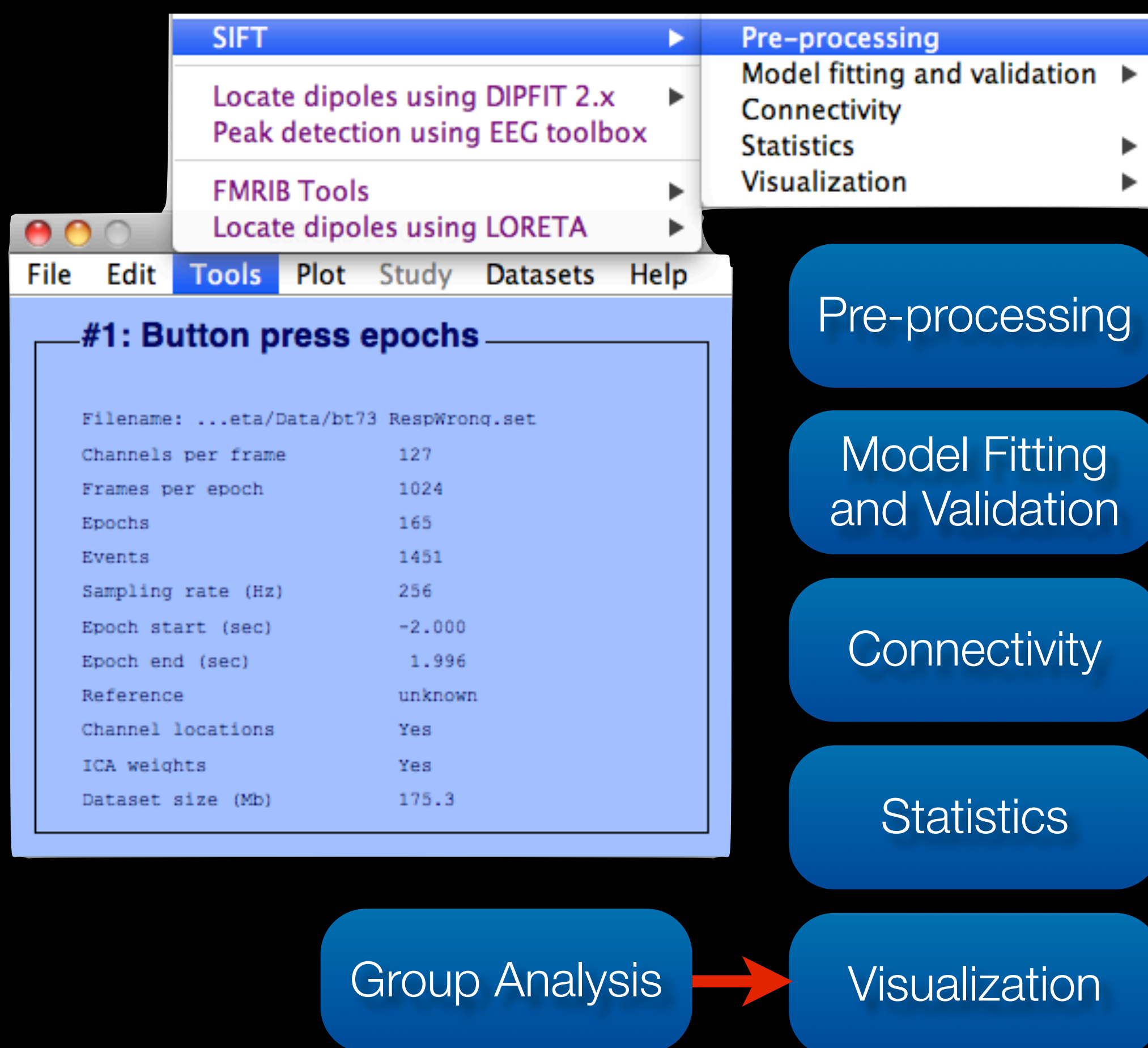


Abstract

A significant challenge in contemporary neuroscience lies in estimating and visualizing the time- and frequency- dependent dynamics of information flow within distributed anatomical networks and relating these dynamics to cognitive phenomena. While scalp EEG affords high temporal resolution, the traditional approach of estimating connectivity between EEG electrode channels suffers from a high risk of Type I errors from volume conduction and non-brain artifacts, with concomitant severe limitations in spatial source resolution. Advances in EEG source-separation and localization based on spatial filtering can significantly reduce these limitations, allowing examination of the time-frequency dynamics of directed information flow between localized cortical sources.

SIFT (Source Information Flow Toolbox) is an (alpha-release) EEGLAB-compatible toolbox for Intracranial and scalp EEG source-domain causal analysis. It affords a variety of granger-causality/information flow estimation approaches and visualization routines (both command-line and GUI accessible). There are four modules: **Data Preprocessing**, **Model Fitting and Validation**, **Connectivity Estimation**, **Statistical Analysis**, and **Visualization**. A sixth **Group Analysis** module will be added in the beta release.



SIFT data processing pipeline. The processing pipeline is accessible from the EEGLAB GUI (although some of the functionality may still remain command-line).

