BWTO2D ver. 1.0

Full User Manual

BWTO2D: A MATLAB GUI for 2D Bayesian Wavelet Topology Optimization

This program was developed and released by:

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1. Introduction

Welcome to BWTO2D, a powerful MATLAB-based graphical user interface (GUI) designed for the advanced analysis of 2D geophysical data. The primary goal of BWTO2D is to extract and map geological lineaments—linear features that are expressions of underlying geological structures like faults or fractures—from gridded datasets.

The application leverages a sophisticated workflow that combines the spatial-frequency decomposition power of the 2D Continuous Wavelet Transform (CWT) with a novel Bayesian Hyperparameter Optimization engine. This allows for both manual and fully automated, unsupervised detection of lineaments, providing a robust tool for geoscientists and researchers.

Key features of BWTO2D include:

- Data Integration: Import and grid scattered point data within a user-defined geographical area.
- Advanced Wavelet Analysis: Utilize specialized mother wavelets, including the Derivatives of Gaussian and Derivatives of Poisson wavelets, to analyze data at multiple scales and orientations.
- Intelligent Feature Selection: Employ a unique algorithm based on localized feature saliency and global weighted dissimilarity to select the most informative CWT-derived features.
- Semi-Automatic and Automatic Lineament Extraction:
  - A manual mode that gives the user full control over all lineament detection parameters.
  - A fully automatic mode that uses Bayesian Hyperparameter Optimization to find the optimal set of parameters for lineament extraction in an unsupervised manner.
- Comprehensive Visualization and Export: View results at every stage, from input data to final lineament maps, and export them to common GIS formats including CSV, GeoTIFF, and Shapefiles.

BWTO2D is a versatile tool suitable for a range of applications in geoscientific research and exploration. It is particularly useful in the fields of:

- Mineral Exploration: Assisting in the identification and analysis of geological faults and lineaments that are critical in mineral deposit studies.
- Geophysical Data Analysis: Providing advanced methods for the interpretation of geophysical data, facilitating the detection of potential field sources.
- Geological Mapping: Enhancing the accuracy of geological maps by integrating spectral feature extraction and lineament analysis.

The program is available for free and can be easily used by anyone with MATLAB installed on their computers. This manual is intended for geoscientists, engineers, and researchers who need to analyze 2D gridded data (such as potential field data or digital elevation models) to identify and map structural lineaments. A basic understanding of MATLAB and familiarity with general geophysical data processing concepts will be beneficial.

2. System requirements

This program is designed to run on any Windows-based personal computer with at least 8 GB of random-access memory (RAM). Increasing the RAM size allows larger images to be processed at once. Since large matrices are operating in this program, the read/write speed of the storage is also essential. A solid-state drive (SSD) with a non-volatile memory express interface (NVMe) is recommended.

BWTO2D is provided either in windows executable or in MATLAB M-File format. The executable format needs normal Microsoft Widows installation, while M-Files require MATLAB 2024b to run. To use the program, locate the M-Files in the current folder of MATLAB and then type BWTO2D in the MATLAB Command Window. This interface offers comprehensive tools for curvilinear lineament extraction with a user-friendly design, ensuring that users can easily manipulate and visualize geoscientific data with precision and efficiency.

BWTO2D is designed to run efficiently on Windows-based personal computers. To ensure optimal performance and to handle the computational demands of the program, the following system requirements are recommended:

Operating System:

- Windows-based PC.

Memory (RAM):

- A minimum of 8 GB of random-access memory (RAM) is required. However, increasing the RAM size is highly recommended as it allows for the processing of larger images simultaneously and enhances overall performance. Larger datasets and complex computations will benefit significantly from additional memory.

Storage:

- Since BWTO2D handles large matrices and extensive data operations, the read/write speed of the storage is crucial. A solid-state drive (SSD) with a non-volatile memory express (NVMe) interface is recommended. This configuration ensures faster data access and smoother performance during intensive computational tasks.

MATLAB Requirements:

- MATLAB (Version R2024b recommended)
- MATLAB Toolboxes:
    - Image Processing Toolbox
    - Mapping Toolbox
    - Statistics and Machine Learning Toolbox
    - Signal Processing Toolbox
    - Wavelet Toolbox

User Interface:

- BWTO2D features a comprehensive and user-friendly graphical interface, which offers a wide array of tools for curvilinear lineament extraction. This design ensures that users can easily manipulate and visualize geoscientific data with precision and efficiency.

Additional Recommendations

- **Processor**: While not explicitly stated, a multi-core processor with high clock speeds will further enhance the performance, especially for more complex and computationally intensive tasks.

- **Graphics**: For advanced visualization, having a dedicated graphics card may improve the rendering speed and quality of graphical outputs.

- **Backup and Storage Management**: Given the potentially large size of data files, regular backups and efficient storage management practices are recommended to prevent data loss and ensure smooth operation.

3. Program interface

When you launch BWTO2D, you will be presented with the main application window (Figure 1). The interface is organized into a series of tabs, each dedicated to a specific stage of the lineament detection workflow. This design guides you logically from data input to final result export.

The main window consists of four primary tabs:

- **Data Sets Tab:** Your starting point. Here, you define the geographic boundaries of your study area and load your 2D point data for analysis.
- **Spectral Tab:** This tab is dedicated to the core feature extraction process using the Continuous Wavelet Transform (CWT). You will select your input data, configure the CWT parameters, and perform feature selection.
- **Lineaments Tab:** In this section, you will use the features generated in the Spectral tab to detect and map lineaments. It provides both a semi-automatic workflow with manual parameter control and a fully automated workflow using Bayesian Hyperparameter Optimization.
- **Export Tab:** The final step. This tab allows you to save your results, including CWT feature maps, lineament density grids, and the final vector lineaments, in formats compatible with GIS and other analysis software.

On the Data Sets tab, you will find two important buttons for managing the application state:

- **Restart Button:** Clicking this button will close all open figures, clear all data from the application's memory, and reset the GUI to its initial state. This is useful when you want to start a completely new analysis from scratch.
- **Close Button:** This will close the BWTO2D application and all associated figures.

