

IDCUBE PRO MANUAL

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23

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www.idcubes.com

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1. Introduction to IDCubePro® – Interactive Discovery Cube

Multi- and hyperspectral imaging modalities encompass a growing number of spectral techniques that find many applications in geospatial, biomedical, machine vision, and other fields. The rapidly increasing number of applications requires convenient easy-to-navigate software that can be used by new and experienced users to analyze data, develop, apply, and deploy novel algorithms. Herein, we present our platform, **IDCubePro®**, an Interactive Discovery Cube that performs essential operations in hyperspectral data analysis to realize the full potential of spectral imaging. The strength of the software lies in its interactive features that enable the users to optimize parameters and obtain visual input for the user in a way not previously accessible with other software packages. The entire software can be operated without any prior programming skills allowing interactive sessions of raw and processed data. Similar to the launched 2020 **IDCubeLite®**, a free version of the software¹ available from <https://www.idcubes.com/>, **IDCubePro®** presents many benefits and offers structural flexibility to discover new, hidden features.

Multi and hyperspectral imaging (HSI) modalities have emerged as an exciting opportunity to explore the optical properties of objects and discover hidden features not accessible by other techniques. In contrast to

¹ Mishra D, Hurbon H, Wang J, Wang ST, Du T, Wu Q, Kim D, Basir S, Cao Q, Zhang H, Xu K, Yu A, Zhang Y, Huang Y, Garnett R, Gerasimchuk-Djordjevic M, Berezin MY. IDCube Lite: Free Interactive Discovery Cube software for multi- and hyperspectral applications. *J Spectr Imaging*. 2021;10: doi: 10.1255/jsi.2021.a1.

the traditional spatial images produced by conventional cameras, spectral imaging generates 3D datasets (datacubes), with spatial and spectral dimensions. With each pixel containing information of the entire medium or high-resolution spectrum, spectral imaging provides abundant information about individual chromophores and their interactions that contribute to the location, intensity, and alteration of the optical signal, significantly better than monochromatic or traditional color cameras. This spectral imaging approach leads to a vastly improved ability to classify and differentiate the objects based on their spectral features, enabling even small, otherwise unnoticeable, features to be amplified.

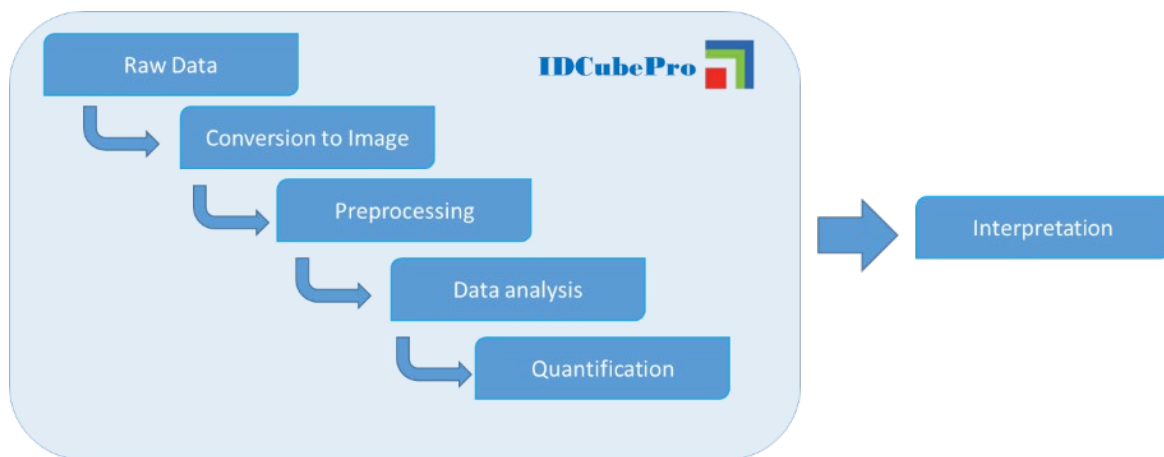
In the last decade, spectral imaging expanded from the narrow niche accessible only to a handful of organizations in academic and governmental research facilities to a broad range of commercial institutions. As spectral imaging hardware (benchtop scanners, handheld HSI cameras, imaging satellites, drones, etc.), has become more available, the number of spectral imaging applications has tremendously increased.

Meaningful analysis of datacubes is the most critical and time-consuming step in many current applications. The high dimensionality of spectral imaging data and their large data sizes (often > 1 GB) gives an excellent opportunity to learn more about the subject; however, the extensive and efficient analyses (i.e., pretreatments, algorithms, visualizations, etc.) of these datasets present the strongest barrier to the imaging workflow. IDCubePro® breaks this gap by bringing a universal, powerful computational platform that enables comprehensive and rapid data analysis for a variety of spectral imaging platforms.

2. Getting Started with IDCubePro®

IDCubePro® is a highly versatile software that performs a large number of essential operations in the spectral imaging domain and enables image analysis for users across a range of technical proficiencies. The goal of the software is to make spectral imaging accessible to new and current users that focus on obtaining useful results rather than (but not excluding) developing algorithms. The strength of the proposed software lies in its intuitive design that enables the user to perform high-level data analysis as well as develop new algorithms via a visual, interactive interface. Built around a collection of spectral imaging algorithms, the software facilitates the search of hidden information inside large datasets providing a new experience of data analysis.

The overall workflow of the IDCubePro® in multi- and hyperspectral (or any three-dimensional data, i.e. time-lapse data, fluorescence lifetime imaging data, etc) is illustrated in this diagram.



3. Representing Hyperspectral Data

The values measured by a hyperspectral imaging sensor are stored in a binary data file in a variety of formats such as *ENVI*, *tiff*, *png*, *mat* (*matlab*), *excel*, *Dicom* (*dcm*), *NIFTI* (*nii*) and others. The data file is often associated with a header file that contains ancillary information (metadata) like sensor parameters, acquisition settings, spatial dimensions, spectral wavelengths, and encoding formats that are required for proper representation of the values in the data file.

For hyperspectral image processing, the values read from the data file are arranged into a three-dimensional (3-D) array of form M -by- N -by- C , where M and N are the spatial dimensions of the acquired data, C is the spectral dimension specifying the number of spectral bands/channels such as wavelengths used during acquisition. Thus, one can consider the hyperspectral image as a three-dimensional (3D) dataset in the form of a stack composed of a set of two-dimensional (2D) monochromatic images. This type of dataset is called a *hyperspectral datacube* or simply a *datacube*.

IDCubePro® extracts the data from the datasets and constructs the datacube by reading the data file and the metadata information and combining them in one file. The generated by IDCubePro® single file stores the datacube and spectral wavelengths. Additional header information can be extracted and stored separately.

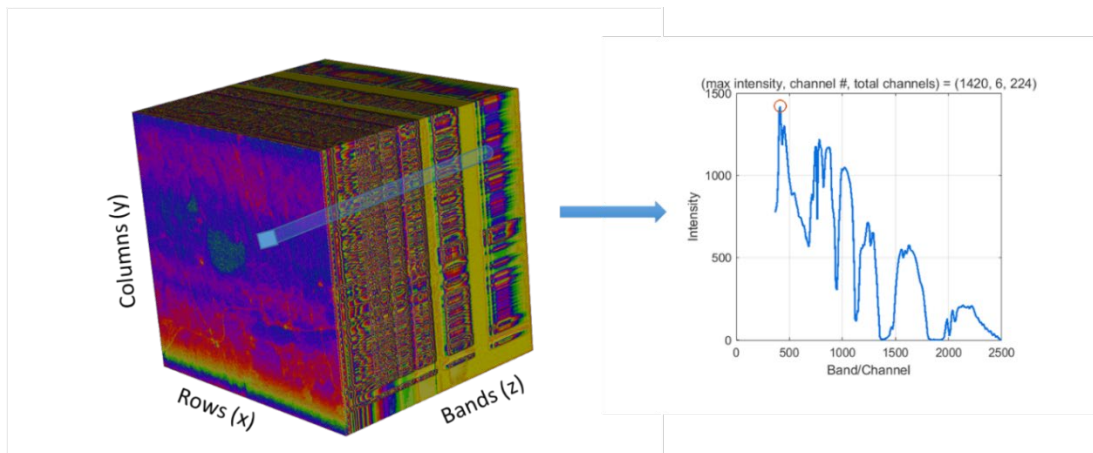
Note, that while IDCubePro® can handle a variety of formats and sources, each hyperspectral imaging system is unique and might need a distinct plugin function to be developed separately.

Color Representation of the Datacube

To visualize and understand the object being imaged, it is important to represent the datacube as a set of 2D images by using a variety of color schemes. The color representation of the datacube enables you to visually inspect the data and facilitate interpretation. You can select a colormap from an extensive menu and use interactive sliders to visualize false color monochromatic and Red-Green-Blue (RGB) representations of the datacube. In addition, IDCubePro® offers a variety of 3D plots to represent the 2D image (such as surface plots). Finally, the user can employ a powerful **3D Viewer Toolbox** to visualize and process the entire datacube.

Preprocessing

Hyperspectral imaging sensors are typically characterized by high spectral resolution and low spatial resolution. By analyzing the pixels of the acquired hyperspectral data, we can determine the spatial and spectral characteristics. Pixels, when viewed individually, are vectors of values that describe the intensity of a location (x,y) along z different bands. Pixel spectra are critical elements of spectral data analysis. These pixel spectra are often distorted due to factors such as sensor noise, uneven light conditions, the presence of spectral artifacts, and low resolution. In addition, there is a number of spatial artifacts that distort the true image. You can identify anomalous pixels and assess the quality of the image to judge where it is useful. The IDCubePro® software offers a wide range of preprocessing techniques for removing undesirable artifacts.



To enhance the spatial resolution of hyperspectral data, you can use image fusion methods. The fusion approach combines information from the low-resolution hyperspectral data with a high-resolution multispectral data or panchromatic image of the same scene. This approach is also known as *sharpening* or *pansharpening*. IDCubePro® offers several functions for sharpening hyperspectral data using high spatial resolution multispectral images.

Dimensionality reduction is another preprocessing step that is necessary for all hyperspectral imaging applications. A large number of bands in the hyperspectral data increases the computational complexity of data processing. At the same time, the contiguous nature of the band images results in redundant information across bands. Neighboring bands in a hyperspectral image have a high correlation, which results in spectral redundancy. These bands can be removed without losing important information. You can visualize the redundancy by building a correlation matrix and removing the redundant bands, thus decreasing dimensionality.

Compression methods include powerful methods based on Principal Component Analysis, Independent Component Analysis and Wavelets transformation techniques.

IDCubePro® offers several approaches for reducing the spectral dimensionality of a datacube from relatively straightforward band removal and spectral binning to orthogonal transforms using principal component analysis (PCA) and maximum noise fraction (MNF). **PCA** and **MNF** toolboxes transform the original datacube into a new datacube where the bands/channels are replaced with principal components. The total number of principal components is equivalent to the number of bands/channels in the original dataset. The software presents principal components in descending order of the amount of total variance, with the most important components coming first. The newly generated datacube can be saved for further hyperspectral data analysis. To reduce the size of the datacube, the user can perform ‘spectral’ cropping keeping only the most important components (i.e., the first 10 components). Spectral dimensionality reduction using PCA or MNF is implemented in several toolboxes such as **Endmembers Extraction** and **t-SNE**. Alternatively, you can apply **PCA** or **ICA** (independent component analysis) compression.

Spectral Unmixing and Classification

In a hyperspectral image, the intensity values recorded at each pixel in the region specify the spectral characteristics of the region. The pixels that belong to a homogeneous profile with a relatively pure spectral signature are known as *pure pixels*. These pure pixels constitute the *endmembers* of the hyperspectral data. Heterogeneous profiles are a combination of two or more distinct homogeneous surfaces. The pixels belonging to heterogeneous profiles are known as *mixed pixels*. The spectral signature of a mixed pixel is a combination of two or more endmember signatures. This spatial heterogeneity is often due to the low spatial resolution of the hyperspectral sensor but might also represent a physical mixture of two signals. *Spectral unmixing* is the process of decomposing the spectral signatures of mixed pixels into their constituent endmembers. The spectral unmixing process involves two steps: *Endmember extraction* and *Spectral Matching* implemented in **Endmember Extraction** and **Spectral Matching Toolboxes**.

Endmember extraction — The spectra of the endmembers are prominent features in the hyperspectral data and can be used for efficient *spectral unmixing*, *segmentation*, and *classification* of hyperspectral images. Convex geometry-based algorithms, such as pixel purity index (PPI), fast iterative pixel purity index (FIPPI), and N-finder (N-FINDR) are some of the efficient approaches for endmember extraction. Once the endmembers are identified, you can estimate the fractional amount of each endmember present in each pixel. This can be achieved by constructing the *abundance maps* for each endmember, which represent the distribution of endmember spectra in the image.

Spectral matching — IDCube enables the user to interpret the pixel spectra by performing *spectral matching*. Spectral matching identifies the class of an endmember material by comparing its spectra with a reference spectrum. The reference spectra usually represent pure spectral signatures of materials, which are available as spectral libraries in the *ECOSTRESS* format² available from <https://speclib.jpl.nasa.gov/>. With IDCubePro®, you can also generate your own reference spectra and save them in the *ECOSTRESS* format. Then, you can compute the similarity between the saved spectra and the entire datacube.

Hyperspectral image processing applications include classification, target detection, anomaly detection, and other types of analysis.

- You can segment and classify each pixel in a hyperspectral image through a variety of unmixing algorithms, such as *Spectral Angle Mapping*, *Phasor*, *k-Means*, *t-SNE*, or *Contrast Maximization*.

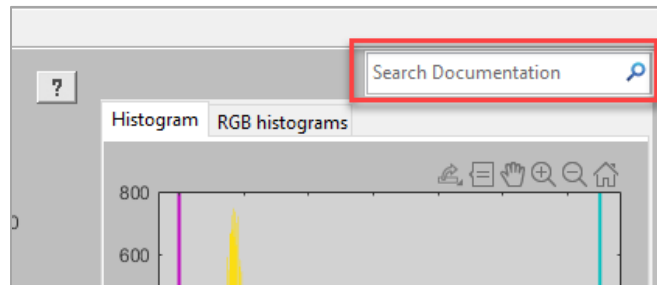
² Meerdink, Susan K., et al. "The ECOSTRESS spectral library version 1.0." *Remote Sensing of Environment* 230 (2019): 111196.

- You can perform target detection by matching the known spectral signature of a target material to the pixel spectra in hyperspectral data.
- You can also use hyperspectral image processing for anomaly detection and material analysis.

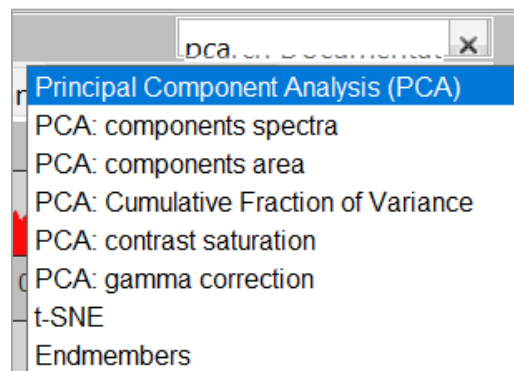
You can also perform machine learning techniques for advanced segmentation.