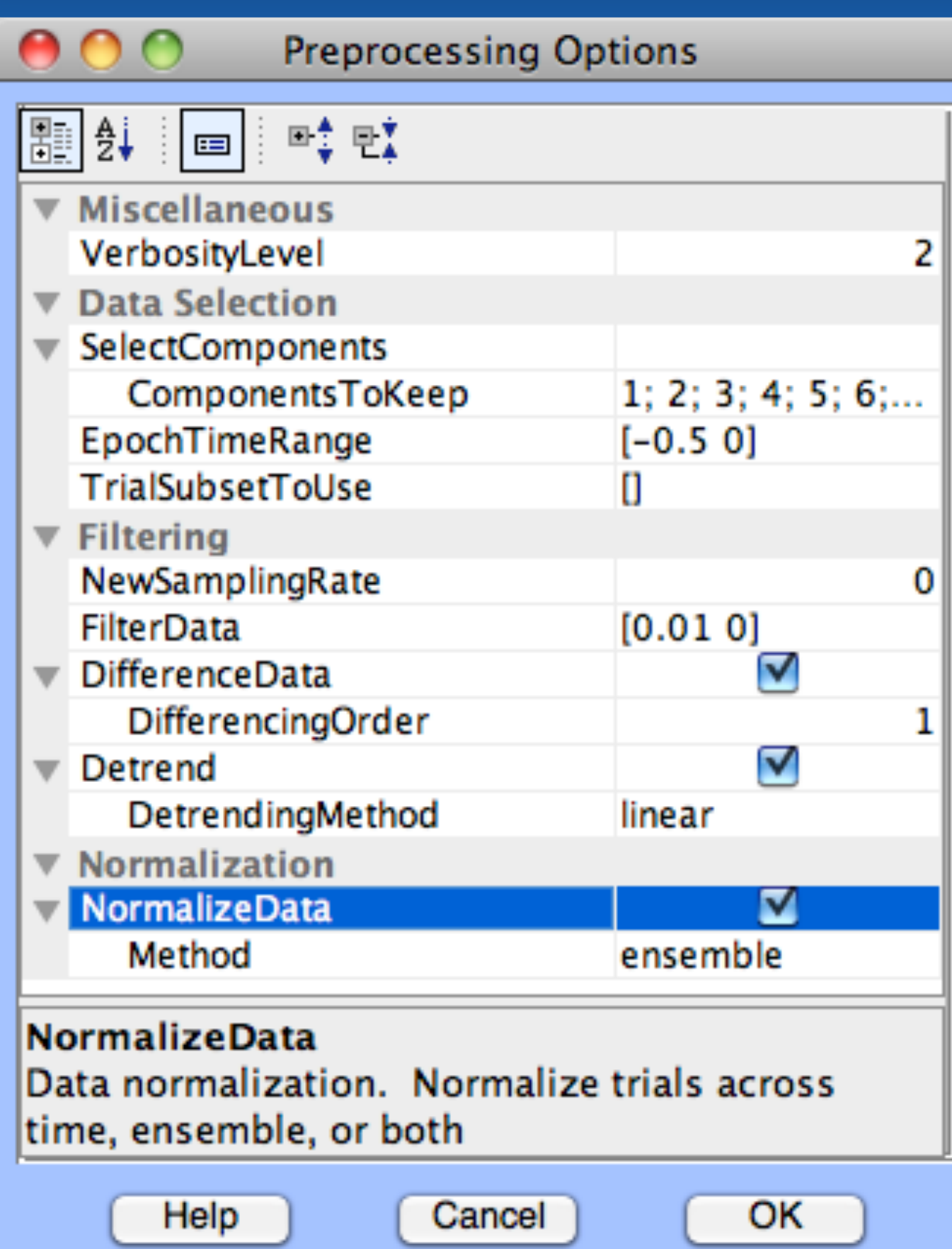
References and Thanks

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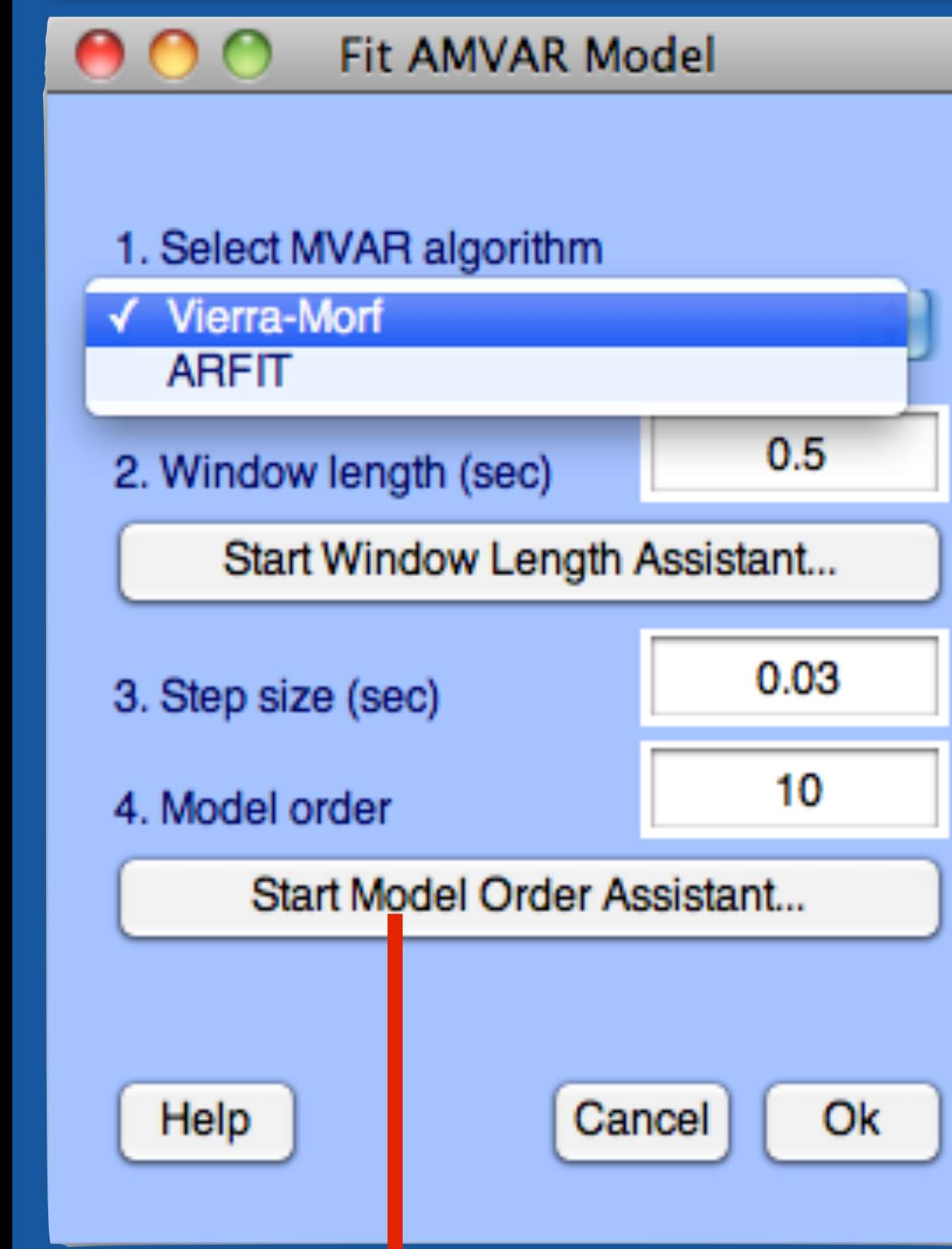
Preprocessing

Pre-processing is the first step in the SIFT analysis pipeline. SIFT 0.1a is currently restricted to source-domain analysis and generally assumes you have performed source-separation (e.g., Independent Component Analysis). To use the Brainmovie3D or Causal Projection visualizations, source localization must also be performed (e.g., dipfit). The **preprocessing** module currently contains routines for filtering, data selection, detrending, differencing, and normalization.