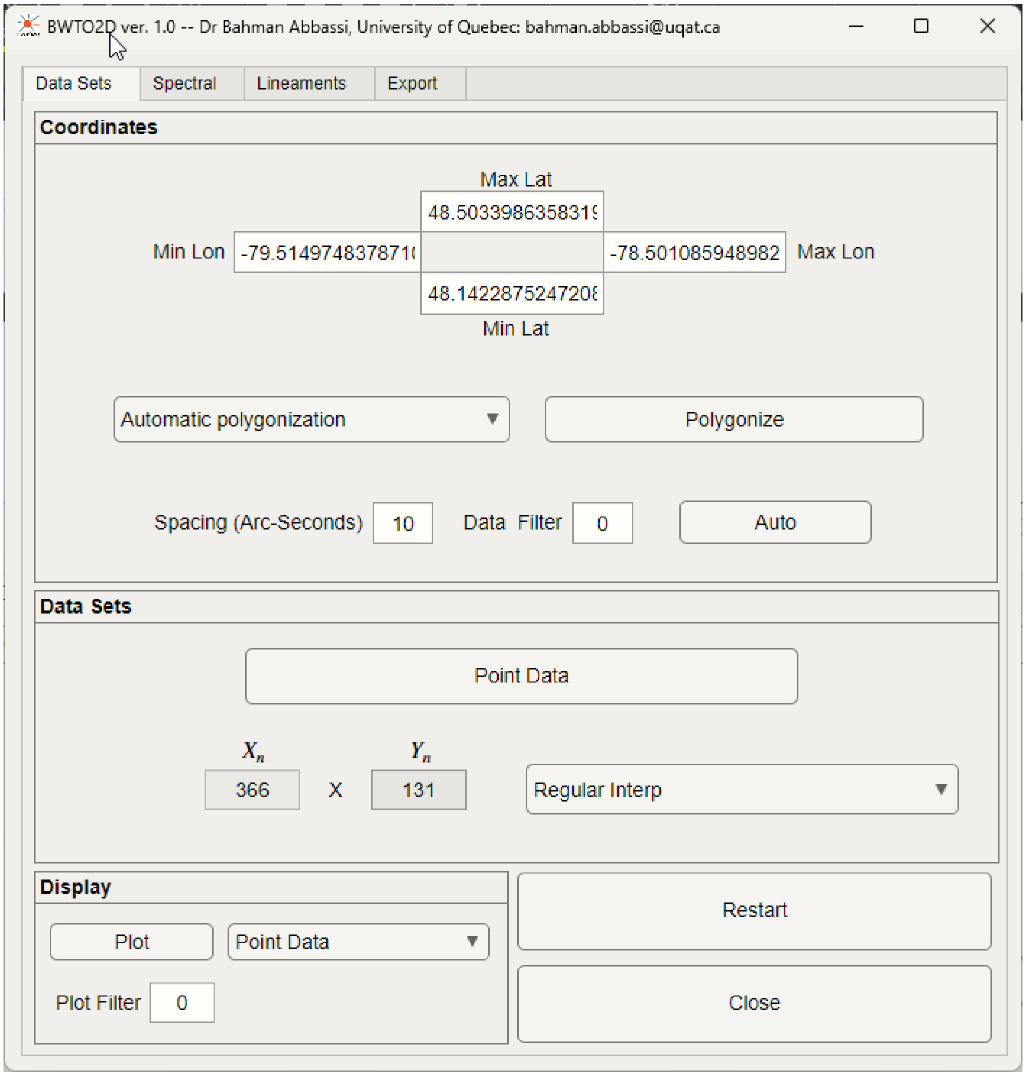

Figure 1: The **BWTO2D** Program Interface showcasing the primary functionalities and layout for user interaction.

4. Theory

This section provides a brief overview of the key theoretical concepts and algorithms that form the foundation of the BWTO2D application. Understanding these principles will help you make more informed decisions when selecting parameters and interpreting results.

4.1. The 2D Continuous Wavelet Transform (CWT)

The 2D Continuous Wavelet Transform (CWT) is the core engine for feature extraction in BWTO2D. Unlike traditional Fourier analysis which only provides frequency information, the CWT is a spatial-frequency analysis method. It decomposes a 2D signal (like a geophysical grid) into a set of coefficients that are localized in both space and frequency (scale).

The transform works by convolving the input image with a "mother wavelet"—a small, wave-like function—that has been scaled (stretched or compressed) and rotated. By doing this for a range of scales and angles, the CWT can effectively isolate and enhance features of a specific size and orientation, making it exceptionally well-suited for detecting linear features like geological lineaments (Antoine et al., 2004; Abbassi, 2018; Abbassi and Cheng, 2021; Abbassi et al., 2022; YAWTB Team, 2025).

4.2. Mother Wavelets for Lineament Detection

The choice of the mother wavelet is crucial as it determines the type of features the CWT will be most sensitive to. BWTO2D employs two specialized, asymmetric wavelets.

4.2.1 Derivatives of Gaussian

This wavelet is created by taking the partial derivatives of a 2D Gaussian function. Its mathematical form in the frequency domain (*kx*, *ky*) is:

$$\hat{\psi}(k_x, k_y) = (ik_x)^n (ik_y)^m exp(-\frac{{k_x}^2 + {k_y}^2}{2})$$

where n and m are the derivative orders (OrderX and OrderY in the GUI). By changing the derivative orders, the wavelet can be tuned to detect different types of anomalies, such as step-edges or ridges, making it highly versatile.

4.2.2 Derivatives of Poisson

This wavelet is derived from the Poisson kernel, which is fundamental in potential field theory. Its form in the frequency domain is:

$$\hat{\psi}(k_x, k_y) = (ik_x)^n (ik_y)^m \sqrt{{k_x}^2 + {k_y}^2} exp(-Z\sqrt{{k_x}^2 + {k_y}^2})$$

where n and m are the derivative orders and Z is a parameter corresponding to the upward continuation height. This makes the Poisson wavelet particularly effective for analyzing potential field data (e.g., gravity and magnetics), as the Z parameter allows for inherent vertical scaling of the analysis.