Search Documentation

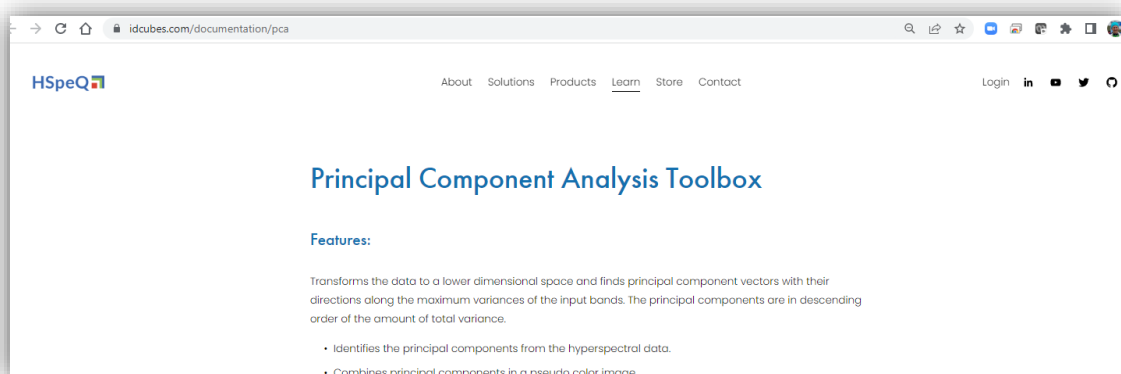
Typing in this field allows you to search the documentation right from the IDCube interface. Start typing any of the terms and you will be connected with a relevant section of the technical documentation on our IDCube website.



For example, typing PCA will give a list of links to the website-located information.



The information from the website will be open:



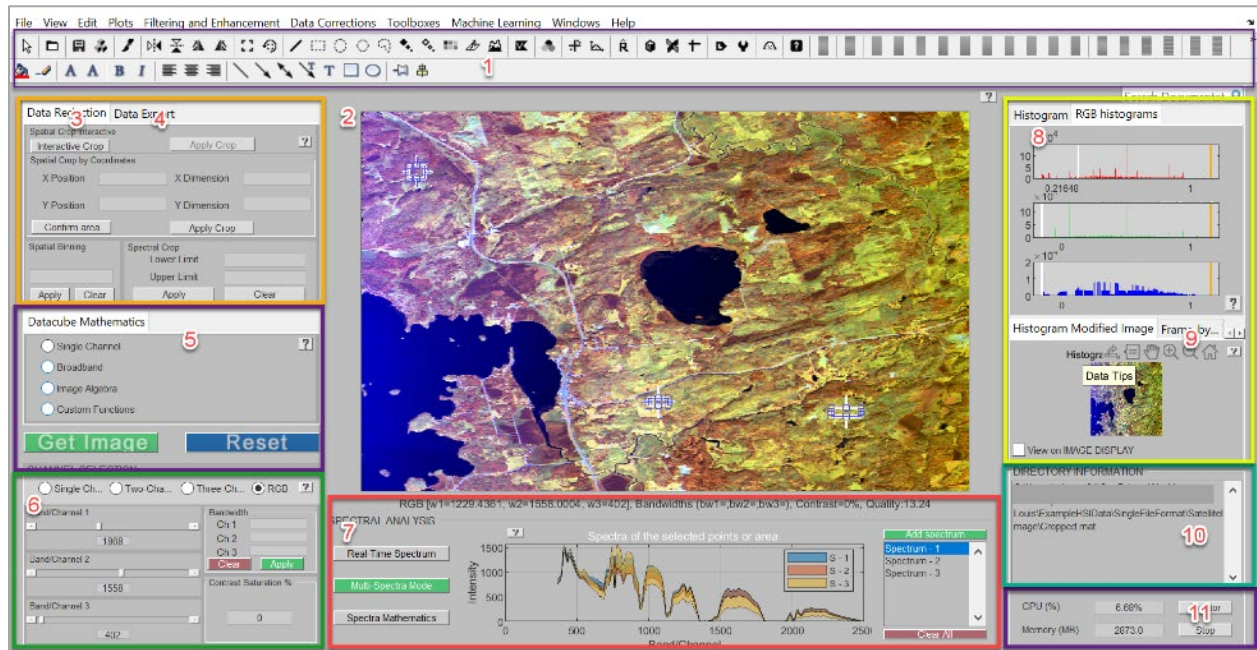
Keyboard and Mouse Shortcuts

The implemented keyboard and mouse shortcuts can be applied to most images and plots, including image display, spectral plots, and histograms. The following shortcuts enable quick manipulation of the image space.

| Shortcut | Description |
|--------------------------------------|---|
| Help with shortcuts | |
| H | Press 'H' at any time to display Help. Dismiss by pressing 'H' again. |
| Image zoom shortcuts | |
| Z | Zoom In |
| Shift+Z | Zoom Out |
| X | Zoom in X Dimension |
| Shift+X | Zoom Out in X Dimension |
| Y | Zoom in Y Dimension |
| Shift+Y | Zoom Out in Y Dimension |
| Directional Control | |
| Arrow Keys | Arrow keys can be used for Pan |
| Image modifications shortcuts | |
| N | Normal Axes/Expand Image |
| E | Equal Axes/Normal Image |
| G | Toggle Grid |
| Spacebar | Toggle Axis Ticks |
| Mouse Controls | |
| Left Click | Activate Zoom/Pan Functions |
| Right Click | Pan in any direction |
| Scroll In/Out | Zoom In/Out |

4. Main Interface

The software is built using a modular architecture. The heart of the IDCubePro® is the **Main Interface** that is composed of the following panels:


























Panels in the Main Interface:













1. Toolbar Panel, 2. Image Display Panel, 3. Data Reduction Panel, 4. Data Export Panel, 5. Datacube Mathematics Panel, 6. Interactive Band/Channel Selection Panel, 7. Spectral Analysis Panel, 8. Image Adjustment Panel, 9. Frame-By-Frame Panel, 10. Directory Information Panel, 11. Computer Information Panel (might not be available in Mac OS).

5. Toolbars

Features: Many of the toolboxes and features have accompanying icons. This manual covers each type of icon in the corresponding sections.



| Icon | Function |
|---|--|
|  | Plot Edit Mode |
|  | Open IDCube format |
|  | Close the file with or without saving the changes. IDCube interface returns to the original view |
|  | Save As... |
|  | Flips the main image horizontally |
|  | Flips the main image vertically |
|  | Rotate clockwise |
|  | Rotate counterclockwise |
|  | Activates crop |
|  | Measures the distance between two points using a straight line and visualizes the profile (see Area Information Toolbar) |
|  | Measures the area of the rectangle in a specific region of interest <ul style="list-style-type: none"> Provides mean, standard deviation, and pixel area (see Area Information Toolbar) |
|  | Measures the area of the circle in a specific region of interest <ul style="list-style-type: none"> Provides mean, standard deviation, and pixel area (see Area Information Toolbar) |
|  | Measures the area of the polygon in a specific region of interest <ul style="list-style-type: none"> Provides mean, standard deviation, and pixel area (see Area Information Toolbar) |
|  | Measures area of freestyle shape in a specific region of interest <ul style="list-style-type: none"> Provides mean, standard deviation, and pixel area (see Area Information Toolbar) |
|  | Activates Principal Component Analysis (PCA) toolbox |
|  | Activates Maximum Noise Fraction (MNF) toolbox |
|  | Activates Classification toolbox |
|  | Activates Spectral Signature Matching (SSM) toolbox |
|  | Activates Endmembers toolbox |
|  | Activates Vegetation Indices toolbox |
|  | Activates Maximize Contrast Between Two Regions toolbox |
|  | Activates t-SNE Clustering toolbox |
|  | Activates Phasor Clustering Segmentation toolbox |

| | |
|---|--|
|  | Activates Correlation Matrix (R-squared plot) toolbox |
|  | Activates 3D Viewer toolbox |
|  | Opens Get 3D Slice under the 3D Viewer toolbox |
|  | Opens Get orthogonal slice under the 3D Viewer toolbox |
|  | Opens the Data Fusion toolbox |
|  | Opens the labeling tool for machine learning |
|  | Activates Machine Learning toolbox |
|  | Resets to the original dataset |
|  | Opens a LUT generator |
|  | Stop calculations |
|  | Keyboard shortcuts |
|  | Information |

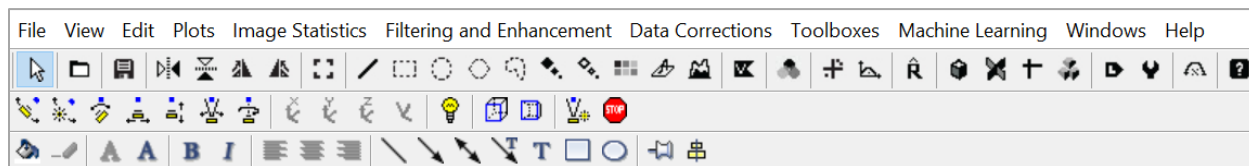
5.1. Working in the Plot Edit Mode

The IDCubePro® supports a point-and-click editing mode that you can use to customize the appearance of your graphs, panels, and entire windows. This section describes how to enter the **Plot Edit** mode and perform basic editing tasks, including selecting, cutting, copying, pasting, moving, and resizing objects and modifying other images, plots, and panels properties.

Starting Plot Edit Mode


Before you can select objects in a figure by clicking on them, you must activate the plot-editing mode. There are several ways to activate a **Plot Edit** mode:

Choose the **Edit Plot** icon  on the figure window **Main Toolbar** menu or select **Edit Plot** from the **Edit** menu. You can also use a hot key **Ctrl+E**.



When an interface window is in the **Plot Edit** mode, the **Edit Plot** button in the toolbar is depressed and turned blue.

Exiting Plot Edit Mode

To exit the **Plot Edit** mode, click the selection button . When the **Plot Edit** mode is turned off, this button is no longer depressed, and its color is grey.

Selecting Objects in a Graph

To select an object in a graph, move the cursor over the object and click it.

To select multiple objects at the same time, move the cursor over an object and press **Shift+Click** to select it. Repeat for each object you want to select. You can perform actions on all the selected objects. For example, to remove a textbox annotation and an arrow annotation from a graph, select the objects and then click **Delete**.

Deselecting Objects

To deselect an object, move the cursor off the object onto the figure window background and click the left mouse button (this deselects all selected objects and selects the one you clicked). You can also **Shift+Click** on a selected object to deselect it (doing this will not deselect any other object).

Copying and Pasting Annotation Objects

In the **Plot Edit** mode, you can copy and paste annotations such as textboxes, text arrows, rectangles, and ellipses, in various combinations. If any such objects happen to be pinned to their axes (see **Pinning a Point in the Image**), their copies are pasted unpinned.

Moving and Resizing Objects

To move or resize an object in a graph in the **Plot Edit** mode, perform these steps:

- Select the object.
- To move the object, drag it to the new location. You can also move it one pixel up, down, left, or right with the appropriate **Arrow key** on your keyboard.
- You can **Shift+Click** to select multiple objects and move them as a group. **Arrow keys** work well for this. However, when you resize one of several selected objects, only that object changes size.

NOTE: There are some restrictions on moving and resizing the objects such as panels. You can resize some panel objects, but you can only move them by dragging their edges, one at a time.

Undo/Redo — Eliminating Mistakes

Pressing **Ctrl+Z** enables you to undo a recent operation.

5.2. Area Information and Statistics: ROI Toolbar

The **ROI Toolbar** allows the user to select different areas of interest and acquire statistics from the selected area.



Line Measurement: Provides linear pixel measurement of selection. Allows the user to measure the distance between the points and generate the XY plot of pixel intensities.

Rectangle Measurement: Creates a rectangular region of interest. Allows the user to collect statistics from the ROI and generate a histogram of intensities.

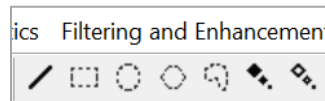
Elliptical Measurement: Creates an elliptical region of interest. Allows the user to collect statistics from the ROI and generate a histogram of intensities.

Polygon Measurement: Creates a polygon region of interest. Allows the user to collect statistics from the ROI and generate a histogram of intensities.

Freehand Measurement: Allows the user to freely draw a region of interest. Allows the user to collect statistics from the ROI and generate a histogram of intensities.

Line Measurement

1. Click the **Line** icon  from the **ROI Toolbar** menu.

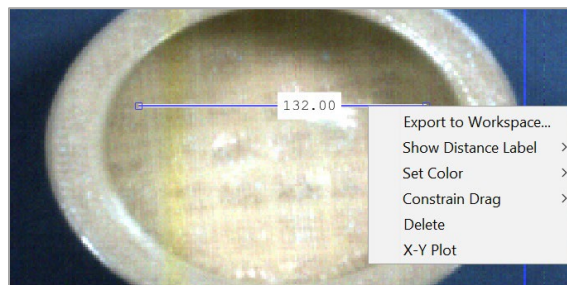


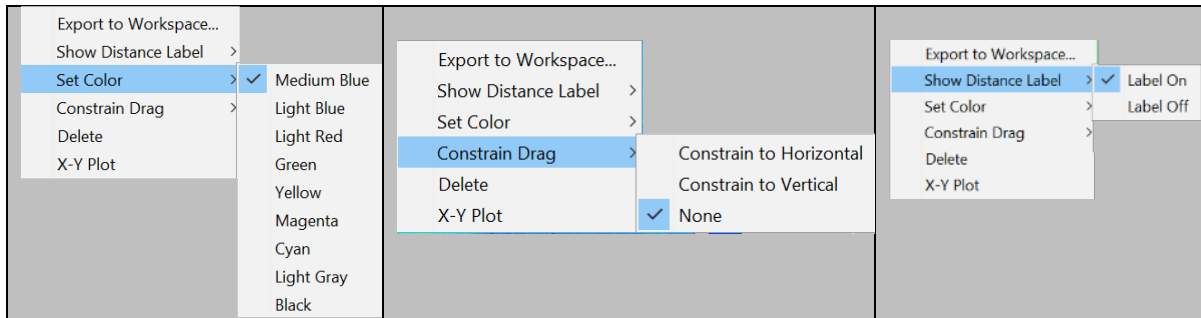
NOTE: In the **Main interface**, activation of the **Line** icon automatically places the line inside the image panel. For the IDCube toolboxes, *you might need to choose a specific panel* by clicking on the panel first and then clicking **Line**.

2. You can change the length of the line, its direction, and location by dragging the line or line ends to a new position.

The number inside the line yields the distance between the points. The distance is measured in pixels.

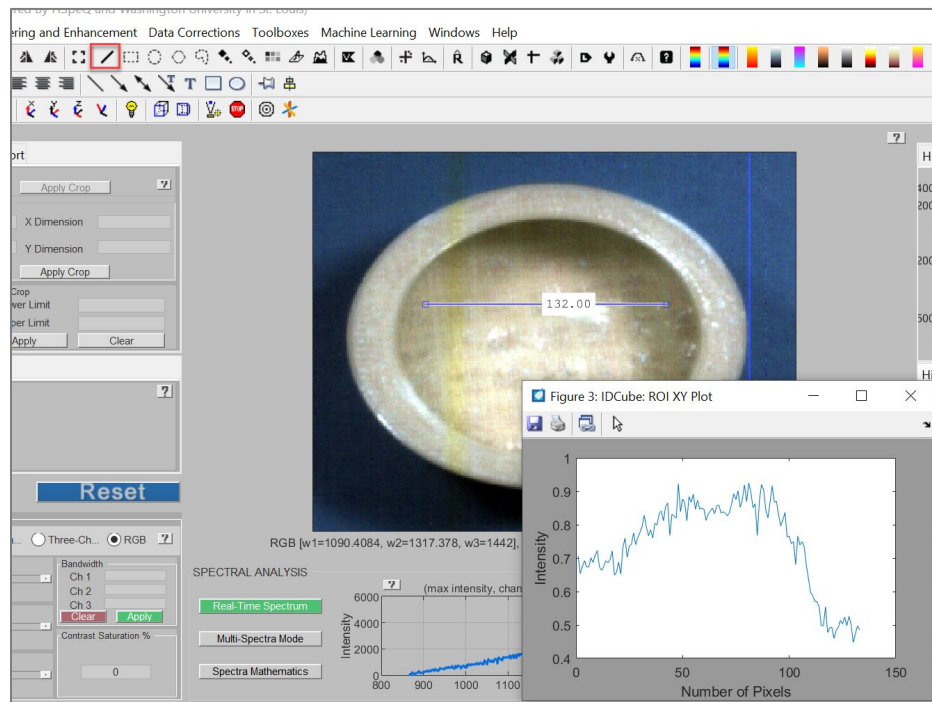
3. Use the **right-click** to activate a menu with several additional functions shown.