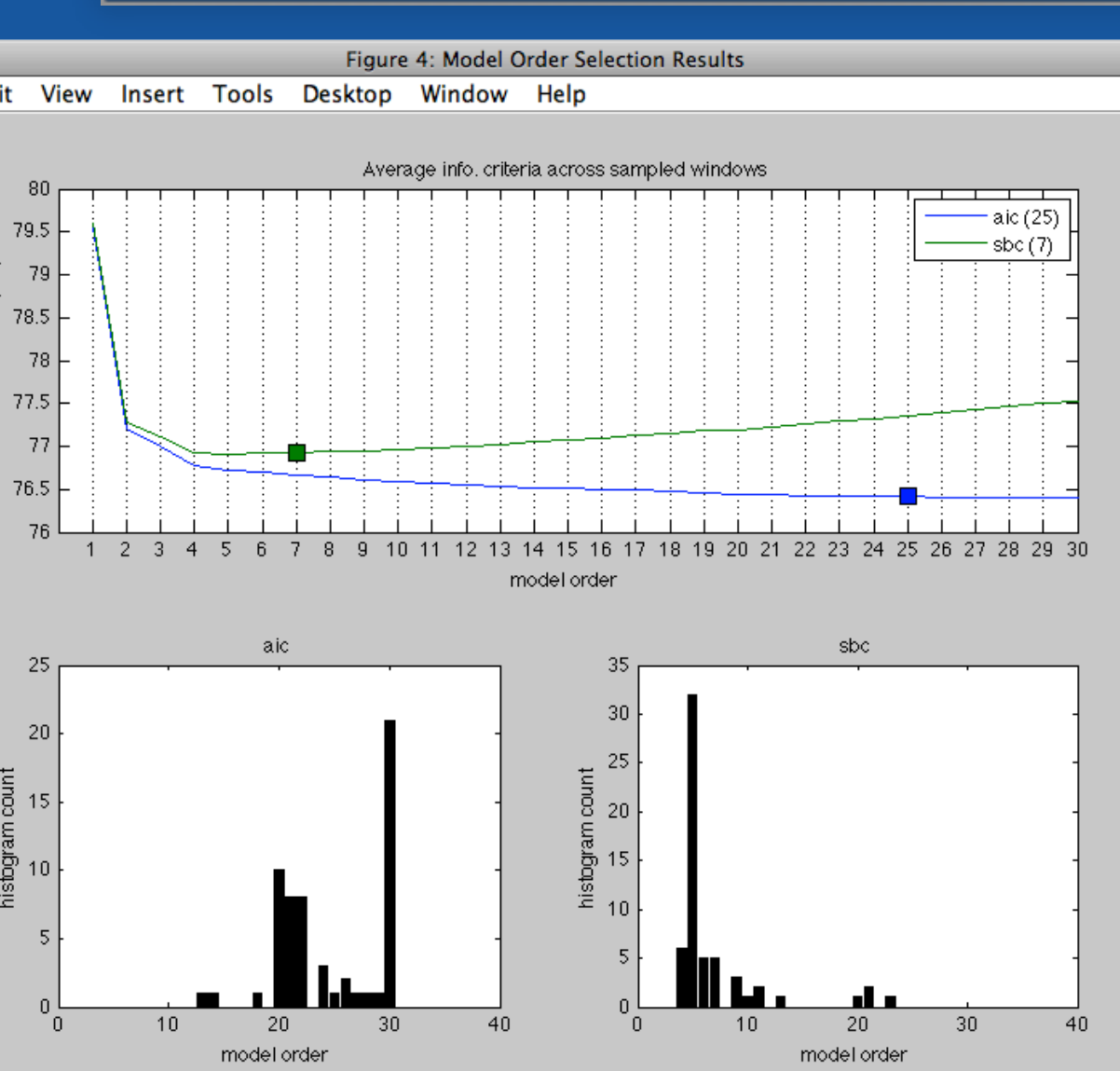
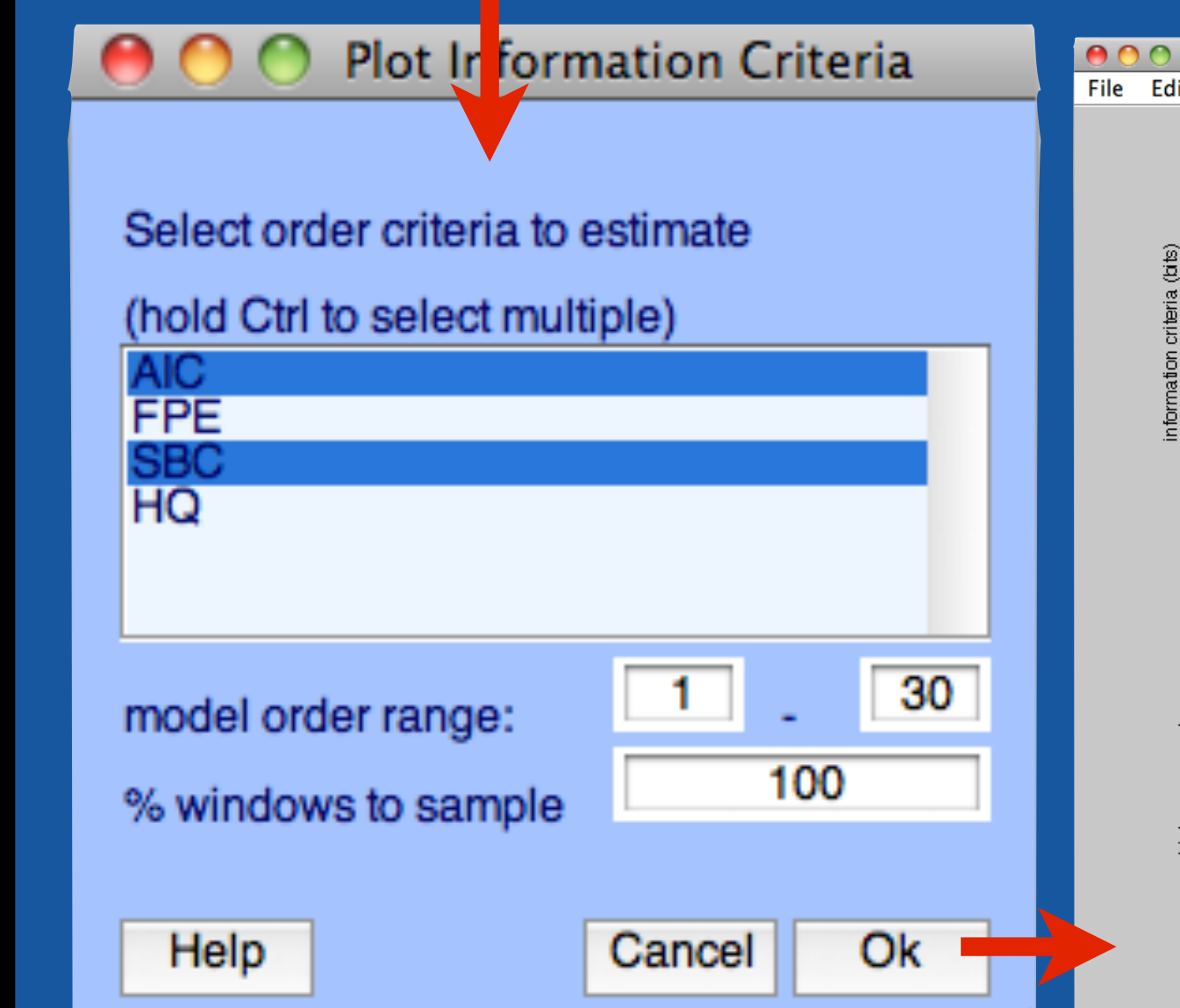