4.3 Lineament Enhancement and Detection

After CWT produces feature maps, a series of steps are taken to isolate and define the lineaments.

4.3.1 Directional Step-Filtering

To further enhance the linear features within the CWT coefficient maps, BWTO2D applies a directional step-filter. This process involves convolving the image with a kernel that has a positive core flanked by negative regions. This kernel is rotated across a user-defined number of angles (NSFA). For each pixel, the maximum response from all angles is retained. This has the effect of amplifying elongated, linear features while suppressing more isotropic or blob-like anomalies. The width of the filter (w) controls the scale of the lineaments being enhanced (Panagiotakis and Kokinou, 2015; Panagiotakis, 2025).

4.3.2 Hysteresis Thresholding

To convert the enhanced, grayscale feature maps into a binary image of faults and non-faults, a two-level hysteresis thresholding technique is used. Instead of using a single threshold, which can be sensitive to noise, this method uses two thresholds (Panagiotakis and Kokinou, 2015; Panagiotakis, 2025):

1. **A high threshold (T_{high})**: Used to identify the core, "strong" parts of a lineament.
2. **A low threshold (T_{low})**: Used to grow these core regions and include connected "weaker" parts of the same lineament.

This process begins by marking all pixels above T_{high} as definite lineaments. Then, any neighboring pixels that are above T_{low} are also included. This allows the algorithm to trace the full extent of a lineament without introducing isolated, noisy pixels.

4.4 Unsupervised Feature Selection

CWT can generate thousands of feature maps. To select the most informative and diverse subset, BWTO2D employs an unsupervised feature selection algorithm. The algorithm works as follows:

1. The map with the highest variance is selected first, as it contains the strongest signal.
2. Subsequent maps are selected iteratively based on a score that combines high variance with high *dissimilarity* to the maps already chosen.
3. Dissimilarity is a weighted combination of two metrics: low spatial correlation and low overlap of their rudimentary edges.

This ensures the final set of features is not redundant and captures a wide range of different structures present in the data.

4.5 Automatic Hyperparameter Tuning: Bayesian Topology Optimization (BTO)

The most advanced feature of BWTO2D is its ability to automatically find the best parameters for lineament extraction. It uses a Bayesian optimization framework (bayesopt) to intelligently search for the high-dimensional parameter space (Archetti and Candelieri, 2019; MathWorks, 2025).

The goal of the optimization is to minimize an objective function (Lineaments_Auto7.m) that quantifies the "quality" or "representativeness" of the resulting lineament network. While the exact formulation is complex, it is based on graph theory, treating lineaments as segments in a graph. The function rewards parameter sets that produce distinct, well-connected lineaments and penalizes those that result in noisy, fragmented, or overly dense maps. By minimizing this function, the BTO engine can autonomously discover the optimal settings for parameters like w, VSFW, SLC, and the CWT settings for your specific dataset.

5. Data Input and Preparation

The first step in any analysis is to define your area of interest and load your data. All of these initial actions are performed in the **Data Sets** tab. This chapter will walk you through defining your project's geographic boundaries and importing your point data to create a workable grid.

5.1. Defining the Coordinate System and Study Area

The **Coordinates** panel is where you establish the geographic extent of your project. BWTO2D provides two methods for this, selected via the Coord Method dropdown menu.

Method 1: Rectangular Coordinates

This method is ideal if you know the exact rectangular boundaries of your study area.

- **Input:** A simple text file (.txt) containing four numerical values: minimum longitude, maximum longitude, minimum latitude, and maximum latitude.
- **Steps:**
    1. From the **Coord Method** dropdown, select Rectangular coordinates.
    2. Click the **Polygonize** button.
    3. A file selection dialog will open. Choose the .txt file that defines your coordinates.
    4. The application will automatically read the file and populate the Min Lon, Max Lon, Min Lat, and Max Lat fields with the specified boundaries.

Method 2: Automatic Polygonization

This method is useful when your study area is defined by the extent of your data points rather than a simple rectangle.

- **Input:** A CSV file or Geosoft XYZ file (.csv or .xyz) containing at least two columns for longitude and latitude of a dataset. You better use the original datasets mapped into in lower resolution and exported as CSV file. Larger CSV files slow down the masking process.
- **Steps:**

1. From the **Coord Method** dropdown, select Automatic polygonization.
2. Click the **Polygonize** button.
3. A file selection dialog will open. Choose the .csv or .xyz file containing your data points.
4. The application will read all the points and automatically calculate the minimum bounding box required to contain them, populating the Min Lon, Max Lon, Min Lat, and Max Lat fields.

After polygonization, the application uses the value in the **Spacing (Arc-Seconds)** field to determine the resolution of the analysis grid. The resulting grid dimensions are displayed in the read-only Xn and Yn fields.

5.2. Loading and Gridding Point Data

Once the study area is defined, you can load your scattered point data using the **Data Sets** panel.

- **Input:** A .csv or .xyz file with three columns: Longitude, Latitude, and the data value (e.g., gravity anomaly, magnetic intensity).
- **Steps:**
  1. Click the **Point Data** button.
  2. In the file dialog, select your .csv or .xyz data file.
  3. Choose an interpolation method from the **Regular Interp** dropdown:
     - **Regular Interp**: Uses a *Nearest Neighbor* grid data approach.
     - **Scattered Interp**: Uses a *Natural Neighbor Scattered Interpolant*, which is often a good choice for irregularly spaced data.
  4. The application will interpolate your scattered points onto the defined grid. The resulting grid then undergoes an automatic normalization and distribution adjustment routine to prepare it for wavelet analysis.

5.3. Displaying the Input Data

Before proceeding to the next stage, it is good practice to visualize the gridded input data. This is done using the **Display** panel (MathWorks, 2025; Shirvany, 2025).