NOTE: Function **Export to Workspace...** is not available for IDCubePro® users.

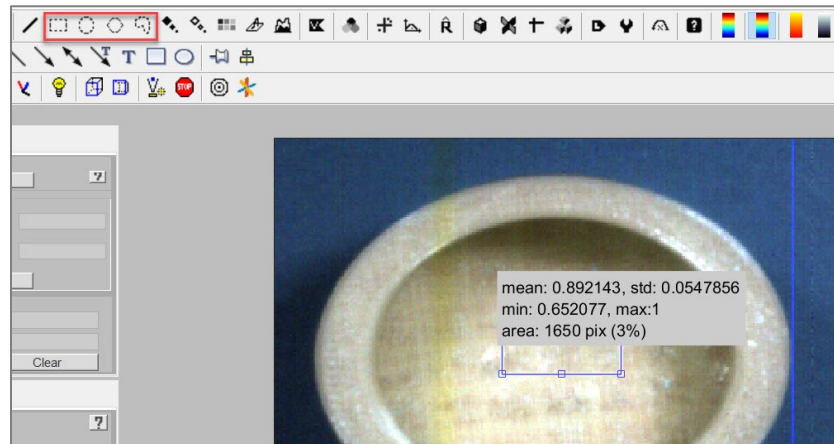
Selecting **X-Y Plot** creates a graph of intensity across the line. Moving the line will update the X-Y plot accordingly.



Area Measurement

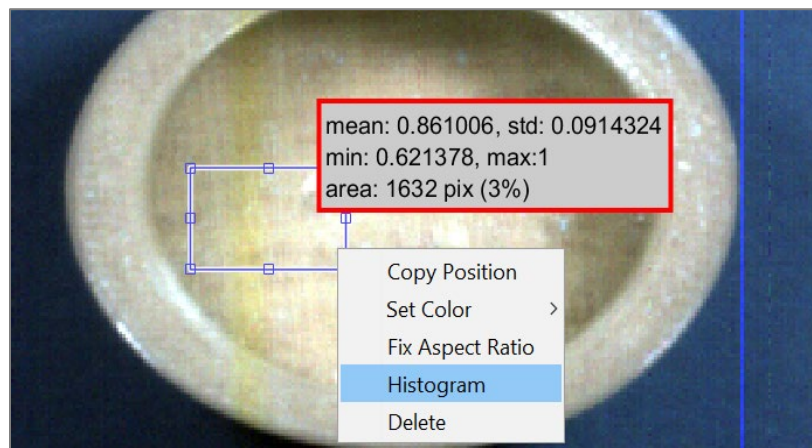
This tool provides basic statistics of the selected region: mean signal intensity, standard deviation, area, area % from the total image, intensity maximum and intensity minimum.

1. Select a region of interest with a **Rectangular, Ellipse, Polygon, or Freestyle**. A frame will be formed.

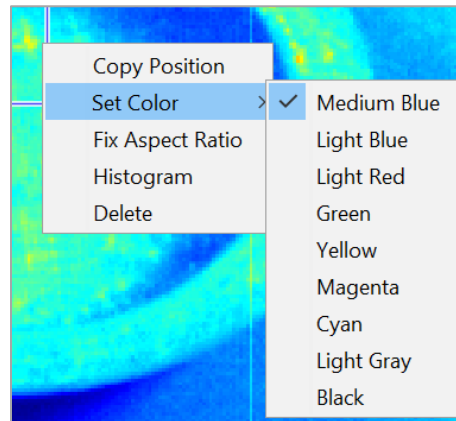


The region of interest will automatically display the region's mean pixel density, standard deviation, minimum, maximum, and area (and area percentage of the entire image).

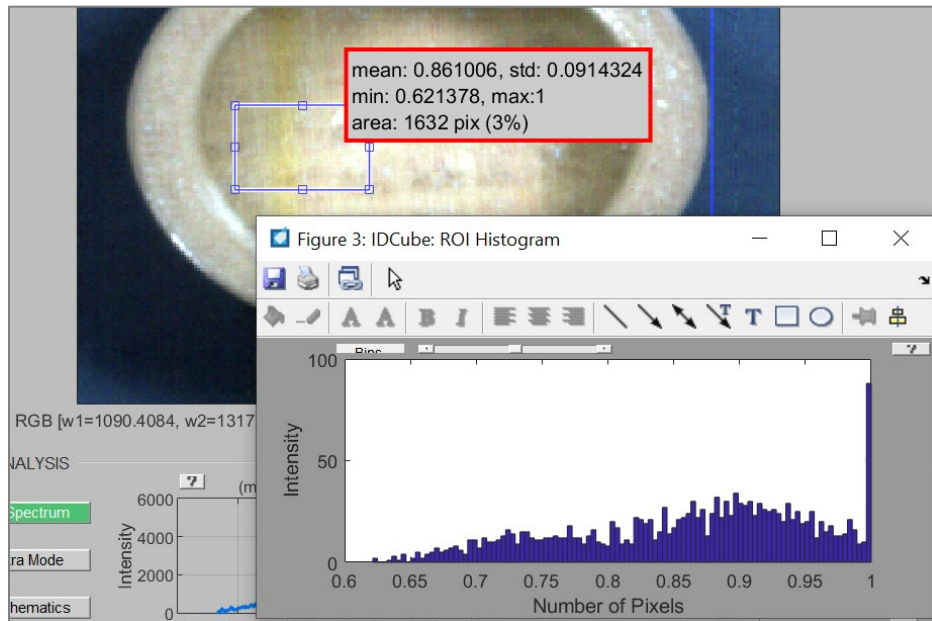
2. Drag the corners or the frame to a new location.
3. **Right-click** on the frame to open a selection menu.



- a) **Copy Position** enables the user to record and store a position. Click **Copy Position** and then Paste in your document. For the rectangular frame. The location coordinate will be in the following form: [X Y Width Height].
- b) Set **Color Selecting** histogram creates a graph of intensity vs the number of pixels.
- c) Select the color of the frame from the dropdown menu.



- d) **Fix Aspect Ratio** enables the user to move the frame without accidentally changing its shape.
- e) Visualize the histogram from the selected area. **NOTE:** Moving the region of interest will update the histogram accordingly. The number of bins in the histogram can be adjusted by moving the slider above the plot.



References

Yi Sui (2022). Add an ROI toolbar to your figure.

(<https://www.mathworks.com/matlabcentral/fileexchange/41120-add-an-roi-toolbar-to-your-figure>).

MATLAB Central File Exchange. Retrieved April 30, 2022.

5.3. Color Toolbar (LUT)

The **Color Toolbar** provides color adjustment through the variety of **Look Up Tables (LUTs)** options including a custom LUT generator and User-defined LUT:

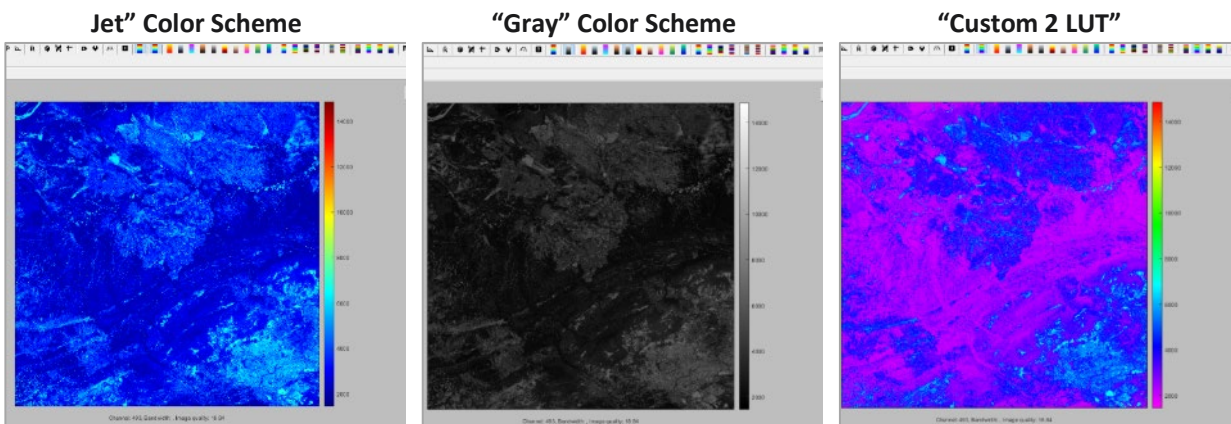


The first selection window displays the original color scheme, which is set to “jet” as default. The second selection window displays the previously selected color scheme. The following color schemes are available and are listed below in order from left to right: User Defined LUT, Autumn, Bone, Cool, Copper, Gray, Hot, Pink, Spring, Summer, Winter, Jet, HSV, Colorcube, Flag, Lines, and Prism.

LUT generator and the User defined colormap  is described in a corresponding section ([LUT generator](#)) and enables generating LUT and save it for future use.

Custom color schemes are also available (custom 1-4 LUT).

Examples:

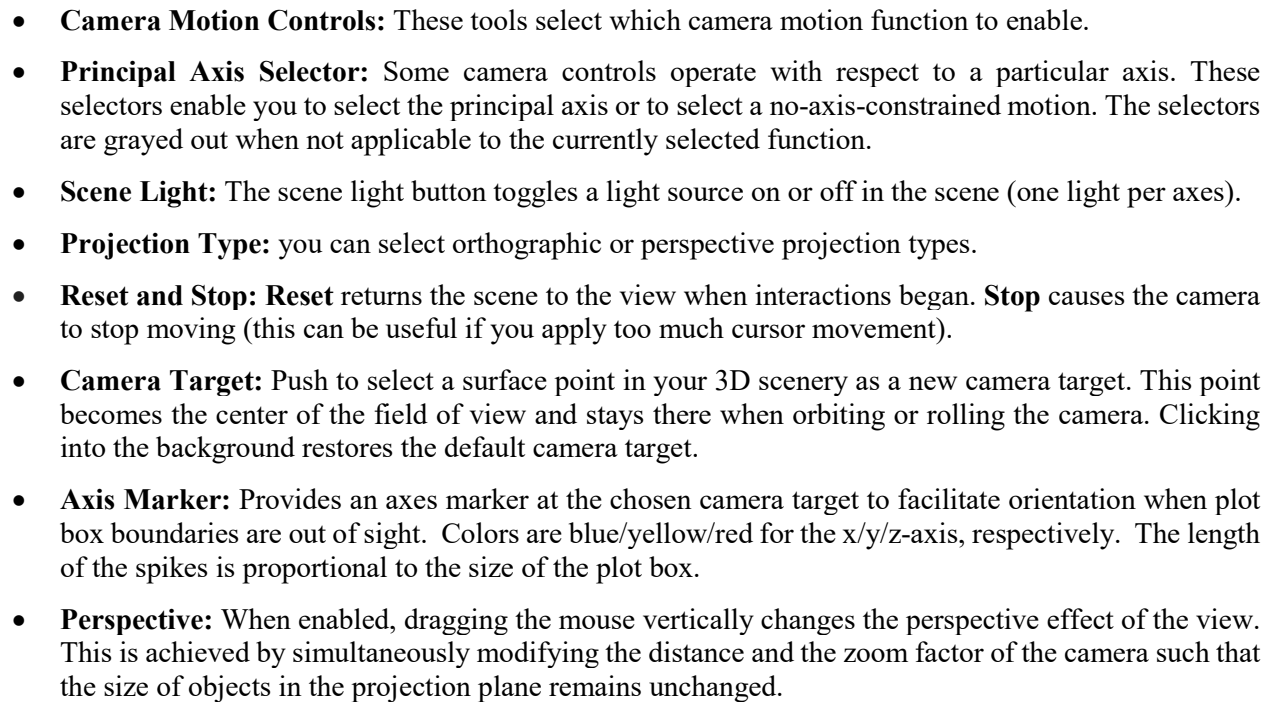


References

Based on: US (2022). lutbar: a pedestrian colormap toolbar/context menu creator (<https://www.mathworks.com/matlabcentral/fileexchange/9137-lutbar-a-pedestrian-colormap-toolbar-contextmenu-creator>), *MATLAB Central File Exchange*. Retrieved April 30, 2022.

The **Camera Toolbar** enables you to perform a number of viewing operations interactively in 3D. You can select the type of camera motion control by clicking on the toolbar buttons.

The toolbar contains the following parts:

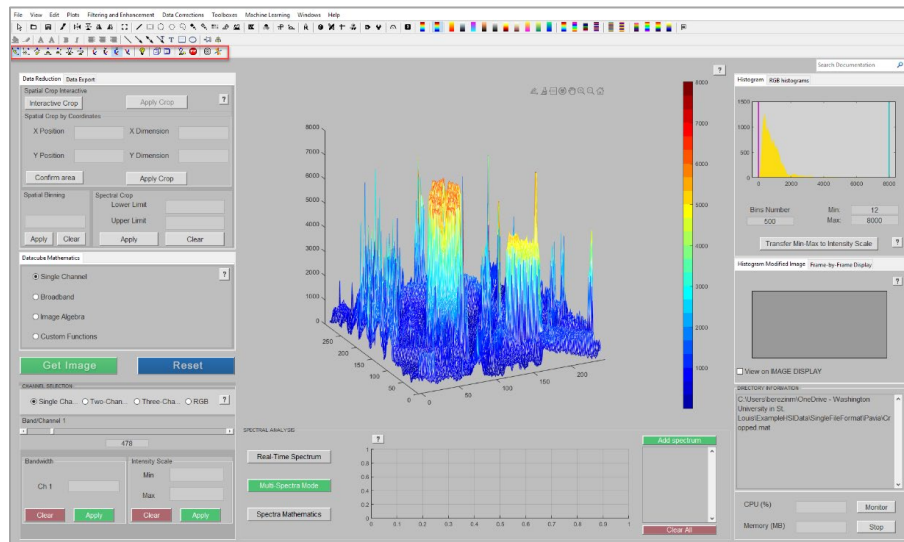


1. In the default vie Camera Toolbar is on. You can remove it by clicking Open a file and select **View** → **Close Camera Toolbar** or to put it back go to **View** → **Camera Toolbar**.

| View | Edit | Plots | Image Statistics | Fi |
|-------------------------|------|-------|------------------|----|
| Camera Toolbar | | | | |
| Colortheme | | | | > |
| Close LUT Toolbar | | | | |
| List of Bands/Channels | | | | |
| Image Scale | | | Ctrl+G | |
| Expanded View | | | Ctrl+N | |
| View Header Information | | | | |
| View Image Information | | | Ctrl+I | |
| View HeatMap | | | | |
| Edit Plot | | | Ctrl+E | |
| Turn Instructions Off | | | | |