Model Fitting and Validation

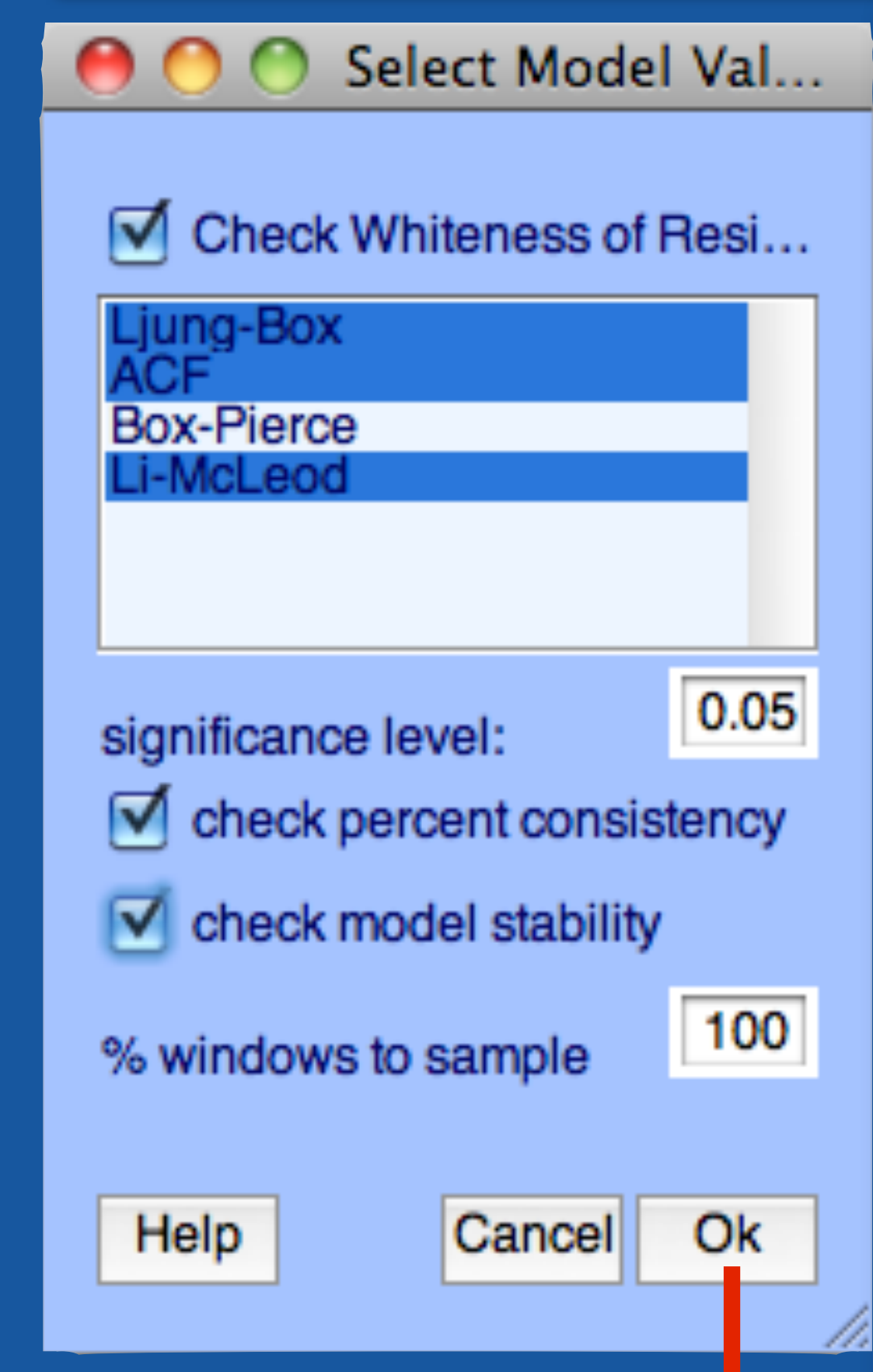
Model Fitting



SIFT is currently designed to accommodate a variety of time-varying **vector autoregression** (VAR/MVAR) modeling approaches, including adaptive parametric methods (**AMVAR** [1], **Kalman filtering**) and non-parametric methods (**spectral matrix factorization**). We are currently working on adding Sparse and Bayesian MVAR modeling and Transfer Entropy. For parametric methods, a **Model Order Assistant** allows you to examine distributions of model order selection criteria (AIC, SBC, FPE, HQ) across your windows.