- **Steps:**

  1. From the **Select** dropdown, select Point Data.
  2. (Optional) Enter a value in the **Plot Filter** field. This applies a Gaussian smoothing filter to the data for visualization purposes only, which can help in reducing high-frequency noise in the plot. A value of 0 applies no filter.
  3. Click the **Plot** button. A new figure window will appear showing a surface plot of your gridded data.

This completes the data input and preparation stage. The application now holds a normalized, gridded representation of your data and is ready for feature extraction. Let me know when you are ready to proceed to the next chapter.

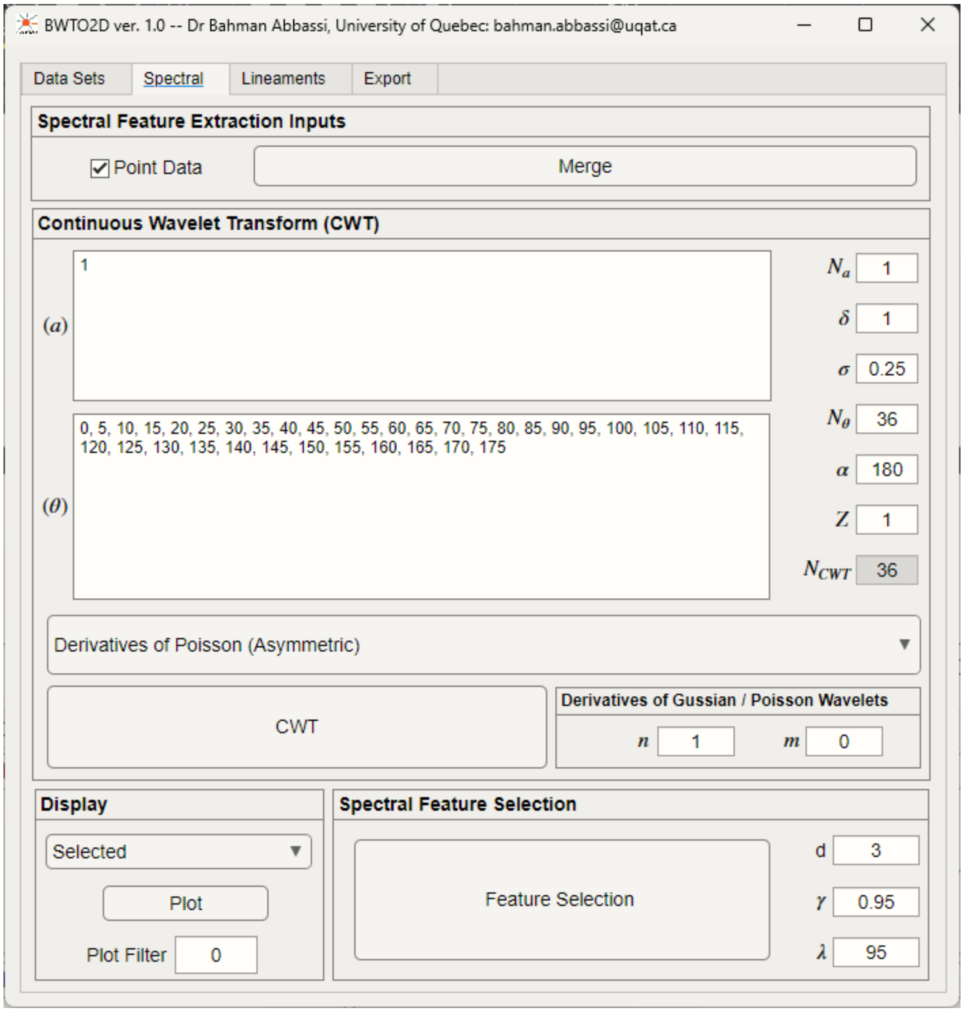

Figure 2: The Spectral tab for Spectral Feature Extraction stage.

6. Spectral Feature Extraction

Once your data is loaded and gridded, the next step is to transform it into the spectral domain to extract features that are sensitive to linear/curvilinear structures. This is the primary purpose of the **Spectral** tab. This process uses the 2D Continuous Wavelet Transform (CWT) to decompose the input data into a series of maps, each highlighting features at a specific scale and orientation.

6.1 Preparing CWT Inputs

Before running CWT, you must specify which of your loaded datasets will be used for the analysis.

How it works: In the **Spectral Feature Extraction Inputs** panel, you select the desired datasets.

Steps:

1. Check the box next to **Point Data** to include the dataset you loaded in the Data Sets tab.
2. Select Mother Wavelet type: Gaussian or Poisson.
3. Set your desired parameters: You can use the predefined default values and later configure them.
4. Click the **Merge** button. The application will combine the selected datasets into a single input matrix for the CWT. The GUI will automatically calculate and display the total number of resulting CWT features in the **number of CWT Features** (N_{CWT}) field.

6.2. Configuring the Continuous Wavelet Transform (CWT)

The **Continuous Wavelet Transform (CWT)** panel contains the core parameters that control the feature extraction process. The choices made here will significantly impact on the type and quality of the lineaments detected.

- Mother Wavelet Selection

This is the most critical parameter. The mother wavelet is the kernel function that is scaled and rotated to match features in the data. BWTO2D offers two specialized, asymmetric wavelets suitable for edge and lineament detection.

- **Derivatives of Gaussian (Asymmetric)**: A versatile and widely used wavelet for feature detection, created by taking the partial derivatives of a 2D Gaussian function.

- **Derivatives of Poisson (Asymmetric)**: A wavelet derived from the Poisson kernel, particularly useful for potential field data analysis. It includes an upward continuation parameter (Z). Higher values of Z tend to filter out noise and emphasize broader anomalies from deeper sources, which are particularly useful for gravity and magnetic data.

Note: Each time changing the Mother Wavelet, demands pushing the Merge button.

