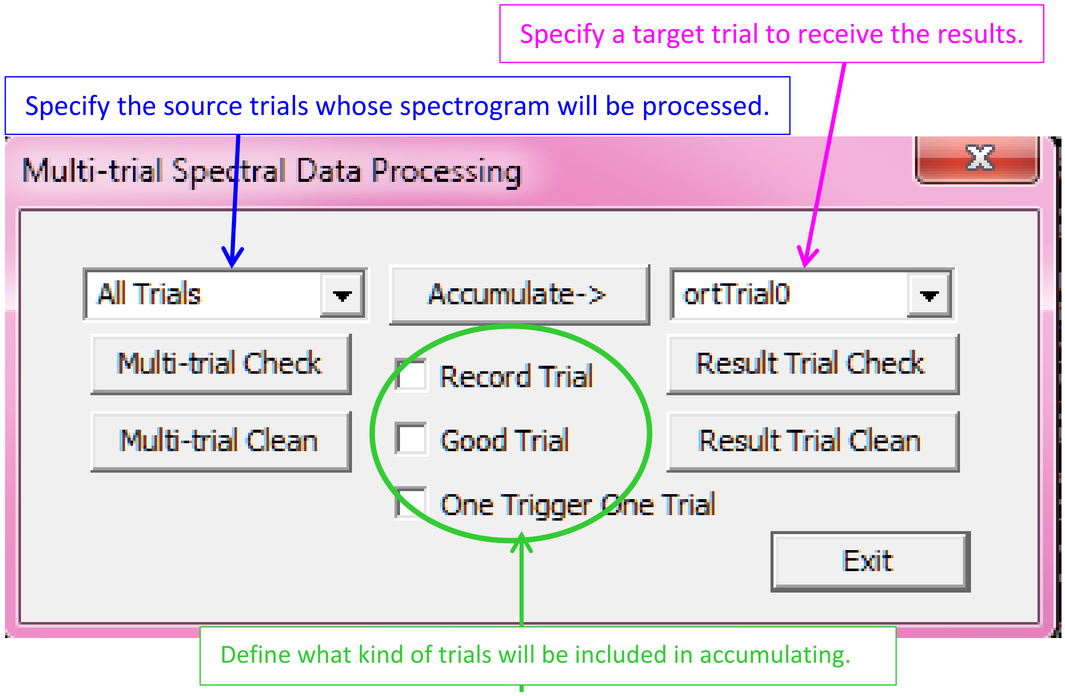

Figure 8. Multi-trial Spectral Data Processing. Spectral data computed in multiple trials can be accumulated to one trial. This processing will accumulated for every channel and every time-frequency point. Therefore, the processing reveals time-frequency locked signals in.

Re-sampling and time-frequency analysis

As the development of high-sampling rate EEG/MEG systems as well as the discovery high-frequency oscillations (HFOs) in the brain, EEG/MEG data are now typically digitized at a very high-frequency range (> 1,000 Hz).

Understandably, EEG/MEG data include brain signals as well as some background noise or artifacts. To minimize signals which we are not interested in, it is a good idea to filter the data before performing time-frequency transform. The filter band is typically identical or slightly wider than the frequency range of waveform. For example, a band pass filter (8-12 Hz) is typically applied to a wavelet transform of 8-12 Hz.

> Though we frequently mention "band-pass-filter", in many cases, we just imply the combination of a low-pass filter and a high-pass filter. Please note that, low-pass filter defines the upper frequency edge while high-pass filter defines the lower frequency edge. A high-pass filter of 8 Hz and a low-pass filter of 12 Hz "equals" to a band-pass filter of 8-12 Hz.

Generally speaking, wavelet transform of high-frequency signals digitized at a high-sampling rate is faster. However, wavelet transform of low-frequency signals digitized at a low-sampling rate can be time-consuming. To solve this problem, one solution is to re-sampling EEG/MEG data (typically, de-sampling) according to the frequency of interest (FOI). The following tables show some examples of re-sampling parameters.

Table 1. Band-pass Filter, resampling and time-frequency analyses (sampling rate =12000 Hz, recording time=120 seconds)

Filter Frequency	Re-sample (RS) (RS points-> Frequency)	Spectral frequency Range
1-4 Hz	750 - > 16 (4*4->16 Hz) 1920 points->120,000 ms	1-4 Hz
4-8 Hz	375->32(4*8->32 hz) 3840 points ->120,000 ms	4-8 Hz
8-12 Hz	252->47 (4*12->48 hz) 5714 points ->119,994 ms	8-12 Hz
12-30 Hz	100->120(4*30->120 hz) 14400 points ->120,000 ms	12-30 Hz
30-55 Hz	55->218 (4*55->220 hz) 26181 points->119,996 ms	30-55 Hz (if power-line noise=60 Hz)
65-90 Hz	34->353 (4*90->360 hz) 42352 points->119,997 ms	65-90 Hz (if power-line noise=60 Hz)
90-200 Hz	15->800 (4*200->800hz) 96001 point->120,000 ms	90-200 Hz
200-1000 Hz	3->4000(4*1000->4000hz) 480000 points->120,000 ms	200-1000 Hz
1000-2000 Hz	3-4000 (4*2000->8000 hz) 480000 point->120,000 ms	1000-2000 Hz

Table 1. Band-pass Filter, resampling and time-frequency analyses (sampling rate =4,000 Hz, recording time=120 seconds)

Filter Frequency	Re-sample (RS) (RS points-> Frequency)	Spectral frequency Range
1-4 Hz	250 - > 16 Hz (4*4->16)	1-4 Hz
4-8 Hz	125->32 Hz (4*8->32) 3840 points->120,000 ms	4-8 Hz
8-12 Hz	84->47 Hz (4*12->48) 5712 points ->119,952(120,000) ms	8-12 Hz
12-30 Hz	34->117 Hz (4*30->120) 14110 points ->120,000 ms	12-30 Hz
30-55 Hz	19->211 Hz(4*55->220) 25264 points ->120,000 ms	30-55 Hz
65-90 Hz	12->333 (4*90->360) 39960 points ->120,000ms	65-90 Hz
90-200 Hz	5->800 (4*200->800) 96000 points ->120,000ms	90-200 Hz
200-1000 Hz	1->4000 (4*1000->4000) 480000 points ->120,000ms	200-1000 Hz
1000-2000 Hz	1->4000 Hz (2*2000->4000) 480000 points - >120,000 ms	1000-2000 Hz

Index

V