Validation



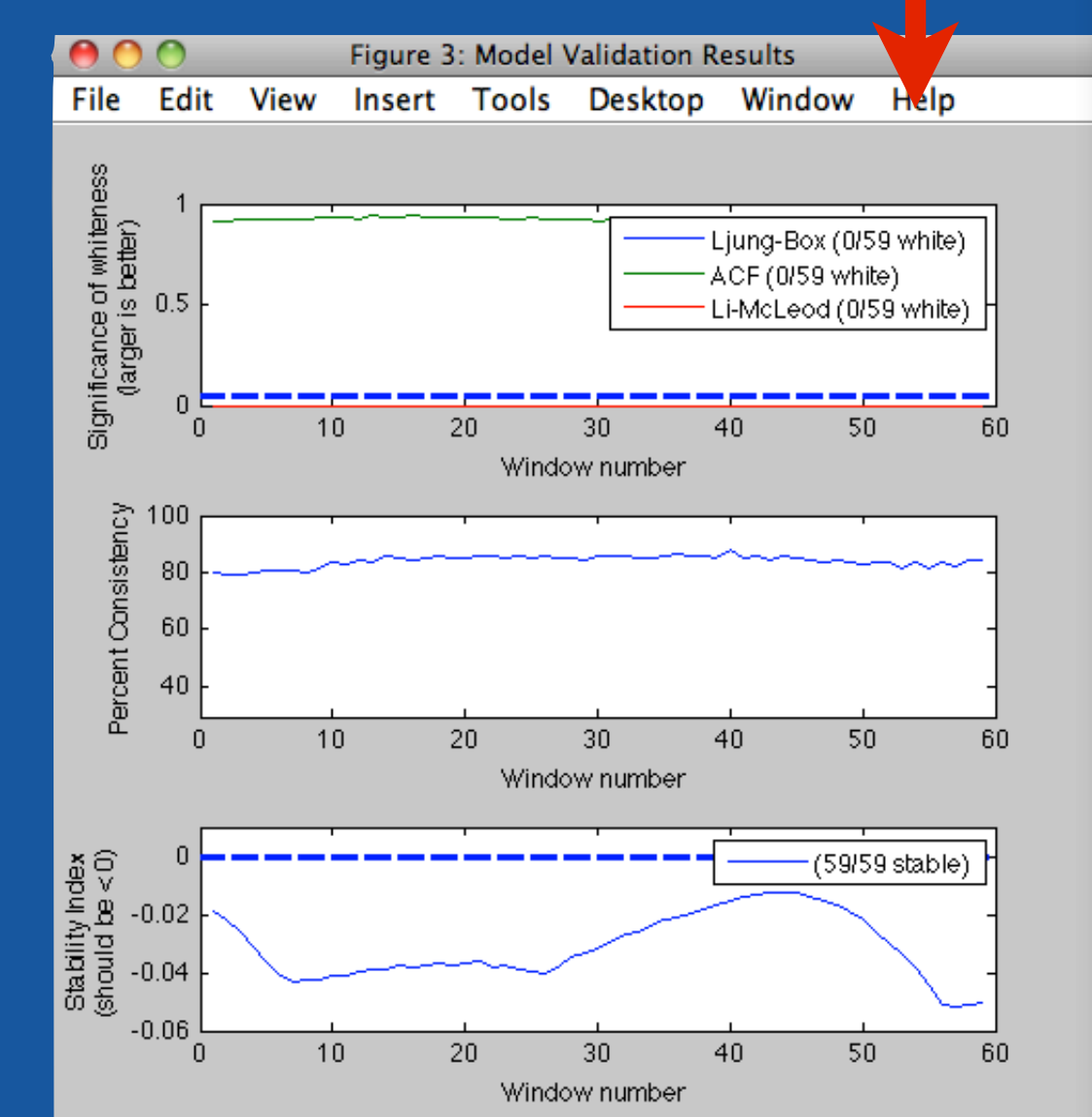
For parametric MVAR methods, the **Model Validation** routines allow the user to assess the quality of the model fit.

Residual whiteness can be rigorously assessed using several Portmanteau and autocorrelation function tests.

Percent consistency [1] denotes the ability of the model to generate data with the same covariance structure as the original data.