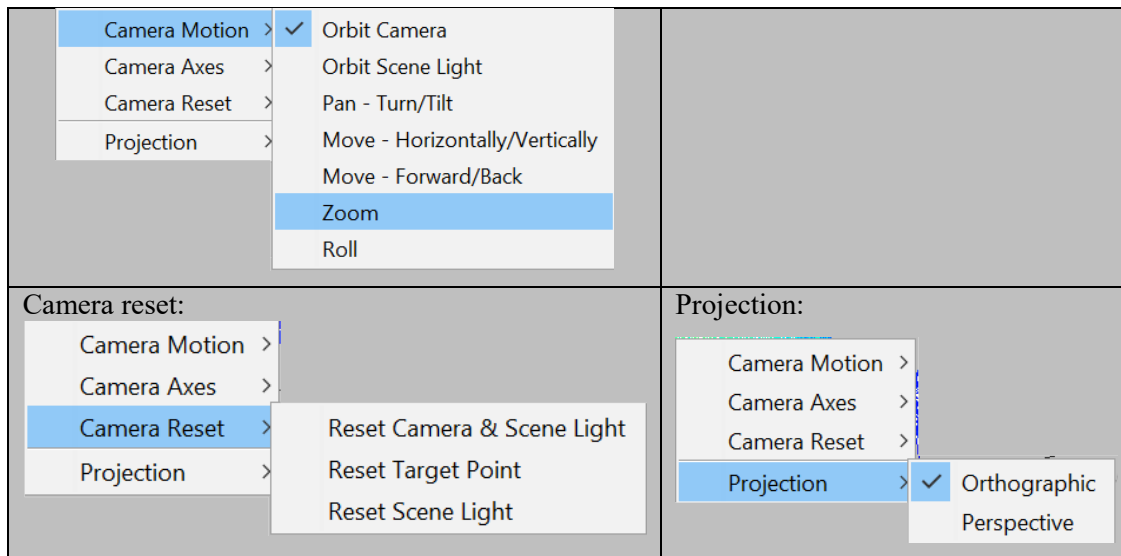
| View | Edit | Plots | Image Statistics | Fi |
|-------------------------|------|-------|------------------|----|
| Colortheme | | | | > |
| Close LUT Toolbar | | | | |
| Close Camera Toolbar | | | | |
| List of Bands/Channels | | | | |
| Image Scale | | | Ctrl+G | |
| Expanded View | | | Ctrl+N | |
| View Header Information | | | | |
| View Image Information | | | Ctrl+I | |
| View HeatMap | | | | |
| Edit Plot | | | Ctrl+E | |
| Turn Instructions Off | | | | |

Alternatively, go to the **Plots** tab and select a 3D plot such as **Mesh 3D**, **Surface 3D**, **Contour 3D**, or **Hybrid 3D**. This action will activate **Camera Toolbar**.




- You can select the functions from the **Camera Toolbar** icons or activate the same menu using a **right-click** menu on the IMAGE DISPLAY panel. When the right click is applied the following menus will appear:

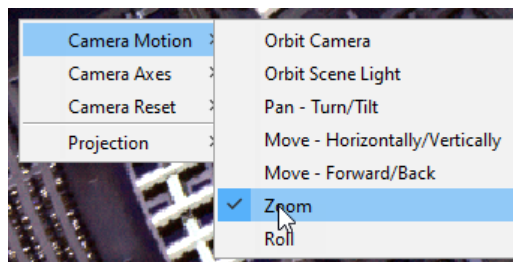
| | |
|-------|---|
| Zoom: | Rotation axis: |
| | <div> <div>Camera Motion ></div> <div> <div>Camera Axes ></div> <div> X Principal Axis Y Principal Axis Z Principal Axis No Principal Axis </div> </div> <div>Camera Reset ></div> <div>Projection ></div> </div> |



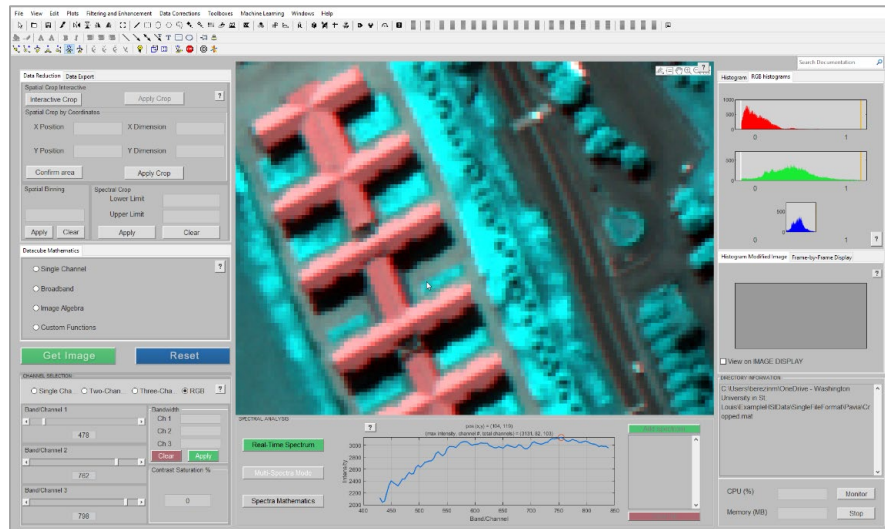
Additional information:

Once activated, the **Camera Toolbar** can be also used for manipulations of 2D datacube representations. The number of functions however is limited and might vary between the types of images. An example below, shows how the **Zoom Camera** function can be used to increase the size of the image beyond the image display.

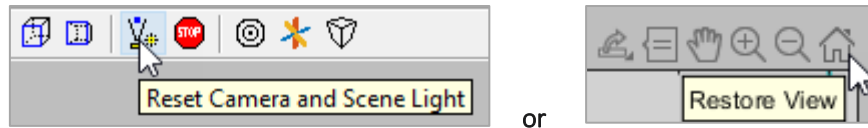
When the file is open and the **Color Toolbar** is activated, click the **Zoom Camera** icon  or select from the **right-click** menu.



Position the cursor over the **Image Display** and click, hold down the left mouse button, then move the cursor toward the center to zoom.



3. You can reset the image back to the original by using one of the two methods:
 - Click **Reset Camera and Scene Light** in the **Camera Toolbar**.
 - Click **Restore View** in the **Strip Toolbar**, located in the right corner of the image panels.



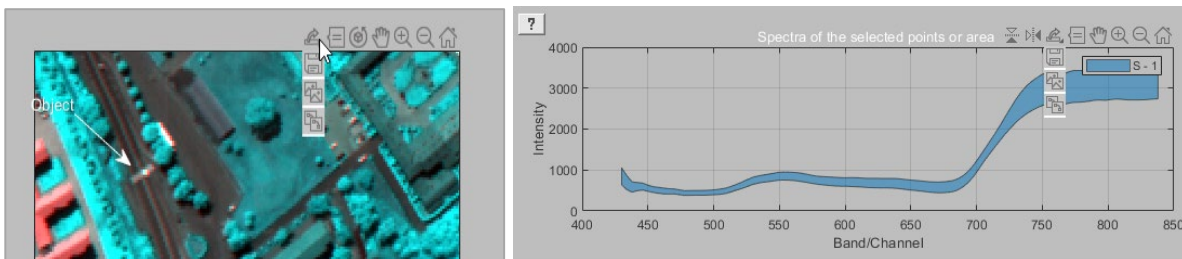
References:

The algorithm is built in part using *BetterCameraToolbar* developed by Ulrich Reif, 2022, <https://www.mathworks.com/matlabcentral/fileexchange/70605-bettercameratoolbar>, *MATLAB Central File Exchange*. Retrieved May 2, 2022.

5.5. Strip Toolbar

Hovering over the right corner of image and plot panels reveals a drop-down menu with options for reversing (flipping) spectral axes, exporting the images and spectra, moving, zooming, and panning the image as well as viewing information about individual pixels.

- The images and plots used in IDCube feature a hidden **Strip Toolbar** that can be activated by hovering over the right corner of the image or plot.
- Strip Toolbar** houses individual buttons. If checked the buttons turn blue.
- The buttons from this toolbar have priority over other commands. To continue working with other functionalities implemented in IDCube, uncheck any buttons from the **Strip Toolbar** that are checked.



| Button Name | Icon | Description | Availability |
|-----------------|------|---|------------------------------------|
| Flip Vertical | | Flips Y axis on the spectral plot | Only for spectral data |
| Flip Horizontal | | Flips X axis of the spectral plot | Only for spectral data |
| Save As | | Export options | Everywhere |
| Brush | | Toggles data brushing mode. | Only for scatter and spectral data |
| Data Tips | | Toggles data cursor mode. | Everywhere |
| Rotate | | Toggles rotate mode. | Only for 3D objects |
| Pan | | Toggles pan mode. | Everywhere |
| Zoom In | | Toggles zoom-in mode. | Everywhere |
| Zoom out | | Toggles zoom-out mode. | Everywhere |
| Restore View | | Restores original view of axes or tiled chart layout. | Everywhere |

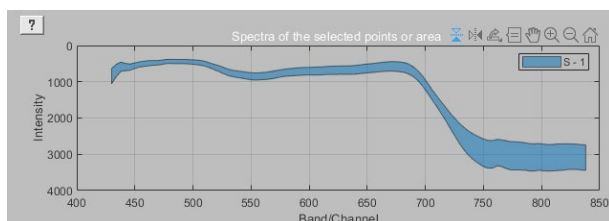
Hovering over the 'export' button reveals a drop-down menu with options for exporting the content of the chart or image:

| Button Name | Icon | Description |
|------------------------|------|---|
| Save As | | Save the content as a tightly cropped image or PDF. |
| Copy As Image | | Copy the content as an image. |
| Copy as Vector Graphic | | Copy the content as a vector graphic. |

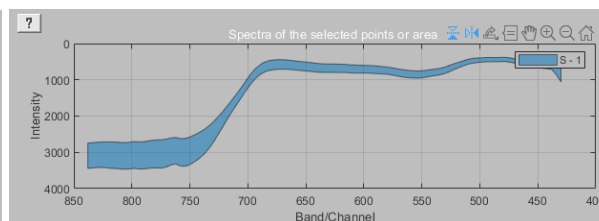
Flipping spectral axes

The direction of the axes in the spectral windows can be reversed. The default direction is from low to high values. Pressing ‘flip’ buttons reverse the directions of axes. Blue colors of the flip icon indicate ‘reverse’ direction as shown in the spectral images below. The spectral view can be returned to the original by pressing the buttons again.

Y axis flipping



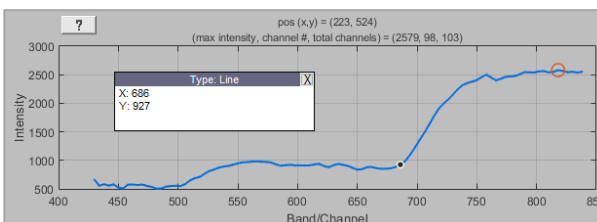
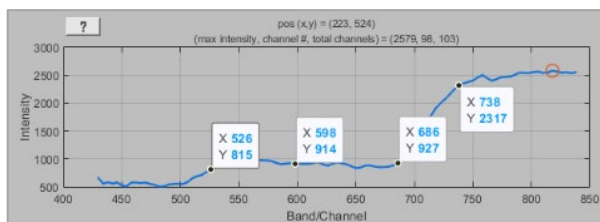
X, Y axes flipping



Adding DataTips

Data tips are small text boxes that display information about individual data points. By default, the data tips include the data specified during chart creation that correspond to the individual data point.

- Activate the **DataTip** icon by changing the line color to blue (or another color depending on the color theme of the software).
- Interactively create data tips by clicking on data points in a chart, for example, line and scatter plots. Press **Shift+Click** to put additional **DataTips**.



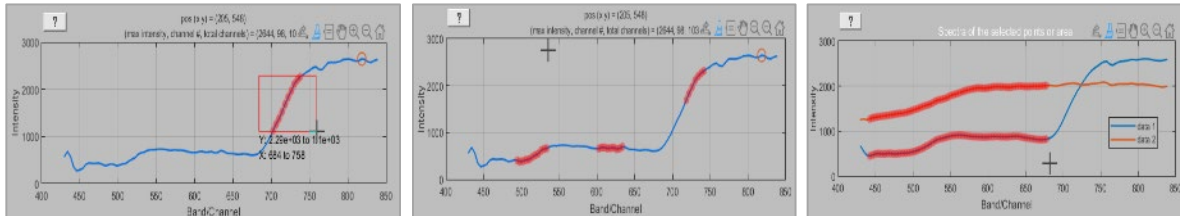
Right-click on the **DataTip** activates the following menu.

| Action | Hotkeys | Description |
|---------------------------------|--------------------|--|
| Selection Style | | Based on a Mouse Position. Snaps to Nearest Data Vertex (default). |
| Display Style | | Places a frame inside the figure (see the picture above on the right). Data Tip (default) (see the picture above, on the left). |
| Create New DataTip | Shift+Click | Creates new DataTip in addition to the existing. |
| Delete Current DataTip | Delete | Deletes the current single DataTip. |
| Delete All DataTips | | Deletes all single DataTips. |
| Export Cursor Data to Workspace | | Only available for developers of IDCube. |

Some of the described buttons might perform additional task specific functions. The descriptions of these functions are considered in the corresponding applications.

How to do Brushing

Brushing enables the user to interactively mark, delete, modify, and save observations in graphs. Selection of one or several groups of data points as shown below with single or multiple brushing groups or several spectra.



NOTE: Not all charts support data brushing. The absence of the brushing icon indicates that this chart is not supported. For example, brushing for the **Multi-Spectra** mode is not supported.

Mouse Gestures for Data Brushing

You can brush graphs in several ways. The basic operation is to drag the mouse to highlight all observations within the rectangle you define. The following table lists data brushing gestures and their effects.

| Action | Gesture | Result |
|--|--|---|
| Select data using a Region of Interest (ROI) | ROI mouse drag | ROI rectangle (or rectangular prism for 3-D axes) appears during the gesture and all brushable observations within the rectangle are highlighted. All previously made brushing marks are removed. The ROI rectangle disappears when the mouse button is released. |
| Select a single point | Single Left click on a graphic object that supports data brushing | Produces an equivalent result to ROI rectangle, brushing where the rectangle encloses only the single vertex on the graphical object closest to the mouse. All other brushing annotations in the figure are removed. |
| Add a point to the selection or remove a highlighted one | Single Left click on a graphic object that supports data brushing with the Shift key pressed | Equivalent brushing by dragging an ROI rectangle that encloses only the single vertex on the graphical object closest to the mouse. All other brushed regions in the figure remain brushed. |
| Add to or subtract from ROI | Click on ROI drag with the Shift or Ctrl keys pressed | ROI grows; all unbrushed vertices within the rectangle become brushed and all brushed observations in it become unbrushed. All brushed vertices outside the ROI remain brushed. |

Work with Brushed Datapoints

After brushing is performed, the **right-click** activates the following menu:

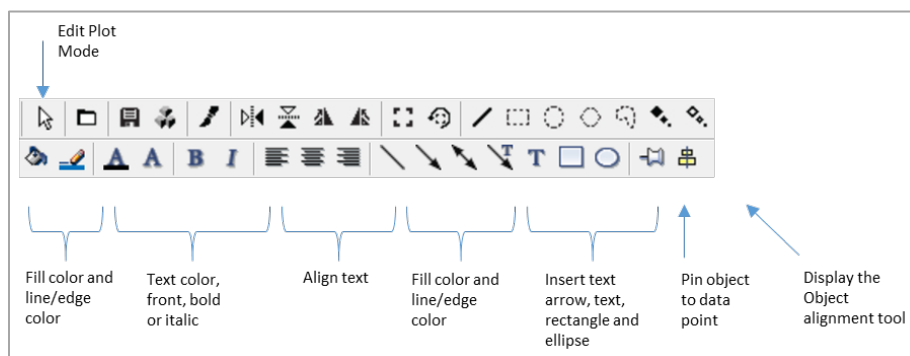
| Action | Result |
|-----------------|---|
| Replace with | Replaces the values either with Not a Number (NaN) values or constants. |
| Color | Enables the user to select the color. A Color Picker will be activated. The color will be applied with the next brushing. |
| Removed Brushed | Deletes brushed points. |


| Action | Result |
|----------------------------|--|
| Removed Unbrushed | Deletes unbrushed points. |
| Export Unbrushed... | Only available for developers of IDCube. |
| Paste Data to Command Line | Only available for developers of IDCube. |
| Copy Data to Clipboard | Enables copying the data and exporting it to Excel and other software. |
| Clear All Brushing | Removes brushing. |

5.6. Annotation Toolbar

Allows the user to add text and shape outlines to the image for presentation purposes.