- CWT Parameters

- **Number of Scales (N_a)**: Defines how many different sizes (scales) of the wavelet will be used. More scales allow for the detection of features across a wider range of sizes but increase computation time. For lineament detection tasks na = 1 is usually the best choice.
- **Scale Dilation Factor (δ)**: Controls the spacing between consecutive scales. A value of 1 creates a linear sequence (e.g., 1, 2, 3...), while a larger value creates a sparser set of scales (e.g., 1, 3, 5... for a factor of 2). Default value of 1 is usually good for lineament detection tasks.
- **Wavelet Smoothness Filter Ratio (σ)**: This value applies to a Gaussian smoothing filter to the resulting CWT coefficient maps, which can help reduce high-frequency noises and artefacts produced by the CWT.
- **Number of CWT Angles (N_θ)**: The number of different orientations the wavelet will be rotated to at each scale. A higher number provides better angular resolution.
- **Derivatives Orders (*n* and *m*):** These define the derivative order of the mother wavelet in the X and Y directions, respectively. Different orders make the wavelet sensitive to different types of features (e.g., step-edges vs. ridges). For most cases values or n = 1, m = 0 or m = 0, n = 1 are enough for efficient lineament detection.
- **Poisson Upward Continuation (*Z*)**: (Only active for the *Derivatives of Poisson* wavelet). This parameter corresponds to the upward continuation height in potential field theory.

Once these are set, the Scales (a) and Angles text boxes will automatically populate with the values that will be used in the transformation.

6.3. Running the CWT

After configuring the parameters, click the **CWT** button to start the transformation. The application will perform the 2D CWT on the merged input data by calling the appropriate backend function (cwt2D_DerGus.m or cwt2D_DerPoisson.m) and will generate a large set of feature maps.

6.4. Spectral Feature Selection

CWT can produce hundreds or even thousands of feature maps. The **Spectral Feature Selection** panel allows you to intelligently reduce this number to a smaller, more manageable, and more informative subset. This is done to remove redundant information and focus only on the most distinct features.

How it works: The selection algorithm iteratively picks features that have both high variance (indicating strong signals) and are dissimilar from already selected features. Dissimilarity is a combined measure of both spatial correlation and edge overlap.

Parameters:

- **Feature selection dimension (*d*)**: The target number of features you want to select.
- **Dissimilarity (*γ*)**: A weight (from 0 to 1) that balances the importance of map correlation vs. edge overlap when measuring dissimilarity between two feature maps.
- **Feature Saliency Percentage (*λ*)**: A percentile used to define what constitutes a "rudimentary edge" within a feature map. For example, a value of 95 means the top 5% of positive coefficient values are considered edges.

Steps:

- Set the desired number of final features in the **Feature selection dimension (*d*)** field.
- Adjust the ***γ*** and ***λ*** parameters if needed (default values are often a good starting point).
- Click the **Feature Selection** button. The application will run the selection algorithm (CWTFeatureSelection.m) and store the resulting subset of feature maps.

6.5. Displaying Spectral Results

You can view the outputs of the CWT and the feature selection process using the **Display** panel.

- From the **Select** dropdown, choose either:

- **CWT**: To view all the CWT coefficient maps generated.
- **Selected**: To view only the subset of maps chosen by the feature selection algorithm.

- Click the **Plot** button to visualize the selected maps.

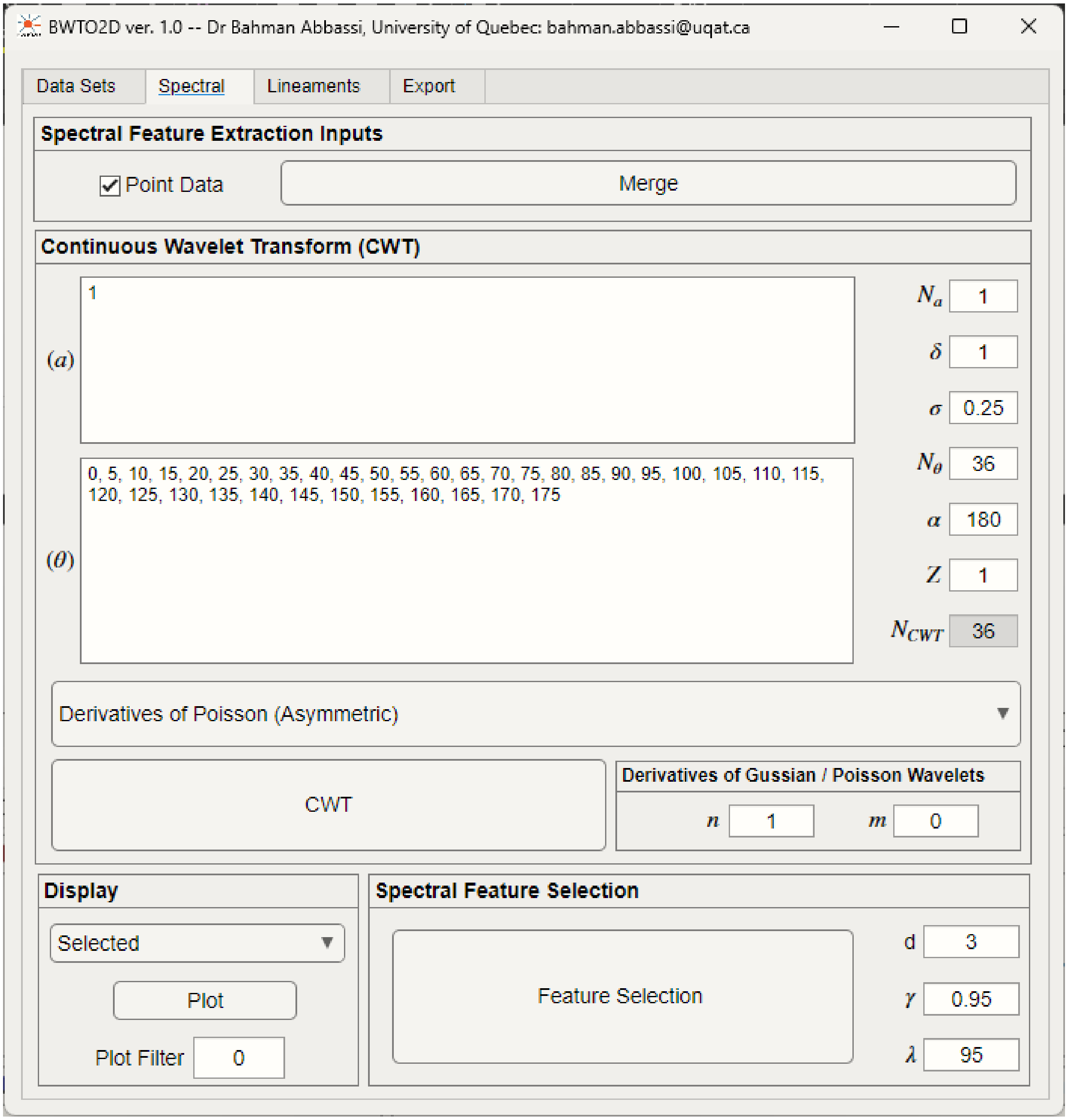

Figure 3: The Spectral tab for Spectral Feature Extraction stage.