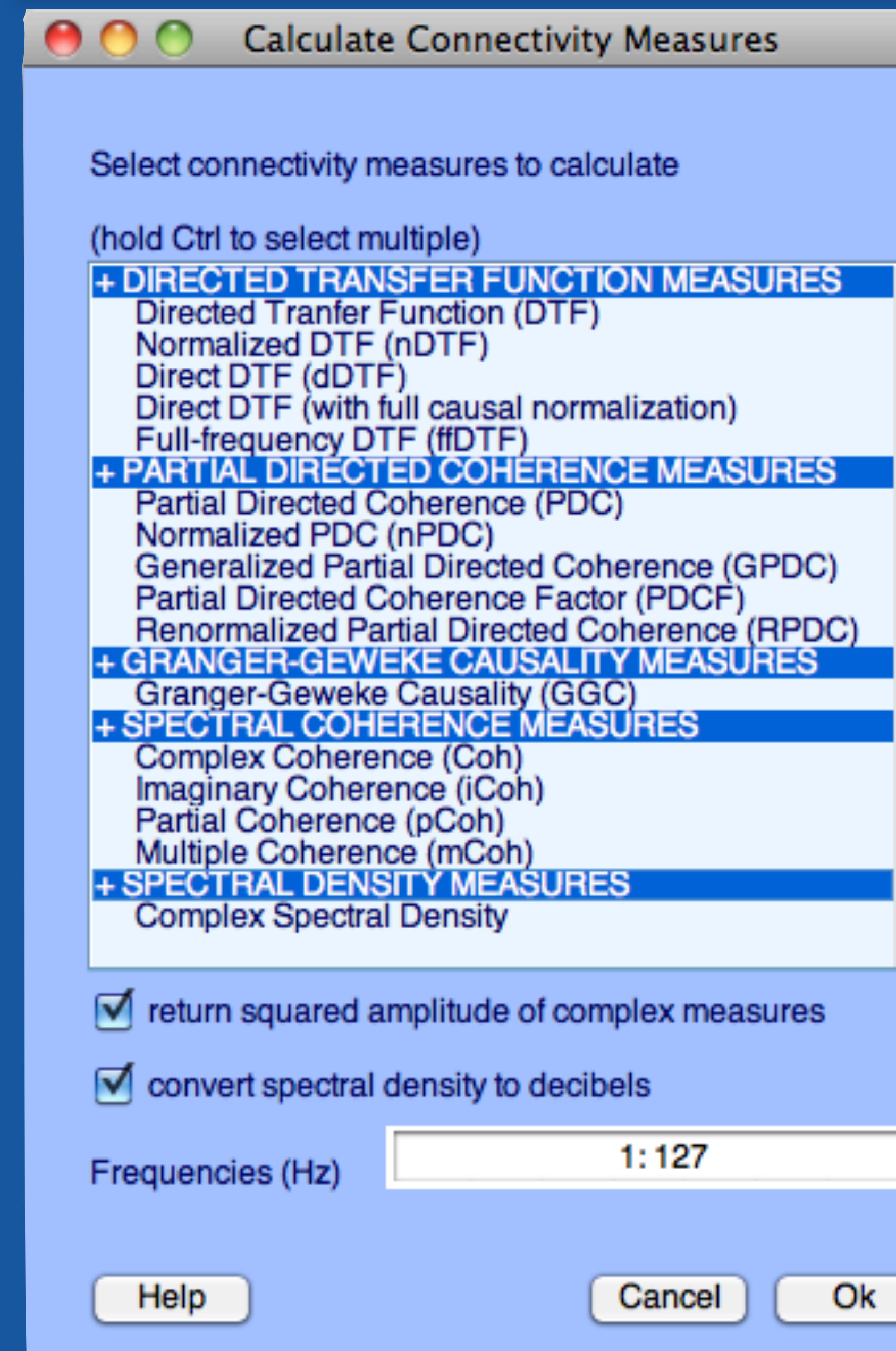
Finally, the **stability/stationarity** of the model can be assessed through analysis of eigenvalues of MVAR process.

A display shows the results of selected tests across all (or a random sample of) windows.



Connectivity

The **Connectivity** module contains routines for obtaining a connectivity matrix from a specified model. SIFT 0.1a supports a wide range of MVAR connectivity estimators including several popular frequency-domain Granger-Causal methods [2].



Statistics

The **Statistics** module (command-line in SIFT 0.1a) affords parametric and nonparametric tests of statistical significance of connectivity. Recently-derived asymptotic tests for Partial Directed Coherence and Directed Transfer function are implemented here [3].

Parametric	Nonparametric
Asymptotic tests and confidence intervals Applies to: PDC, nPDC, DTF, nDTF, RPDC Tests: H_{null} , H_{base} , H_{AB}	Phase-randomization Tests: H_{null} Bootstrap / Jackknife Tests: H_{AB} , H_{base} Simple percentile thresholding

Bayesian

Monte-Carlo estimation of confidence intervals using smoothing splines. (in development)
Tests: H_{AB} , H_{base}

LEGEND:

H is a null hypothesis, C is an $M \times M$ connectivity matrix

$H_{null}: C_1 \leq C_{null}$ (is observed conn. greater than chance?)

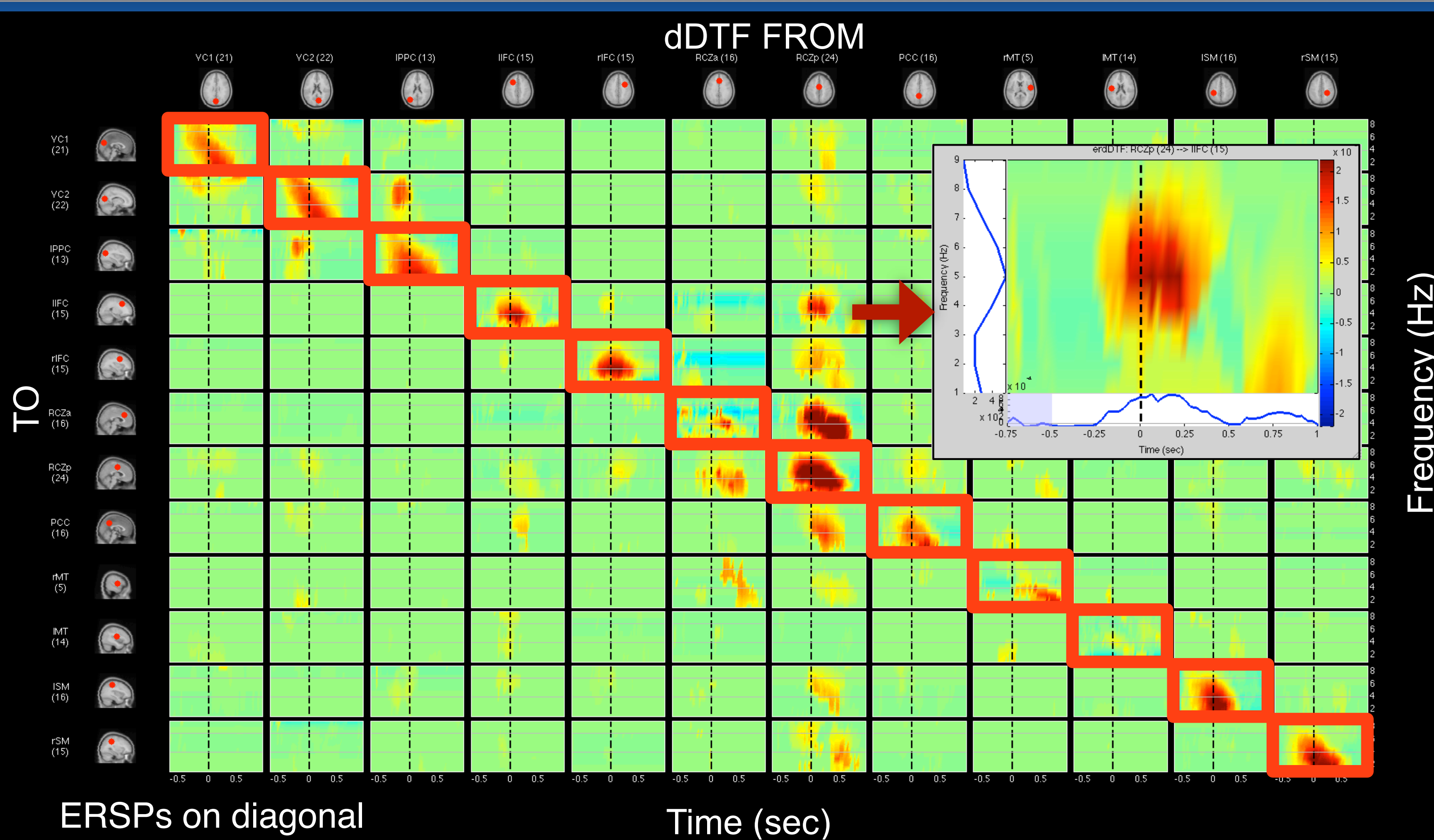
$H_{base}: C_1 \leq C_{baseline}$ (is there a difference from baseline?)