Activate the **Annotation Toolbar** by clicking one of the icons on the toolbar. This action will activate the **Edit Plot** mode where you can move most of the objects including buttons and frames.



Exit the **Edit Plot** mode by clicking the button  located in the **Main Toolbar**. **NOTE:** the changes made in the **Edit Plot** mode can be undone using **Ctrl+Z**. See more about **Edit Plot** mode in the dedicated section.

Enclosing Regions of a Graph in a Rectangle or an Ellipse


You can add a rectangle or an ellipse to draw attention to a specific region of a graph. While either object is selected, you can move and resize it as well as display a **right-click** context menu that enables you to modify behavior and appearance. Insert the rectangle or ellipse by clicking the corresponding button



in the **Annotation Toolbar**. The cursor changes to a cross indicating you can click down, drag, and release the left mouse button to define the size and shape of the object.

Pinning Rectangles and Ellipses

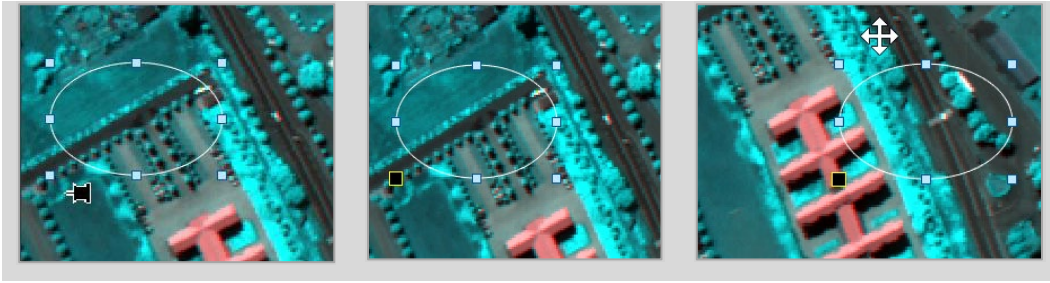
You can attach the rectangle to a particular point in the Image by pinning it to that point. First, click on the

object, then select the pin icon- button in the figure toolbar . A black pin will appear. Move the pin close to the lower corner where the white square is and click. Pinning attaches the lower left corner of the rectangle or ellipse to its current location in the axes data units. You can move the point of attachment by clicking the corner and dragging the anchor to another point. The cursor changes to a pin while you are dragging. You cannot drag or resize a rectangle or an ellipse when it is pinned.


Activate pin

Attach pin

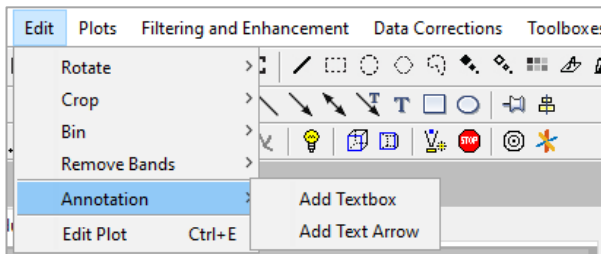
Move pin




Textbox Annotations

A textbox annotation is a rectangle that can contain multiline text. You can attach the textbox to any point in the figure. Insert a textbox by clicking the textbox button in the figure toolbar , then click where you want to place the text. The default behavior for textboxes is for them to automatically resize to accommodate the amount of text you enter. You can also resize the textbox after typing or click and drag the box to a certain size when you create it (when you do this, the textbox stays that size no matter how much text you place within it).

You can also select **Add Textbox** from the **Edit** → **Annotation** menu.




This action also activates **Edit Plot** mode. To exit the mode and return to the main features press icon  located in the **Main Toolbar**.

Selecting Textbox Objects

The textbox must be first activated using the **Edit Plot** button located in the **Main Toolbar** :

- To move the textbox, click the text once to select it.
- To edit the text, double-click within the box.


Pinning the Textbox

You can attach the textbox to a particular point in the Image by pinning it to that point. Select the pin button  in the **Annotation Toolbar** and click a handle of the textbox. By default, pinning attaches the lower left corner of the textbox to its location in the axes data space. Move the point of attachment by clicking on the corner and dragging the anchor to another point, but you cannot drag the textbox when it is pinned.

Annotation Lines and Arrows

Add lines and arrows to a graph and attach them to any point in the Image. The three types of arrows include:

- Single-headed arrow
- Arrow with attached text box (text arrow)
- Double-headed arrow.

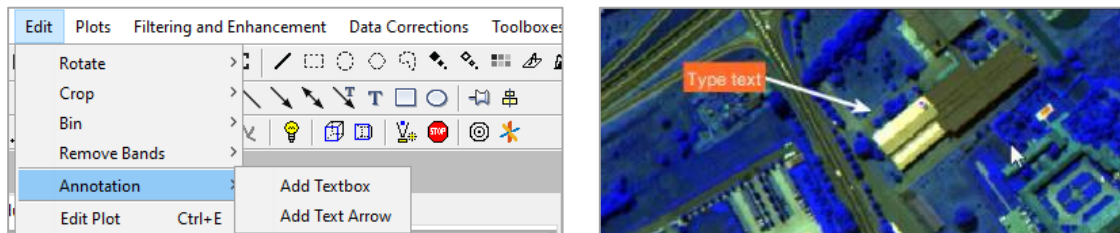
Insert a line or arrow by clicking the appropriate button in the **Annotation Toolbar** , then click down, drag the line or arrow to the desired point, and release the mouse. The arrowhead appears at the terminal end. With the line or arrow selected, **right-click** to display the context menu, which provides access to several options.


Inserting a Text Arrow

A text arrow combines a textbox with an arrow. It is useful for labeling points on a graph. Add a text arrow to a graph by selecting the arrow button that has a T above the arrow. Insert the text arrow and type text in the box.



You can also select **Add Textbox** from the **Edit** → **Annotation** menu. This arrow has a preset design with an orange textbox attached. The design can be changed.




This action also activates **Edit Plot** mode. To exit the mode and return to the main features press icon  located in the **Main Toolbar**.

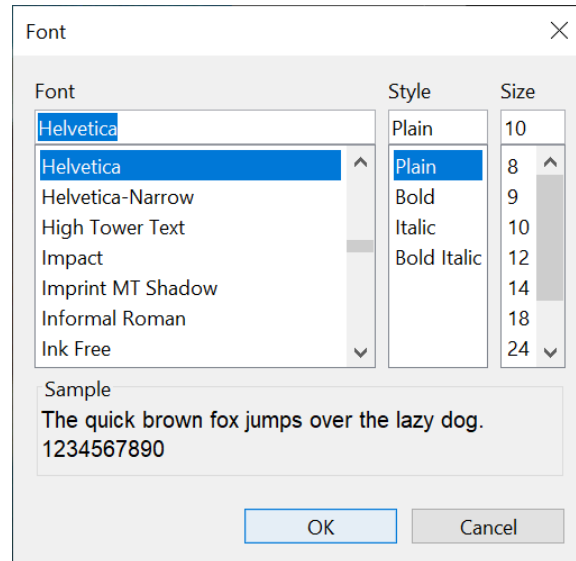
Pinning the Arrowhead End

Attach the arrowhead end to the point of interest on the Image while letting the text box automatically reposition itself as you zoom or pan the graph.

Select the **Pin** button in the **Annotation Toolbar**.


Changing the fonts

Use the following icons to change the font and color of the font: . Double-click inside the object (textbox or text arrow), click on the font icons, and select the font and/or the color.



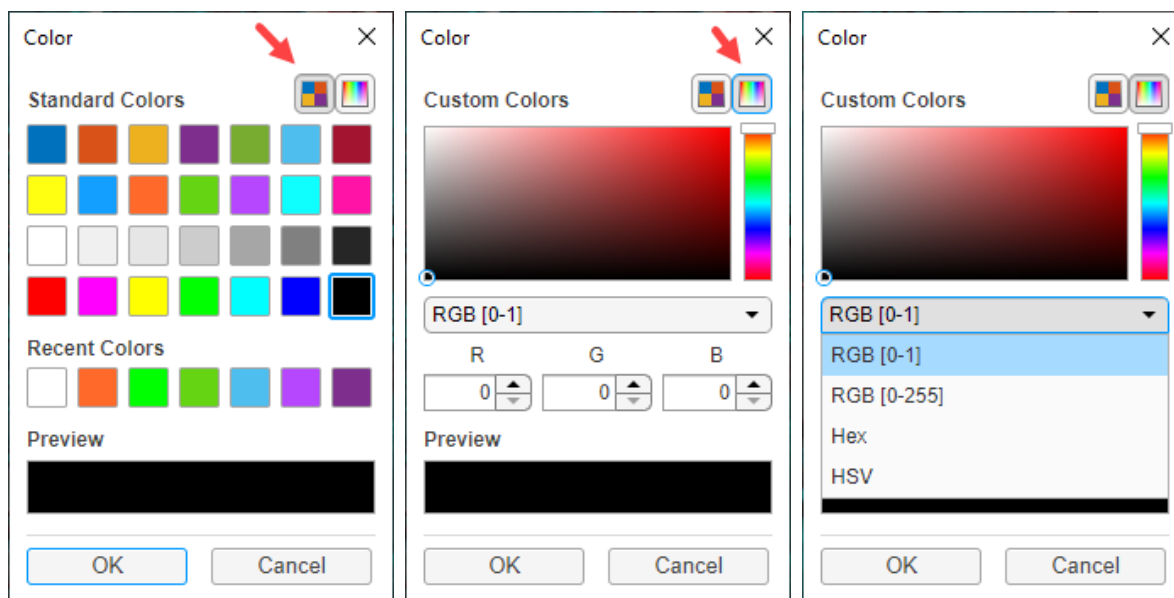
Coloring Texts and Objects

NOTE: Color Picker blocks interaction with other windows until the user closes it.

Coloring of the annotation uses **Color Picker** apps that are activated with the **right-click** menu or using the corresponding icons  from **Annotation Toolbar**.


Two options can be implemented and selected from the top right buttons (shown with arrows):

- The **Standard Colors** app (default).
- The **Custom Colors** app. This color picker provides a tab for selecting custom colors from a gradient as well as intensity. Move the vertical slider to display the desired region of color space. Then click the color gradient to select a color. This app also offers a dropdown menu to select or input the desired color.



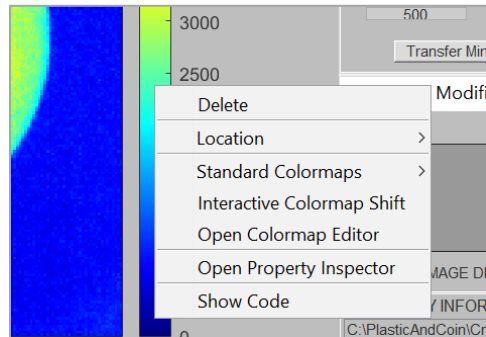
| Group | Option | Description |
|-----------------|---------------|---|
| Standard Colors | Preset colors | Allows the user to select the color by clicking on it. |
| Custom Colors | RGB [0, 1] | Enables the user to input RGB triplet interactively as the red, green, and blue components of the selected color. The intensities must be in the range [0 - 1]. |
| | RGB [0, 255] | Enables the user to input RGB triplet interactively as the red, green, and blue components of the selected color. The intensities must be in the range [0 - 255]. |
| | Hex | Enables the user to input a Hex number (interactively and manually) of a color. |
| | HSV | Enables the user to input HSV triplet interactively as the Hue (H), Saturation (S), and Value (V) components of the selected color. Hue is selected with the scalebar on the left (range 0-360 degrees), S and V are from 0 to 100. |

Removing and Editing Annotations

You can delete or modify any annotation by clicking an **Edit Plot** button  icon located in the **Main Toolbar**. You will have to click this button again to exit the interactive layout.

5.7. Interactive Colorbar

Adds additional interactive features to the existing colorbar to improve visualization and customization of the monochromatic image. Activate the **Interactive Colorbar** menu by making a right click.

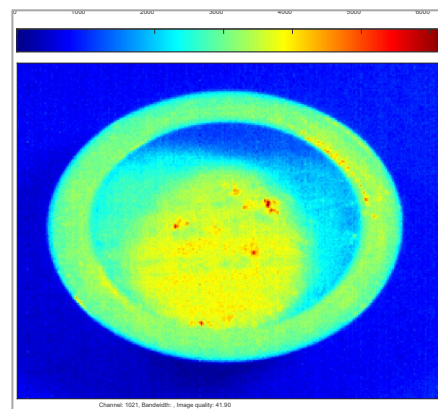
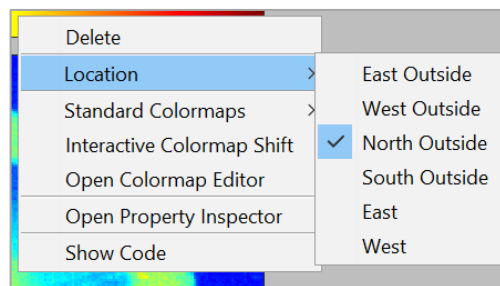


Select from the following options:

| Button Name | Description | Default | Comment |
|----------------------------|--|--------------|-------------------------------|
| Delete | Deletes the toolbar. | n/a | |
| Location | Displays the colorbar in a specific location such as 'north outside'. | East outside | |
| Standard colormap | Choose from the preset colormaps: cool, gray, hot, hsv, jet, turbo and parula. | parula | |
| Interactive colormap shift | Interactively changes the distribution of color values within automatically assigned limits. | n/a | Activates interactive layout. |
| Open colormap editor | Adjusts scale and customized LUTs, not available for IDCubePro® users. | n/a | |
| Open Property Inspector | Analyze properties of graphical objects, not available for IDCubePro® users. | n/a | |
| Show Code | Not available for IDCubePro® users. | n/a | |







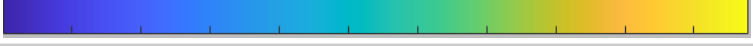
Colorbar Location:

To change the position of the colorbar, **Right click** on the colorbar and select **Location**. An example below shows the **North Outside** location.



Standard Colormaps

To change the colormap, **Right click** on the colorbar and select **Standard Colormaps**. A list of standard colormaps is given in the table below. **NOTE:** a large number of colormaps are available from the toolbar menu.

| Colormap Name | Description |
|------------------|--|
| cool |  |
| gray |  |
| hot |  |
| hsv |  |
| jet |  |
| tubo |  |
| parula (default) |  |

Interactive Colormap Shift:

To shift the mapping of data values into the current colormap, **Right click** on the colorbar and select **Interactive Colormap Shift**. Then, select a color in the colorbar. The cursor will change its shape to a double-headed arrow with a vertical line inside. The entire colorbar will be flanked with four blue squares indicating the activation of the **Edit Plot** mode.



Press the left button on the mouse and drag the cursor. As you drag, the mapping of data values into the colormap shifts. When complete, leave the interactive mode by unchecking **Interactive Colormap Shift** (**Right click** on the colorbar and select **Interactive Colormap Shift** again), or pressing the **Edit Plot** button



from the **Main Toolbar**. The **Edit Plot** button should turn grey.