7. Lineament Detection

This section covers the core lineament detection capabilities of BWTO2D. Here, you will use the spectral features generated in the previous step to identify and map geological lineaments. The tab is organized into two primary workflows: a **Semi-Automatic** process that provides manual control over parameters, and a fully **Automatic** process that uses Bayesian Topology Optimization (BTO). You can directly use the automated method without using Spectral tab.

7.1. Loading Target Data for Validation (Digitized Lineaments Panel)

If you have a pre-existing map of known lineaments (e.g., from manual interpretation or previous studies), you can load it here. This target data is used to calculate the F-beta score, which quantitatively measures how well the automatically extracted lineaments match the known ones.

How it works: You can load target lineaments from either an image file or a point data file. The application will georeference and grid this data according to the project's coordinate system.

Steps:

1. Click **Image** to load a .jpg, .png, or .bmp file. The application requires a corresponding .txt file with the same name in the same folder to georeference the image.
2. Alternatively, click **Point Data** to load a .csv or .xyz file of target points.
3. Set the parameters for processing the target data:
   - **Spacing**: The grid spacing in arc-seconds for the target map.
   - **Target Filter**: Applies a Gaussian filter to the loaded target data to smooth it.
   - **Cut-off 1 & Cut-off 2**: Threshold values automatically set to binarize the target image, isolating the lineament pixels. Default values are the most efficient values. Note: If you aim to change the spacing value, make sure the Cut-off 1 & Cut-off 2 boxes are empty before clicking on the Image/Point Data buttons.
   - **Radius 1 (r_1), Radius 2 (r_2), Beta (β)**: These parameters are used exclusively for calculating the F-beta validation score. r_1 defines the buffer around true positives, r_2 defines a larger buffer for identifying false positives, and β is the weight given to recall

over precision in the F-score calculation. The default values of r_1 = 10 and r_2 = 11 are mostly efficient in most cases.

7.2. Semi-Automatic Lineament Extraction

This workflow is ideal when you want to experiment with different parameters and have direct control over the lineament detection process.

1. **Merge Inputs:** In the Semi-Automatic Lineament Extraction panel, first select the features you want to use.
    - **P**: Check this to include the original Point Data.
    - **CWT Selected**: Check this to include the feature maps selected in the Spectral tab.
    - Click the **Merge** button to combine them.
2. **Set Extraction Parameters:**
    - **Resolution Factor (R)**: An integer to resize the input features before processing. A value of 1 uses the original resolution.
    - **Image Filter Ratio (σ_I)**: Applies a Gaussian filter to the input features before detection.
    - **Step Filtering Width (*w*)**: The kernel size for the directional step-filter. This is a critical parameter controlling the scale of the lineaments to be detected. If not sure, leave this box empty. When pushing the Merge button, the algorithm automatically sets the optimal w value.
    - **Variability of Step Filtering Width (*v*)**: A factor that dynamically adjusts the step filtering width (*w*) based on the variance of each feature map. This allows the algorithm to adapt to features of different strengths.
    - **Number of Step Filtering Angles (N_ϕ)**: The number of directions the step-filter will be applied in to detect lineaments at various orientations.
    - **Lineament confidence threshold (ξ)**: A percentile-based threshold used to keep only the most prominent detected lineaments based on their strength.

3. **Run Extraction:** Click the **Lineament Extraction** button. The application will run the detection algorithm on each merged feature using the specified parameters.

7.3. Automatic Lineament Extraction with BTO

This fully automatic workflow is the most advanced feature of BWTO2D. It independently runs the entire analysis pipeline—from feature generation using CWT to feature selection and final lineament extraction—while automatically optimizing all critical hyperparameters. Therefore, using the Spectral tab beforehand is not required for this mode.

- **How it works:** The application uses a Bayesian optimization algorithm (bayesopt) to intelligently search the parameter space. For each set of trial parameters, it extracts lineaments and evaluates the result using an objective function that measures the "representativeness" of the resulting lineament graph. It seeks to find parameters that produce a map of distinct, well-connected lineaments.

- **Steps:**

  1. **Merge Inputs:** In the Automatic Lineament Extraction panel, check the **P** box to include the Point Data and click **Merge**.

  2. **Select Mother Wavelet:** Choose the mother wavelet to be used for the internal CWT calculations. The Derivatives of Poisson (Asymmetric) is often a good choice for potential field data.

  3. **Set Optimization Parameters:**

     - **BTO Max Iterations**: The number of different parameters set the optimizer will try. A higher number increases the chance of finding the best result but takes longer.

     - The parameters marked with an asterisk (*) are the hyperparameters that the BTO algorithm will automatically optimize. Their search ranges are fixed within the program; however, the user can define the central value for the Step Filtering Width (w^*). The optimization will then search for the optimal w^* in a range around this central value. If left empty, an optimal central value will be estimated automatically.

    - Other parameters in this panel (R, σ_I, etc.) serve as fixed constraints.

4. **Run Optimization:** Click the **Lineament Extraction (BTO)** button. The process will begin and may take a significant amount of time depending on the number of iterations.

5. **View Results:** Once complete, the optimal parameters found by the BTO process will populate the disabled fields marked with an asterisk (*). The final lineament map generated with these optimal parameters is stored and ready for display.