$H_{AB}: C_1^{xy} = C_2^{xy}$ (is there a difference between conditions?)

Visualization

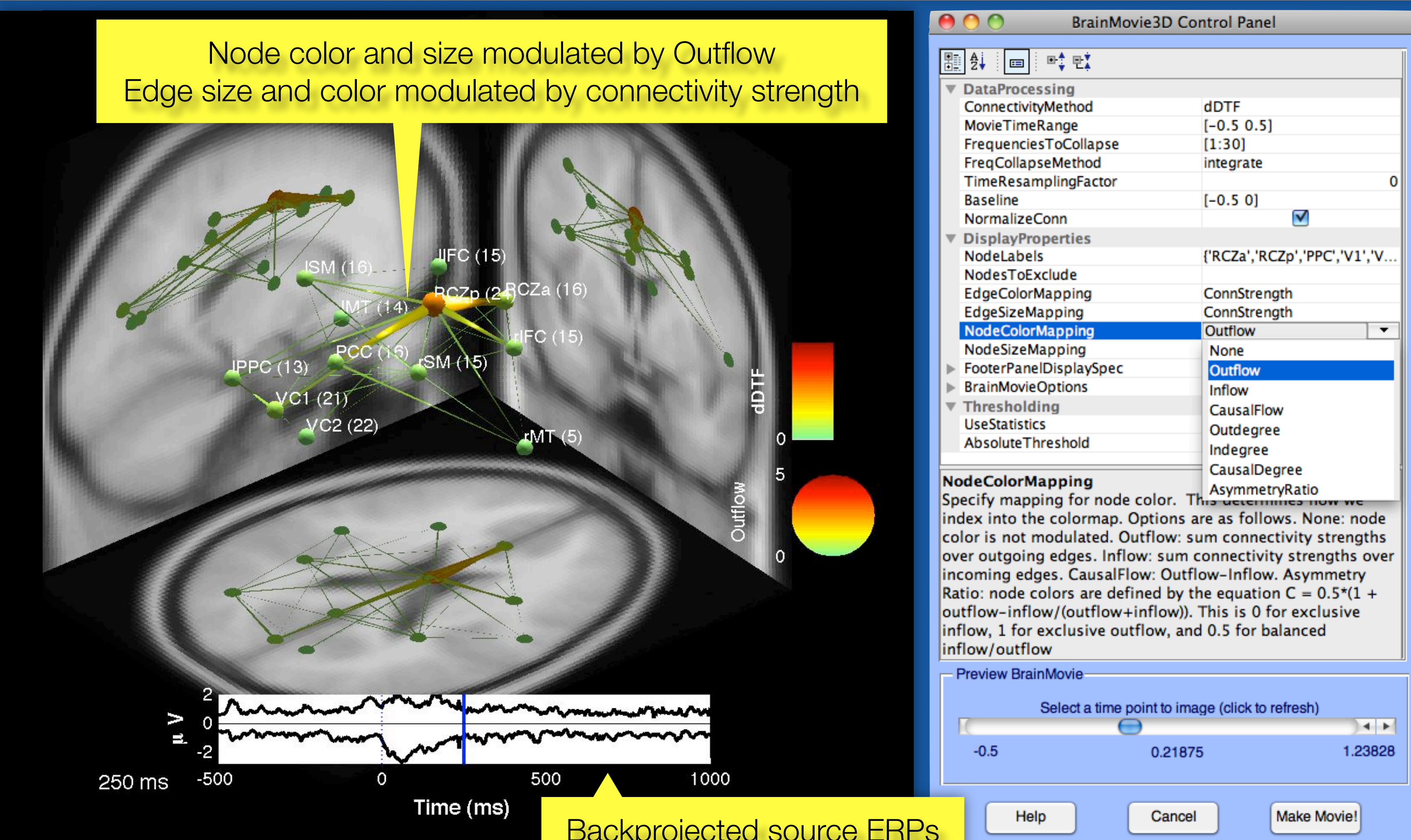
Interactive Time-Frequency Grid

The **Interactive Time-Frequency Grid** affords intuitive exploration of the complete multidimensional connectivity matrix. Each cell of the grid displays a time-frequency image of the information flow from the column source to the row source. Clicking on a cell generates a more detailed image of the pairwise coupling. If 3D coordinates or topographic maps are available for the sources, they can be displayed on the margins of the grid. If statistics are available, significance masking can be applied. The grid is highly customizable, and has a variety of display modes, allowing information from different estimators to be displayed on the diagonal, upper, and lower triangles of the grid.