Tip: In some cases, it is difficult to activate the cursor when the colorbar is in a vertical (i.e., **east** or **west** orientation, see above). If that is the case, change to a different position (i.e., **north** colorbar position), and then adjust the colors. You can then return to your desired colorbar position. The colormap values will not be affected.

6. Panels

6.1. Image Display Panel

NOTE: PAVIA dataset is used as an example.

Basic Information

The panel presents 2D or in certain cases 3D representations of the dataset. Changes in the image can be made by a variety of commands and functions from most of the panels and Tabs.

| Panels affecting Image Display | Description | Effect |
|--|--|---|
| Toolbar panel | Applies colormaps and annotations. | Global to the entire datacube |
| Data Reduction panel | Applies changes the size and binning. | Global to the entire datacube |
| Datacube Mathematics panel | Applies mathematics to the image. | Global to the entire datacube |
| Interactive Band/Channel Selection panel | Select different bands and their combinations. | Only to the current frame |
| Image Adjustment panel | Optimize the visualization of the image. | Only the current frame (can be made global) |
| Frame-by-Frame panel | Animates the frames. | Global to the entire datacube |

| Tabs affecting Image Display | Description | |
|------------------------------|--|--------------------------------------|
| View | Adds scale. | Only to the current frame |
| Edit | Changes the size of the dataset, binning. | Global to the entire datacube |
| Plots | Modifies the plots of the current frame. | Only to the current frame |
| Filtering and enhancements | Applies filters, enhancements, quality controls, and other functions to the entire datasets. | Mostly global to the entire datacube |
| Data correction | Applies corrections to the dataset. | Mostly global to the entire datacube |

Image Zoom and Pan

The presented image can be zoomed in and panned. The Image Display also serves as a gateway to spectral analysis.

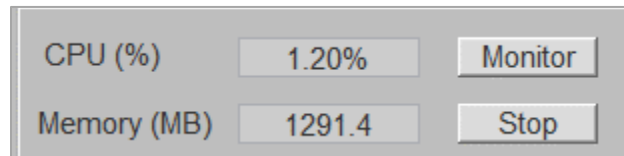
Zoom and Pan can be used in three different ways:

- **Mouse Wheel**
- **Mouse Drag**
- **Strip Toolbar**

1.10. Using Keyboard and Mouse shortcuts (see section Computer Information Panel)

Features:

1. The COMPUTER INFORMATION panel provides real-time information about the user's PC CPU and memory usage.
2. CPU data is displayed as a percentage (%) of the PC's capacity.
3. Memory is displayed in megabytes (MB).



The “Monitor” button starts/resumes the information collecting process.

The “Stop” button pauses the information-collecting process. Functionality can be resumed by pressing the “Monitor” button.

‘Smart’ Zoom (via Mouse Wheel)

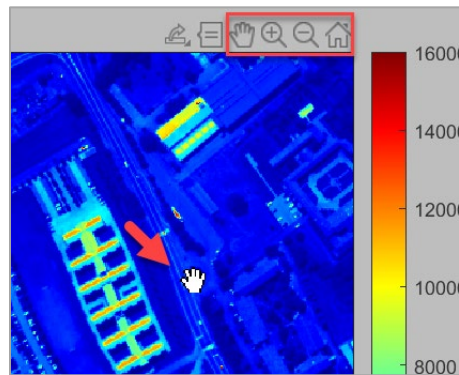
Smart Zoom enables the user to click on any pixel of the image and start zooming the around the pixel by using the wheel of the mouse. The selected pixel remains in the center of the image.

Pan (via Mouse Drag)

In the zoom mode, you can pan the image by the **right-click**, holding the button down (the cursor turns into a hand), and moving the image. You can also combine the **right-click** while pushing down with the keyboard arrow keys to perform panning.

Using Strip Toolbar

This toolbar has **Pan**, **Zoom in**, **Zoom Out**, and **Restore View** buttons.

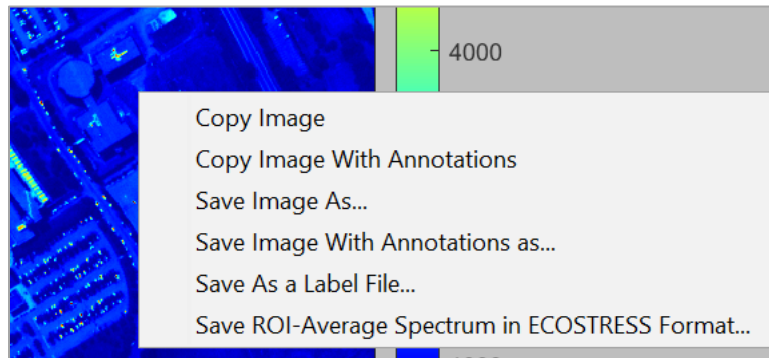


Right Click Menu in the Image Display Panel

Features: Enables the user to activate specific functions in the IMAGE DISPLAY panel through the **right-click** menu.

Steps:

1. Load a file and **Right click** on the image in the IMAGE DISPLAY panel.



2. Select an option from the following menu:

| Option | Description |
|--|---|
| Copy Image | Copies the current image without any additional information. |
| Copy Image with Annotations | Copies the current image with the additional information (i.e., RGB [$w1=586$, $w2=730$, $w3=742$], Bandwidths ($bw1=$, $bw2=$, $bw3=$), Contrast=0%, Quality:13.83). |
| Save Image As... | Saves the current image in <i>png</i> , <i>jpeg</i> , or <i>tiff</i> format with no additional information attached. |
| Save Image with Annotations As... | Saves the current image in <i>png</i> , <i>jpeg</i> , or <i>tiff</i> format with Annotations. |
| Save As a Label file... | Saves the current image in <i>png</i> , and <i>mat</i> formats for machine learning applications. |
| Save ROI Average Spectrum In ECOSTRESS Format. | Provides interactivity to select the region of interest and saves the average spectrum in ECOSTRESS format to use elsewhere. For example, Spectral Matching Toolbox. |

Alternatives:

Saving images in different formats is also available from the **Strip Toolbar**; however, the format of saving and the size of images might be different from the **Right click** menu. Saving an average spectrum from the selected area in the **ECOSTRESS** format is also available from SPECTRAL ANALYSIS panel.

References

Dany Cabrera (2022). Image Mouse Zoom and Pan (<https://github.com/danyalejandro/imgzoompan>), GitHub. Retrieved May 2, 2022.

Ned Gulley (2022). Zoom Keys (<https://github.com/gulley/Ax-Drag>), GitHub. Retrieved May 2, 2022.

6.2. Data Reduction Panel

The panel enables changes to the size of the dataset by either cropping (spatially and spectrally) or binning (spatially and spectrally). These functions are applied globally for the entire datacube.

NOTE: PAVIA dataset is used as an example.

Spatial Crop Interactive

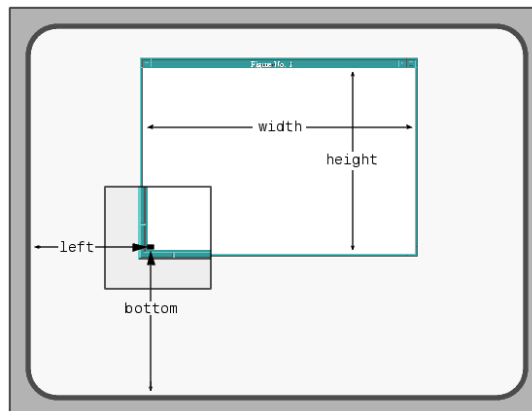
Features: Enables spatial cropping of the entire dataset.

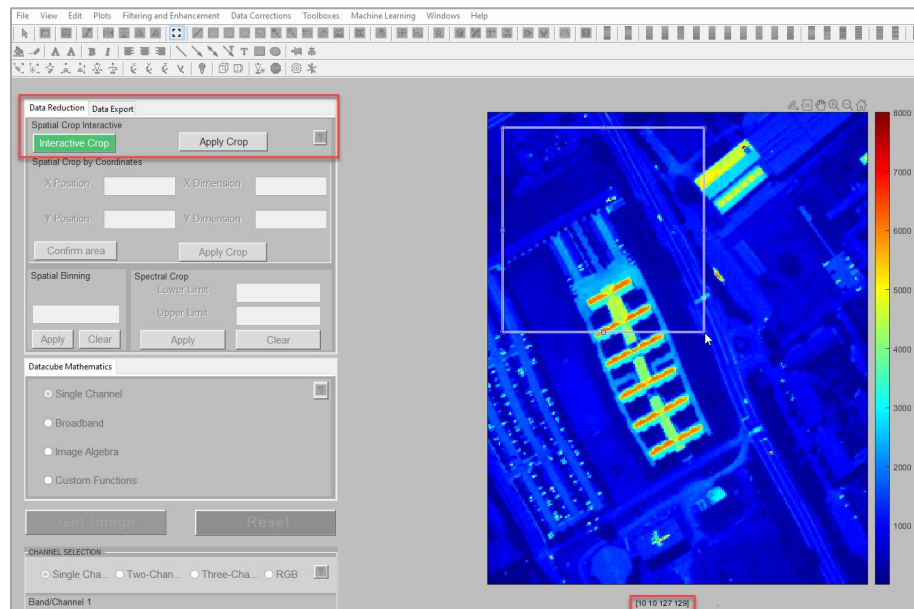
Steps:

1. In the DATA REDUCTION panel click **Select Crop** (also can be triggered by using an icon ) or using **Edit** → **Crop** → **Spatial Crop**.

Spatial crop activates an interactive rectangular (active frame) that enables the user to select the region of interest and crop the rest of the image. (*Press the **Spatial Crop** button again to deactivate the crop function*).

2. Move the boundaries of the active frame with the mouse. The coordinates of the frame in a format *[left bottom width height]* can be seen below the image. The units are pixels. When the active frame size is adjusted, IDCube automatically updates the coordinates to the new values.





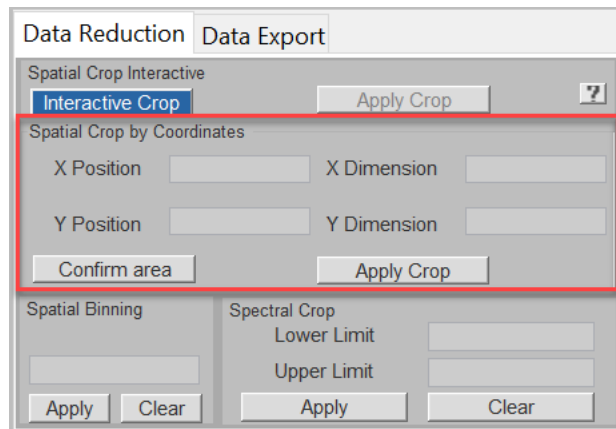
3. Click **Apply Crop**. The change will be applied globally and a new datacube will be stored in the internal memory, without erasing the original data. A new pop-up window with information about the spatial dimension of the new dataset will appear in the left corner showing the dimension of the new frame, type of data, color, maximum, and minimum. In the case of the RGB, the maximum and minimum will not be shown. Click **Reset Image** to return to the original datacube (**NOTE:** all other changes will also be eliminated).
4. (Optional) The new dataset can be saved using a standard **Save Data As...** → **Save as IDCube format** or Data Export function and opened as a new datacube.

Spatial Crop by Coordinates

Features: You will be able to specify the X/Y Position and X/Y Dimension to crop the datacube.

Steps:

1. Open a file.
2. In the DATA REDUCTION panel enters the values under **Spatial Crop by Coordinates**. This method enables the user to apply the same crop coordinates across other images. For that, select the anchor point (X coordinate, Y coordinate), and the dimension in both X and Y directions from the anchor.
3. Activate by clicking **Confirm area** button then click **Apply Crop**. The spatially cropped image is saved in the memory of IDCube, but the original image is not affected. A window **Image Information** will pop up with the updated information about the new dataset.
4. Click **Reset** to return to the original image.

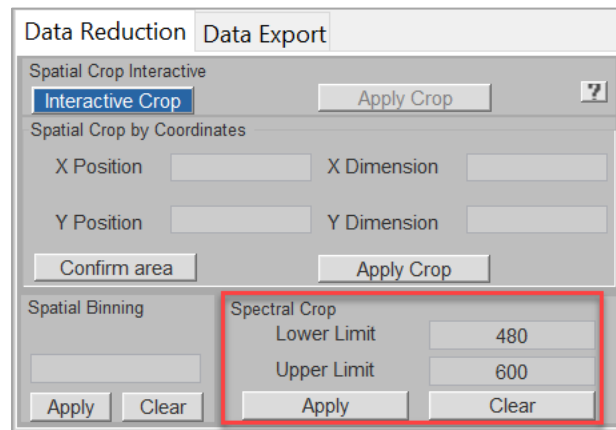


Spectral Crop

Features: Enables spectral cropping of the entire dataset.

Steps:

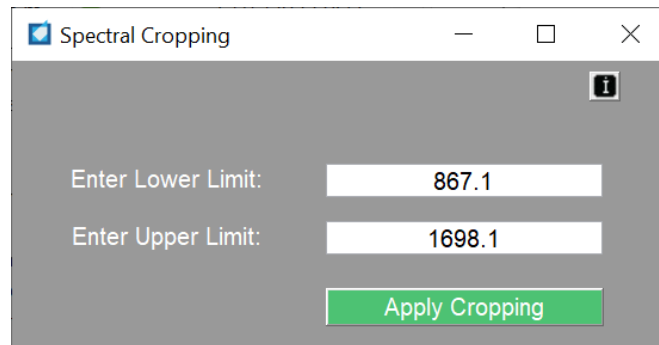
1. Load a file.
2. In the DATA REDUCTION panel enters the values in the **Lower** and **Upper Limits**. This will cut the z-dimension of the datacube from both sides. Click **Clear** to empty the fields.



3. Click **Apply**. The new datacube will be spectrally cropped. The original data will not be affected.
4. Click **Reset** to return to the original image.

Alternatively, this can be done from the **Edit** → **Crop** → **Spectral Crop** function available from the Menu Bar.

A pop-up dialog will ask for the lower and upper limit of channels (i.e., wavelengths) with the default values showing the current lowest and highest channels. Enter the values and click **Apply Cropping**. The original data will not be affected.




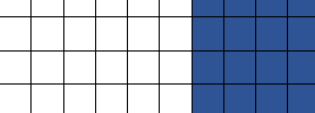


A dialog box titled "Spectral Cropping" with a close button (X) and an information icon (i). It contains two input fields: "Enter Lower Limit:" with the value "867.1" and "Enter Upper Limit:" with the value "1698.1". Below these fields is a green button labeled "Apply Cropping".

Spatial Binning

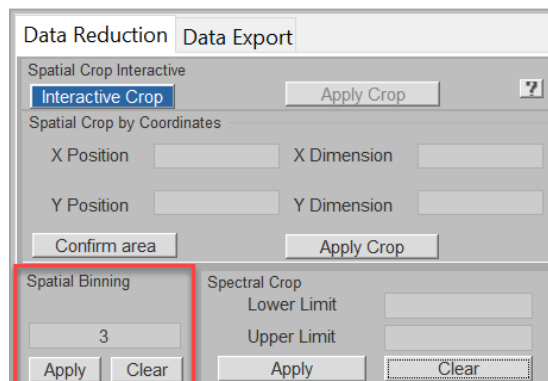
Features: Performs spatial binning of the entire dataset to decrease the number of pixels.