7.4. Displaying and Analyzing Lineament Results

The **Display** panel is used to visualize all outputs from the Lineaments tab.

- **Available Plots:**
    - **Target Data:** Target Lines, Rose Diagram (Target).
    - **Manual Results:** All Lineaments (Manual) (shows individual feature results in tabs), Curvilinearity Control (Manual), Line Densities (Manual), Lineaments (Manual) (stacked result), Deep/Shallow Lineaments (Manual), Rose Diagram (Manual), and Fbeta Score (Manual).
    - **Automatic Results:** All of the same plots as the manual mode (All Lineaments (Auto), etc.), plus several diagnostic plots for the optimization process:
        - **BHO Performance (Auto)**: Shows the convergence of the optimization algorithm over iterations.
        - **BHO Progress (Auto)**: Shows how the value of each hyperparameter changed during the search.
        - **Feature Correlation Matrix (Auto)**: A heatmap showing the correlation between the different hyperparameters.
        - **Importance (Auto)**: A bar chart showing the relative importance of each hyperparameter in achieving the final result.

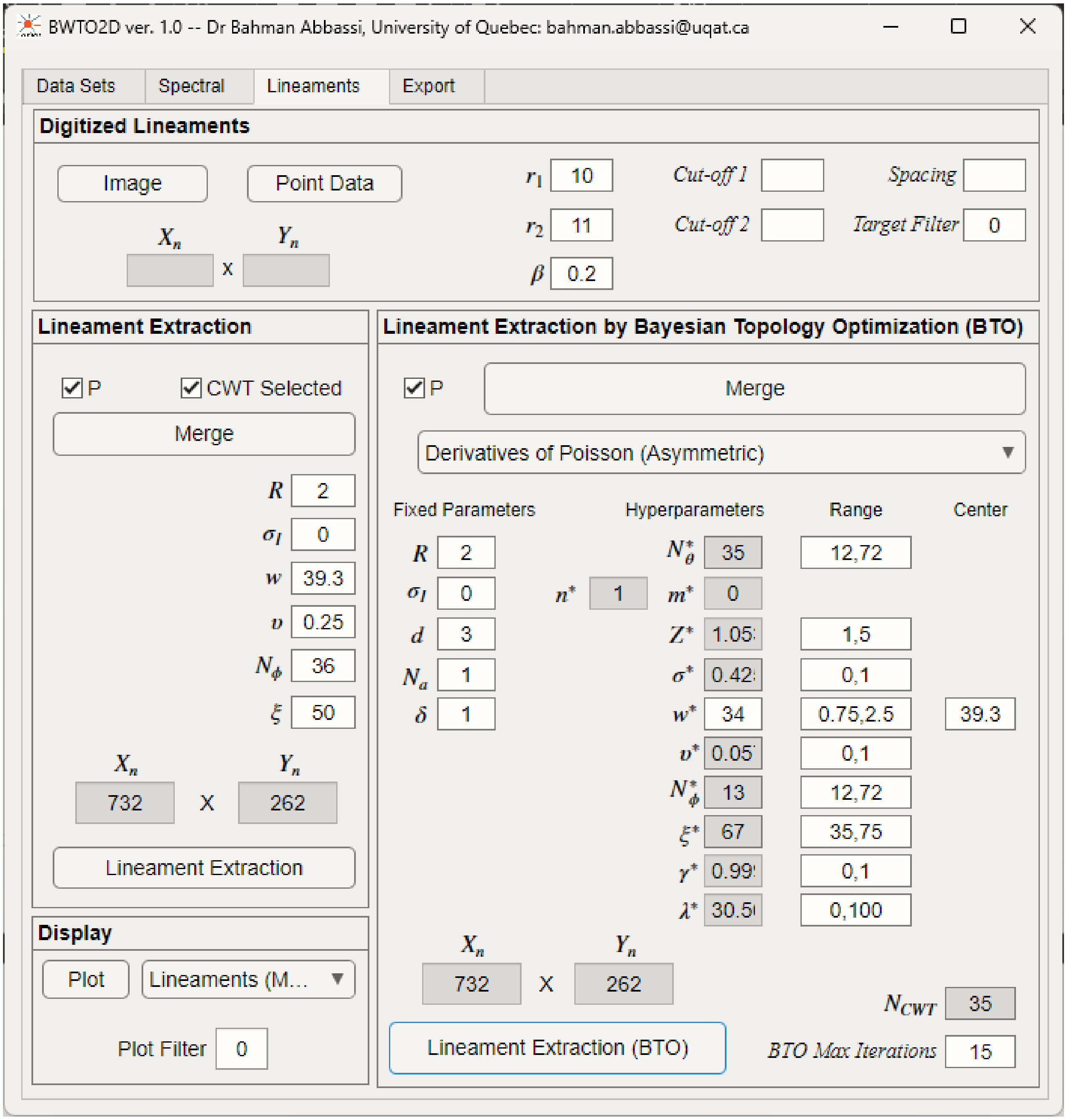

Figure 4: The Lineaments tab for semi-automatic and automatic lineament detection stage.

8. Exporting Results

After completing your analysis, the **Export** tab provides a comprehensive set of options to save your work. You can export raw data, intermediate feature maps, and final lineament products in formats suitable for GIS software and further numerical analysis.

8.1. Selecting Data for Export

The main panel in the Export tab is a large button group where you select the specific dataset you wish to save.

- **Selection:** Use the radio buttons to choose the data to export. The options are logically grouped:
    - **P Data**: The initial gridded point data.
    - **Manual CWT/Selected**: The full CWT results or the feature-selected maps from the semi-automatic workflow.
    - **Manual Lineaments**: The final lineament products from the semi-automatic workflow, including All Lines, Deep Lines, Shallow Lines, and Densities.
    - **Auto CWT/Selected**: The CWT and feature-selected maps generated during the automatic (BTO) workflow.
    - **Auto Lineaments**: The final lineament products from the automatic workflow.
- **Feature Number (#)**: When exporting a dataset that contains multiple maps (like CWT or Selected features), this numerical field allows you to specify the index of the single map you wish to export. For example, to export the 5th CWT feature map, you would set this value to 5.