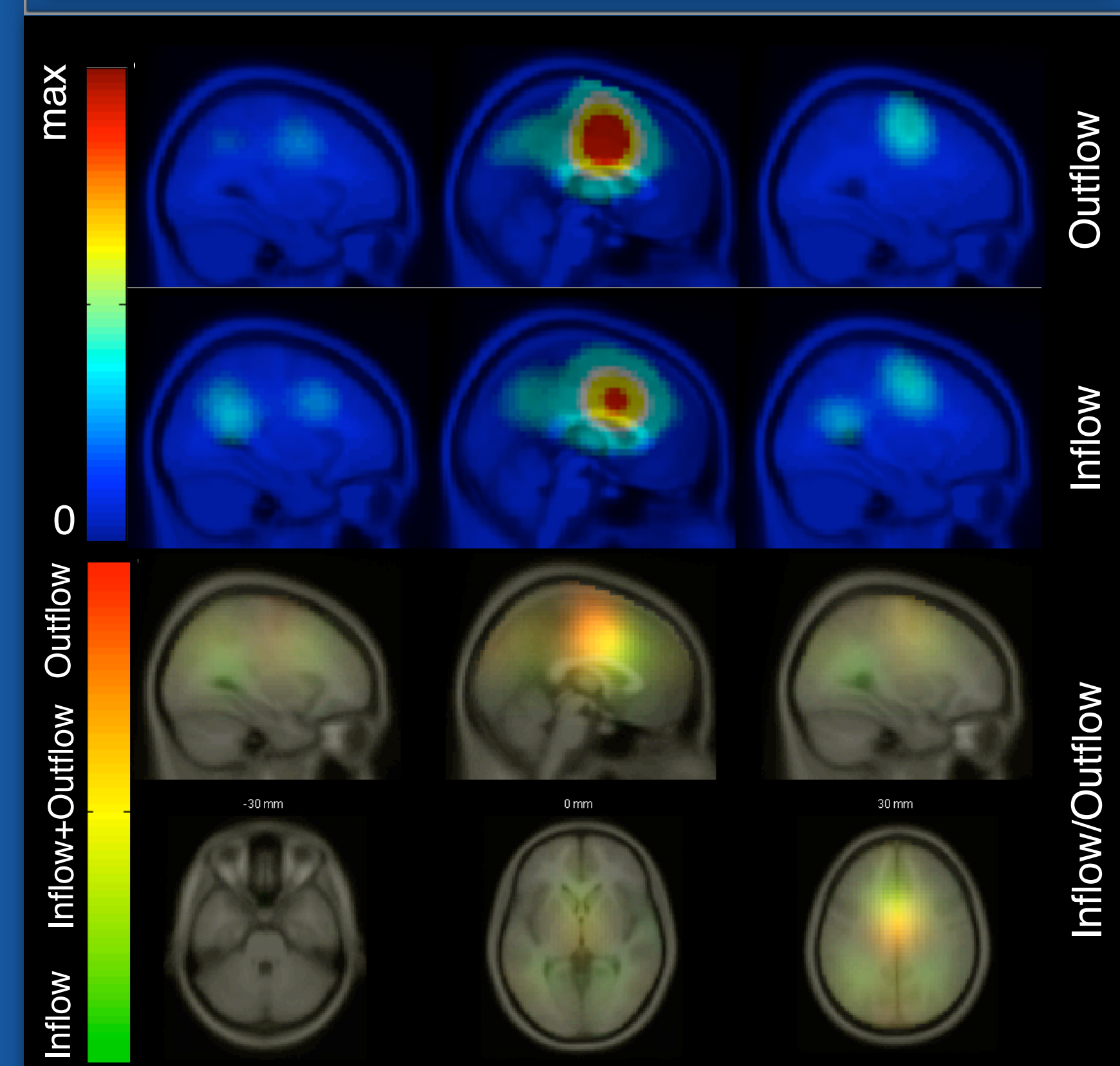
BrainMovie3D

Causal BrainMovie3D affords interactive visualization of directed information flow dynamics across time, frequency and anatomical source location. The 3D model can be rotated and is highly customizable. For instance, edge color and size can be independently modulated by connectivity strength or frequency peak while node color and size can be independently modulated by one of several graph-theoretic measures related to that node, including outflow, inflow, asymmetry ratio and more. A model of the cortical surface can be translucently superimposed on the display for reference.



Causal Projection

The **Causal Projection Movie** is a novel method for visualizing static or time-varying spatial distribution of univariate graph-theoretical quantities (e.g. outflow/inflow, causal asymmetry) or ERSP in the source domain for individual subjects or groups. Causal projection at a given voxel is a sum of gaussian-projected distances to all neighboring sources, each weighted by the amplitude of the specified measure (e.g., causal outflow) for that source.



Group Analysis

SIFT 0.1a does not ship with the Group Analysis module, since we are currently integrating this with EEGLAB's STUDY routines. However, in addition to Causal Projection, two methods for group analysis and statistics will be made available for SIFT 1.0b.

Disjoint Clustering

This approach adopts a 3-stage process: **(1)** Identify K ROI's (clusters) by affinity clustering of sources across subject population using EEGLAB's Measure-Product clustering. **(2)** Average all incoming and outgoing statistically significant connections between each pair of ROI's to create a $[K \times K \times [x \text{ freq} \times \text{time}]]$ group connectivity matrix. **(3)** Visualize the results using any of SIFT's visualization routines. This method suffers from low statistical power when subjects do not have high agreement in terms of source locations (missing variable problem).

Bayesian Mixture Model

A more robust approach (in development with Wes Thompson and to be released in SIFT 1.0b) uses smoothing splines and Monte-Carlo methods for joint estimation of posterior probability (with confidence intervals) of cluster centroid location and between-cluster connectivity. This method takes into account the "missing variable" problem inherent to the disjoint clustering approach and provides robust group connectivity statistics. See [4] for details.