Pixel binning is the process of combining neighboring pixels into a larger pixel. This larger pixel represents the area of all the individual pixels. For example, in 2 x 2 binning, the signal from a square of 4 adjacent pixels is combined into 1, and in 3 x 3 binning, the signal from a square of 9 adjacent pixels is combined into 1. Binning decreases the size of the file and provides averaging.

| Binning options | Combined pixels |
|--------------------------|--|
| None |  |
| 2 x 2 (4 pixels = 1) |  |
| 3 x 3 (9 pixels = 1) |  |
| 4 x 4 (16 pixels = 1) |  |

Steps:

1. Open a file. In the DATA REDUCTION panel enters a single value for the **Spatial Binning**. For example, the value 3 will indicate 3 x 3 binning. Press **Apply** and **Spatial Binning** will be applied to the entire datacube. Click **Clear** to empty the field.



The "Data Reduction" panel shows various options for data processing. The "Spatial Binning" section is highlighted with a red box. It contains a text input field with the value "3", and "Apply" and "Clear" buttons. Above this, the "Spatial Crop by Coordinates" section has fields for X Position, X Dimension, Y Position, and Y Dimension, with "Confirm area" and "Apply Crop" buttons. The "Spectral Crop" section has "Lower Limit" and "Upper Limit" fields with "Apply" and "Clear" buttons. The "Interactive Crop" section has an "Interactive Crop" button and an "Apply Crop" button.

2. Click **Reset** to return to the original datacube. In that case, all changes to the datacube will be rejected.

3. (Optional) The new dataset can be saved using a standard **Save Data As... → Save as IDCube format**.

Alternatively, **Spatial Binning** can be performed from the **Edit → Binning → Spatial Binning** function available from the tab. Enter the number and click **Apply Binning**.

Spectral Binning

Features: Performs spectral binning of the z-direction of the datacube to decrease the number of bands/channels.

Spectral binning is the process of combining neighboring individual bands into a single band. For example, in 2 binning, the signal from 2 adjacent bands is combined into 1, and in 3 binning, the signal from 3 adjacent bands is combined into 1. Spectral Binning decreases the size of the file and provides averaging across the bands.

| Binning options | Combined bands | | | | | | | | | |
|-----------------|----------------|--|--|--|--|--|--|--|--|--|
| None | | | | | | | | | | |
| 2 | | | | | | | | | | |
| 3 | | | | | | | | | | |
| 4 | | | | | | | | | | |

This function is not available from the DATA REDUCTION panel but is available from the **Edit Tab → Binning → Spectral Binning**. Enter the number and click **Apply Binning**.

6.3. Data Export Panel

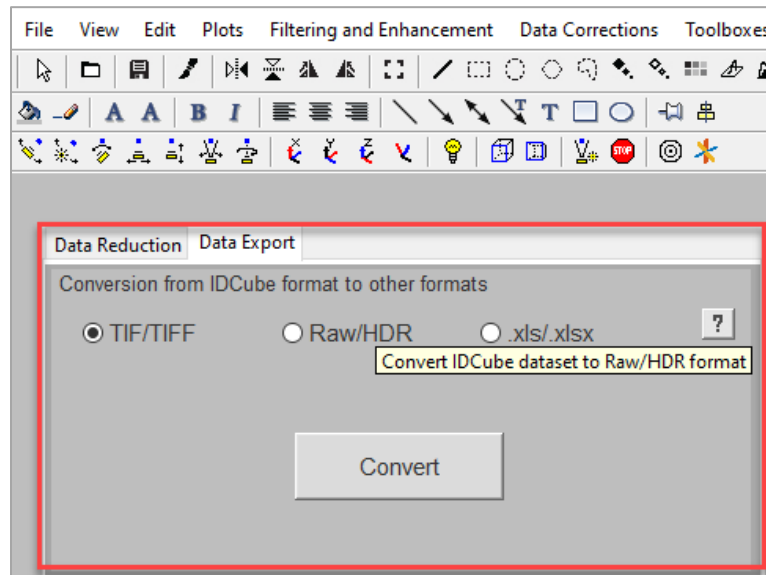
NOTE: PAVIA dataset is used as an example.

Features: Enables the user to export a part of or all of the dataset into a variety of formats including *tiff*, *raw/HDR*, commonly used by a variety of data acquisition systems, such as ENVI, Inc, and *Excel*.

Steps:

Load the image file and select the **Data Export** tab. Available options are:

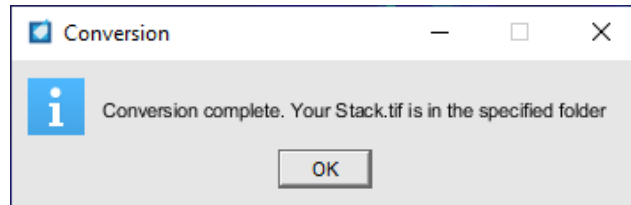
- Convert to a *tif/tiff* stack
- Convert to a *raw/HDR* file
- Convert the entire datacube into Excel
- Convert the selected region of interest into Excel
- Convert the current image into Excel
 - Convert the mean spectrum into Excel
 - Convert all spectra into Excel
- Convert the current image into Excel



Convert into a *tiff* Format

This option saves the images into a stack of frame-by-frame *tiff* files.

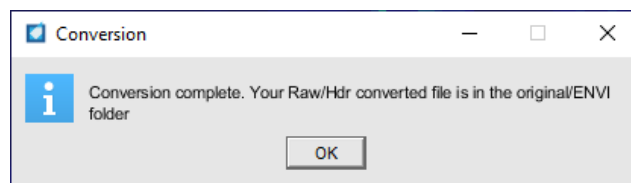
Select a **TIF/TIFF** radio button and click **Convert**. You will be asked to select a folder. The current directory will be your default folder. The stack of tiff files will be automatically saved in the specified directory.



Convert into a *raw/hdr* Format

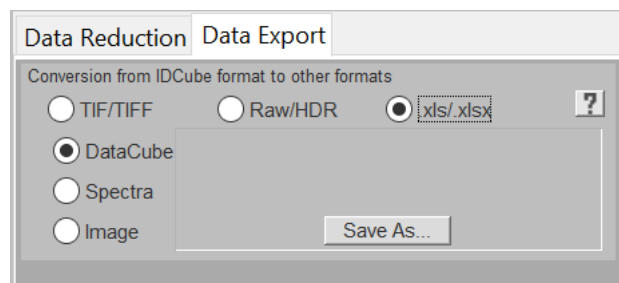
This option saves the entire dataset into one of the most common industry-standard hyperspectral imaging formats used by ENVI Inc., and other companies.

Select a **raw/hdr** radio button and click **Convert**. You will be asked to select a folder. The current directory will be your default folder. The conversion will generate two files (*raw* and *hdr*) in the specified directory.



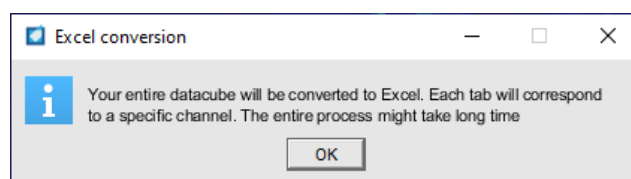
Convert into an Excel Format

When this option is selected three other options will be offered: *i*) convert the entire datacube into Excel, *ii*) convert spectra from the selected regions into Excel, and *iii*) convert the current image into Excel.

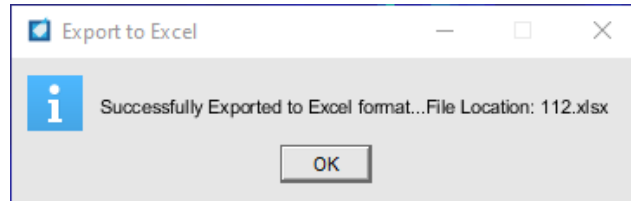


Convert the Entire Datacube into the Excel format

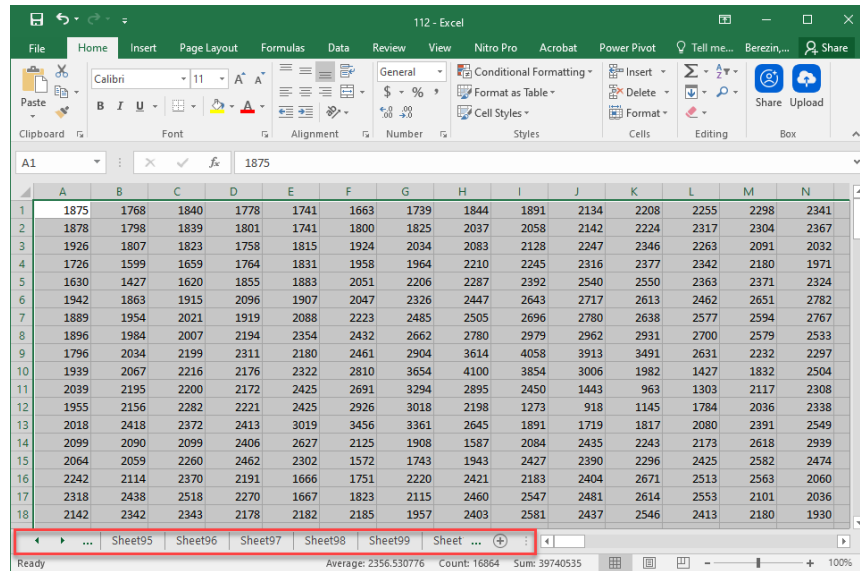
Click **Save As...** and select the name of the file. Click **Save**. A pop-up message will warn that this operation might take a long time.



A pop-up message box will inform when the conversion is complete.



The number of tabs is equivalent to the number of bands/channels. For example, Pavia has 103 channels.

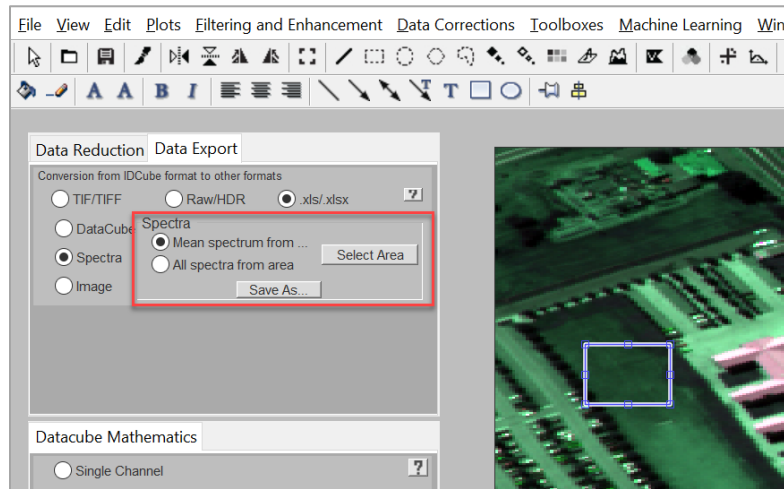


Convert the Spectra into Excel format

This option is interactive. You can either select a single spectrum from the image by clicking somewhere on the image or select a region of interest by drawing a rectangle. Click **Save As...** and select the name of the file. Click **Save**.

Convert Mean Spectrum from the Area

Select **Mean spectrum** from the area and click **Select Area**. Point to a specific location or draw a rectangle over the image and click **Save As...** Select a folder and enter the name of the file. Click **Save**. A pop-up message box will inform you when the conversion is complete.



Open the saved Excel file. **NOTE** that the wavelength values are preserved in the first column.

| | A | B | C | D | E | F | G |
|----|-----|----------|---|---|---|---|---|
| 1 | 430 | 657.68 | | | | | |
| 2 | 434 | 538.4173 | | | | | |
| 3 | 438 | 452.6045 | | | | | |
| 4 | 442 | 429.4036 | | | | | |
| 5 | 446 | 439.0545 | | | | | |
| 6 | 450 | 451.2091 | | | | | |
| 7 | 454 | 450.3509 | | | | | |
| 8 | 458 | 428.6709 | | | | | |
| 9 | 462 | 415.0618 | | | | | |
| 10 | 466 | 413.9818 | | | | | |
| 11 | 470 | 416.2764 | | | | | |
| 12 | 474 | 401.1855 | | | | | |
| 13 | 478 | 390.8473 | | | | | |
| 14 | 482 | 393.0709 | | | | | |
| 15 | 486 | 399.6673 | | | | | |
| 16 | 490 | 401.36 | | | | | |
| 17 | 494 | 405.6 | | | | | |
| 18 | 498 | 414.54 | | | | | |
| 19 | 502 | 425.3745 | | | | | |
| 20 | 506 | 438.3255 | | | | | |
| 21 | 510 | 458.0073 | | | | | |
| 22 | 514 | 490.9709 | | | | | |

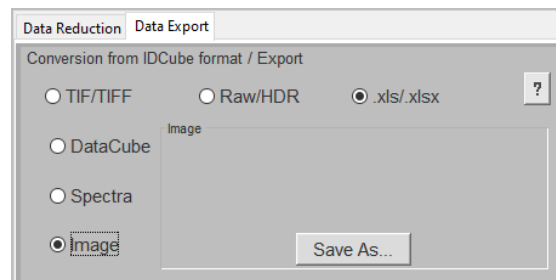
Convert All Spectra from the Area

Select **All Spectra from the Area** and click **Select Area**. Draw a rectangle over the image and click **Save As...** Select a folder and enter the name of the file. Click **Save**. When the conversion is complete a popup message box will appear.

Open the saved Excel file. The left column represents bands/channels. **NOTE:** that the wavelength values are preserved.

Convert the Currently Displayed Image into Excel Format

Click **Save As...** select the folder and enter the name of the file. Click **Save**. When the conversion is complete a popup message box will appear.



Open an Excel file. The rows and columns represent the spatial dimension of the saved image.

Alternatives: Some of the functions can be also activated through the File → Export IDCube to other formats.

6.4. Datacube Mathematics Panel

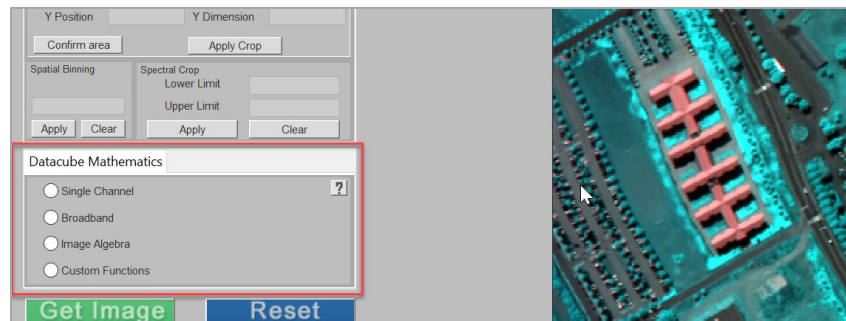
NOTE: PAVIA dataset is used as the example

Features:

- Enables image algebra to be performed on the entire dataset.
- Enables broadband image analysis.
- Performs mathematics on the image offering more than 50 math functions.
- Saves the new datacube.

Steps (could be used in a different order):

1. Load the data using **File** → **Open**.

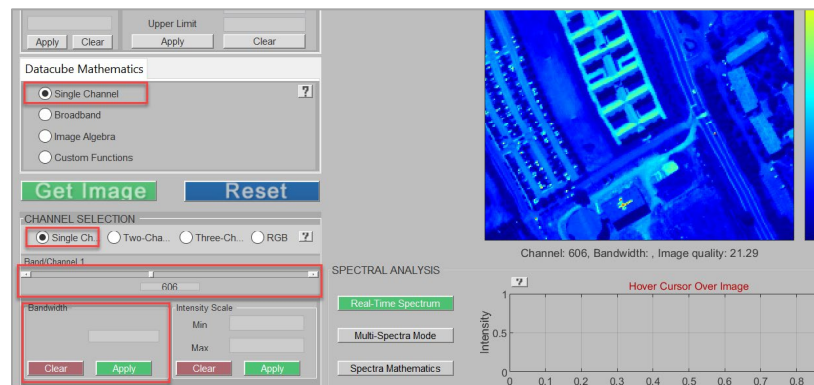


Single Channel

Check the **Single Channel** radio button. This will activate a **Single Channel** in the CHANNEL SELECTION panel. Alternatively, you can click the **Single Channel** radio button.