8.2. Exporting to CSV Format

This option is useful for exporting gridded data into a simple text format.

- **How it works:** For any selected gridded dataset (e.g., CWT (Manual), Densities (Auto)), this function saves a three-column ASCII file: X-coordinate, Y-coordinate, and Value. For lineament data, it saves the coordinates of the vertices that make up the lines.

- **Steps:**
    1. Select the desired dataset using the radio buttons.
    2. If applicable, specify the feature number in the # field.
    3. Click the **Export to CSV** button. A file save dialog will appear, allowing you to choose a location and name for your file.

8.3. Exporting to GIS Formats (GeoTIFF and Shapefile)

This is the most powerful export option, as it saves your data in standard geospatial formats, preserving spatial referencing for easy integration into GIS platforms like ArcGIS or QGIS.

- **How it works:** The **Export to TIF** button has dual functionality depending on the type of data selected.
- **Steps:**
    1. Select the desired dataset using the radio buttons.
    2. If applicable, specify the feature number.
    3. Click the **Export to TIF** button.
- **Export Behavior:**
    - If you select a **gridded dataset** (like P Data, CWT, Selected, or Densities), the application will save the data as a **GeoTIFF (.tif) file**. This is a standard raster format that stores the georeferencing information (coordinate system and extent) directly within the file.
    - If you select a **lineament dataset** (like All Lines, Deep Lines, or Shallow Lines), the application will save the vector lineaments as an **Esri Shapefile (.shp)**. This is the industry-standard vector format for geospatial data and is created using the shapewrite function from the MATLAB Mapping Toolbox.

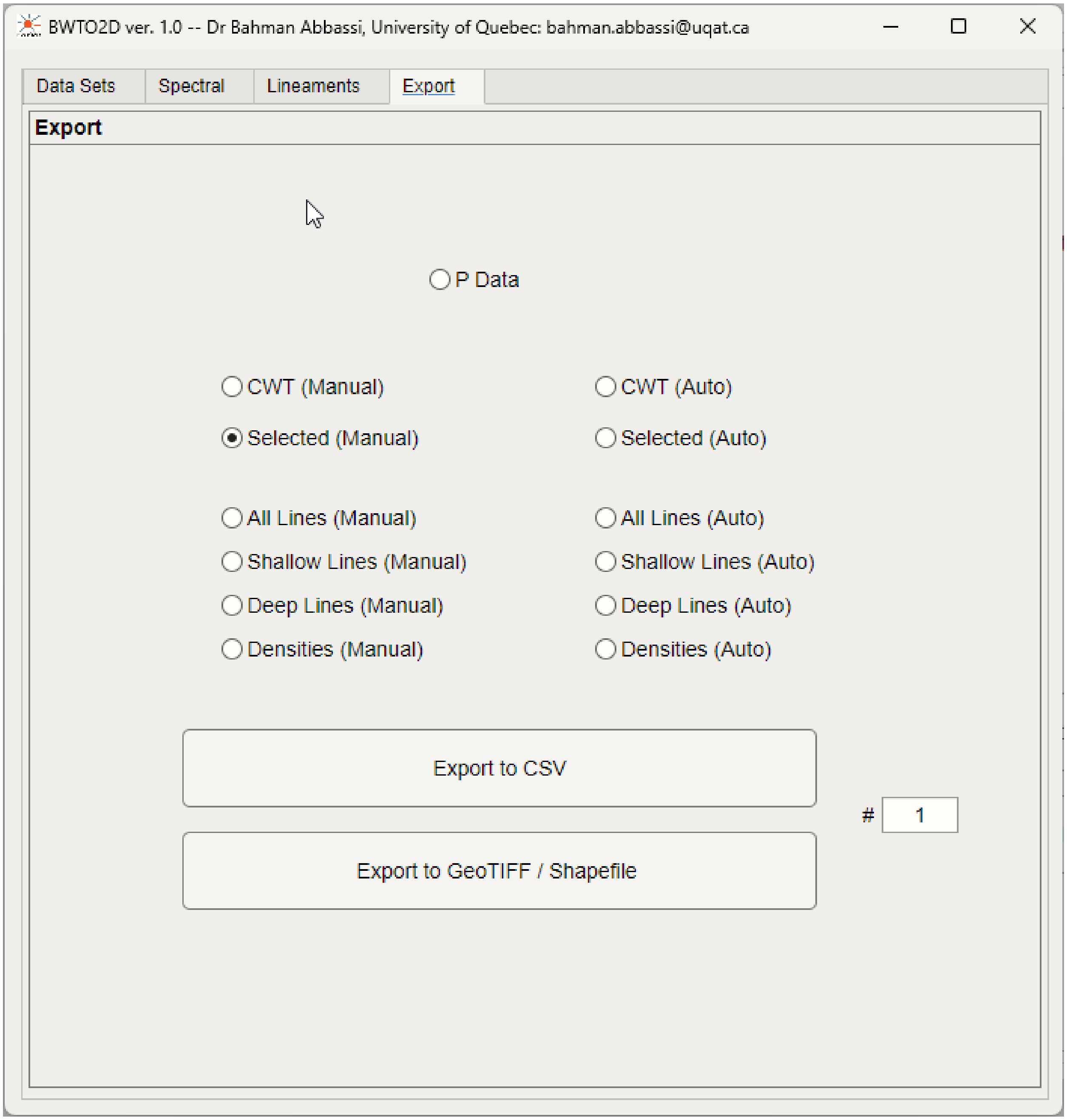

Figure 5: Exporting results in the form of CSV, GeoTIFF and Shapefile (vector) formats.

Conclusion

This manual has guided you through the complete workflow of the BWTO2D application, from loading and preparing your data to extracting lineaments using both manual and advanced automated techniques. By leveraging the power of wavelet analysis and Bayesian optimization, BWTO2D provides a robust and flexible tool for geological feature detection. We hope you find it valuable in your research and exploration endeavors.

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