The user can select any single wavelength as well as the bandwidth. The image will be immediately updated with the new image.

The slider automatically detects the highest and lowest band. If no wavelengths of other units are assigned, the slider will follow the number of the detected bands starting from #1. You can also type the band number/channel, etc. number.



Broadband

Check the **Broadband** radio button. That will automatically select the **Two-Channel** option in the CHANNEL SELECTION panel. The broadband will correspond to the wavelengths between wavelength 1 and wavelength 2, (i.e., from 442 to 698 nm) as shown below. **NOTE:** that bandwidths will be deactivated when **Broadband** is selected.

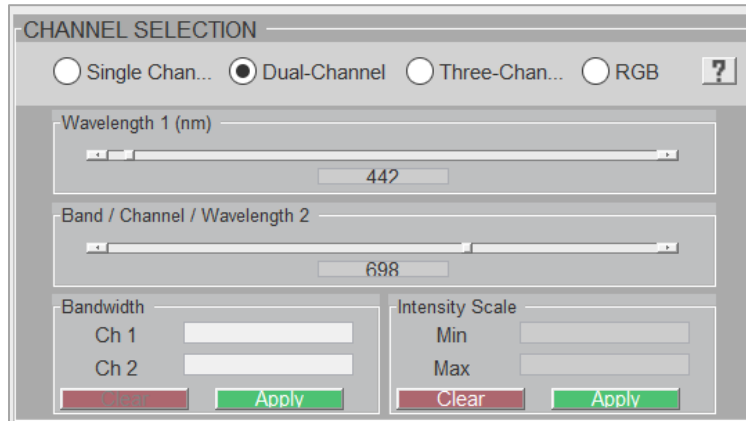


Image Algebra

Check the **Image Algebra** radio button. That will activate a dropdown menu with preselected commonly used algebra and logical functions. This selection will automatically activate the **Two-Channel** option in the CHANNEL SELECTION panel.

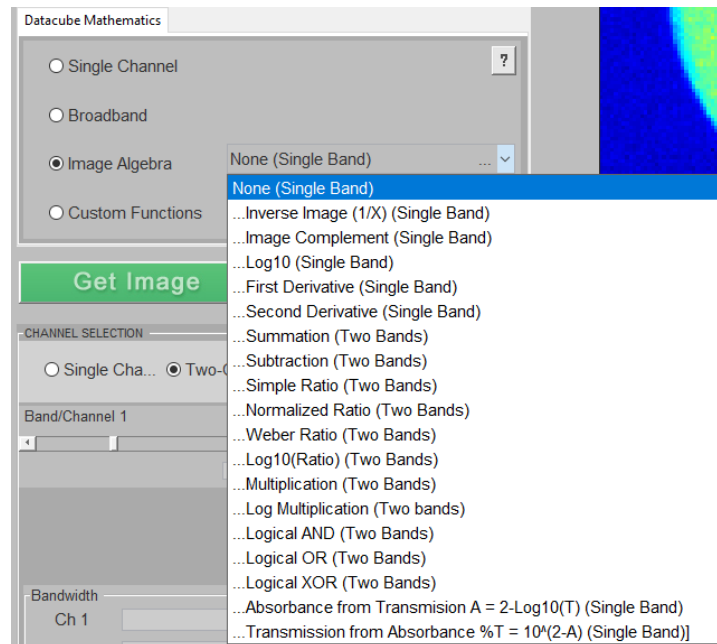


Table 1. Functions implemented in Image Algebra

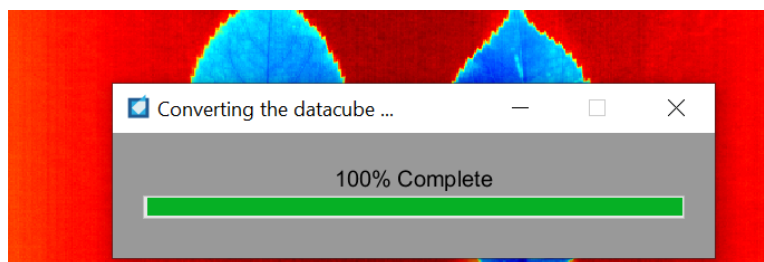
| Description | Number of bands | Mathematical Expression or function |
|------------------------------|-----------------|-------------------------------------|
| None (default) | Single Band | $w1$ |
| Inverse image | Single Band | $1/w1$ |
| Image complement | Single Band | $imcomplement(w1)$ |
| First derivative | Single Band | $gradient(w1)$ |
| Second derivative | Single Band | $gradient(gradient(w1))$ |
| Summation | Two Bands | $w1 + w2$ |
| Simple Ratio | Two Bands | $w1./w2$ |
| Normalized Ratio | Two Bands | $(w1-w2)/(w1+w2)$ |
| Weber Ratio | Two Bands | $(w1-w2)/w2$ |
| Log10[Ratio] | Two Bands | $Log10(w1./w2)$ |
| Multiplication | Two Bands | $w1 \times w2$ |
| Log10[Multiplication] | Two Bands | $Log10(w1 \times w2)$ |
| Logical AND | Two Bands | $w1 \text{ AND } w2$ |
| Logical OR | Two Bands | $w1 \text{ OR } w2$ |
| Logical XOR | Two Bands | $w1 \text{ XOR } w2$ |
| Absorbance from Transmission | Single Band | $A=2-\log_{10}(T)$ |
| Transmission from Absorbance | Single Band | $\%T=10^{(2-A)}$ |

IMPORTANT: The changes induced by the functions implemented by **Image Algebra** are global and applied to the entire datacube. These changes are passed to other functions, filters, toolboxes, etc. but *not passed* to other **Image Algebra** functions. Since the changes are global use the **Reset** button when you need to remove the effect of the function.

If you selected one function from the **Image Algebra** dropdown menu and then another, the previous function will be canceled, the dataset will be reset to the original datacube and a second function will be applied.

Pressing the **Get Image** button will have no additional effect.

If a **Two Bands** function is applied, the new datacube will use the first band ($w1$) as a variable and the second band ($w2$) as a constant.



A message box **Converting the datacube** will inform when the conversion is completed. To verify that the conversion was successful, check **Real-Time Spectrum** from the SPECTRAL ANALYSIS panel.

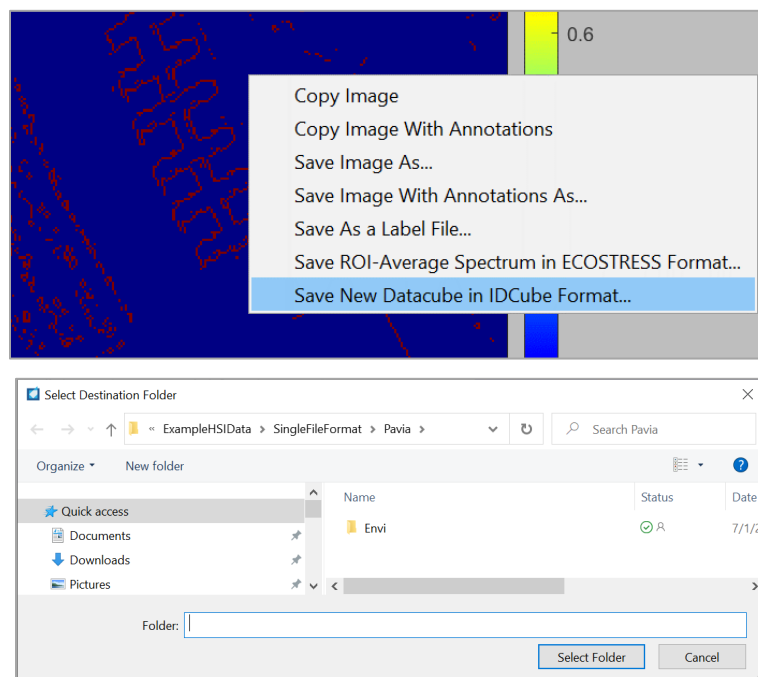
The function is activated immediately after its selection from the **Image Algebra** dropdown menu. Clicking **Get Image** will repeat this function.

You can save the new datacube via **File** → **Save Data As...** → **Save in IDCube format (Ctrl+S)** or **Right click** on the image and select **Save New Datacube in IDCube Format...** and select a folder where a new file will be stored. Alternatively, **Right click** on the IMAGE DISPLAY panel and select **Save New Datacube in IDCube Format...** and select a folder where a new file will be stored.

Custom Functions

Select the **Custom Functions** radio button. This will automatically activate an interactive field where the user can type an equation. After entering an equation, click the green **Get Image** button. The produced image will be seen on the IMAGE DISPLAY panel. You can change the bands to visualize individual slices.

IMPORTANT: The changes induced by the functions implemented in Custom Functions are *not global and do not apply to the entire datacube*. These changes are not passed to filters, toolboxes, etc. The changes are only temporally and therefore other commands will remove the effect of the custom function. To store the entire datacube affected by the custom function, **Right click** on the image and select **Save New Datacube in IDCube Format...** and select a folder where a new file will be stored.



Format and Notation

Type an equation using the following format:

Examples:

$$w1 + w2$$

$$\sin(w1+w2)$$

$$\sin(w1./w2)$$

$$\sin(w1.*w2) \text{ (use dots for divisions and multiplications)}$$

Up to three selected channels are supported. Use $w1$, $w2$, or $w3$ and their combinations. Combine any of the functions with other functions:

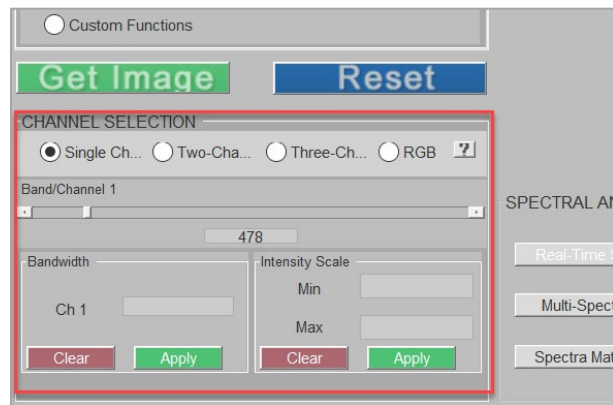
Examples: $\log(\sin(\sqrt{w1.*w2}))$
 $\text{fftshift}(\text{erf}(\cos(w1)))$

The list of equations and functions supported by IDCube is given in **Appendix 1**.

6.5. Interactive Band/Channel Selection Panel

NOTE: Plastic and Coin dataset (cropped) is used as an example.

The panel consists of several functional units: Single channel visualization, Two - channel visualization, Three - channel visualization, Bandwidths, and Constant Saturation.



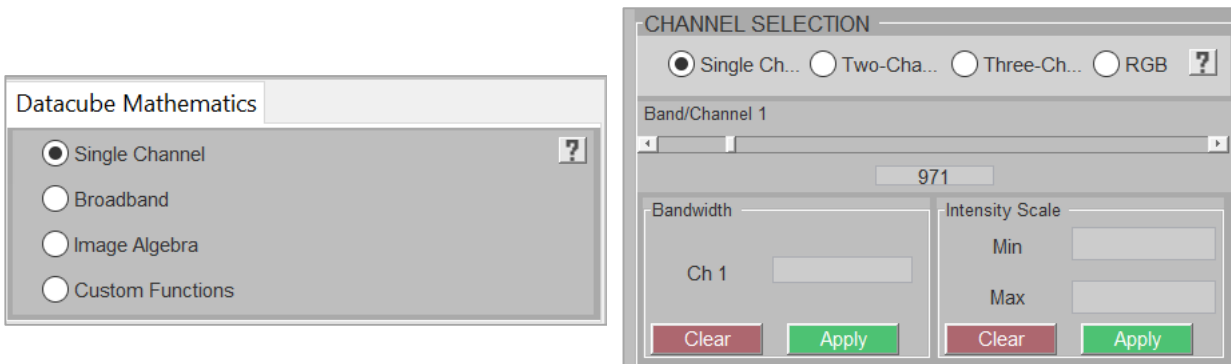
Single Channel Visualization

Features:

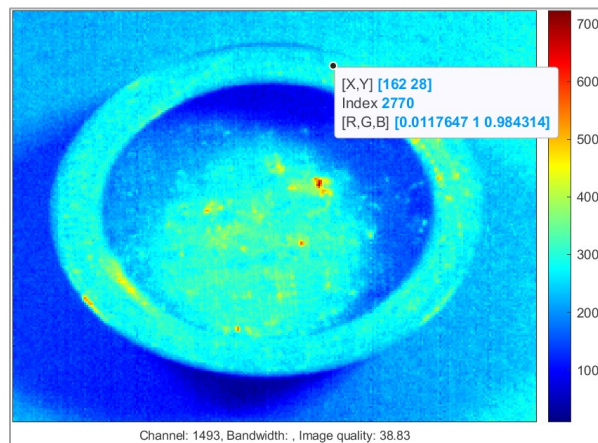
Use this option to visualize the image at any single band/channel. The resulting image will be monochromatic.

Steps:

1. Open a file. The default view is monochromatic using a randomly selected single channel. Both DATACUBE MATHEMATICS and CHANNEL SELECTION panels will show **Single Channel radio button** clicked.
2. Change the values of **Bands/Channels 1** by either entering values in the boxes or using sliders. The main image will be automatically updated. The input values along with other information will be added to the caption under the main image.



- The values for each pixel can be visualized by clicking a **Data Tips** icon on the **Strip Toolbar** and pointing to the pixel of interest. **Data Tip** shows the coordinate, the intensity of the pixel (index), and the assigned color using the RGB notation (normalized to 0-1).



(Optional). You can increase the number of bands assigned to each channel by entering values in the **BANDWIDTHS** panel.

(Optional). You can fine-tune the image by adjusting histograms in the **HISTOGRAM** panel.

Pressing the **Reset** button will return the image to the original unprocessed state in the monochromatic mode.

Notes:

Large datasets might cause a delay in updating the slider value and the image. Click the green **Get Image** button to ensure the effect.

The sliders work well for a relatively large number of bands that are uniformly distributed. For a small number of bands (10 or less, i.e., in multispectral imaging) adding the values manually might be necessary.

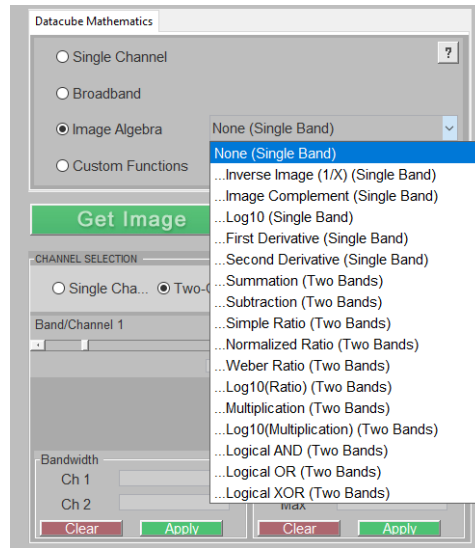
Two-Channel Visualization

NOTE: Plastic and Coin dataset (cropped) is used as an example.

Features: Use this option to visualize the image of any combinations of two bands/channels and the corresponding mathematics using preset Image Algebra functions. The resulting image will be monochromatic.

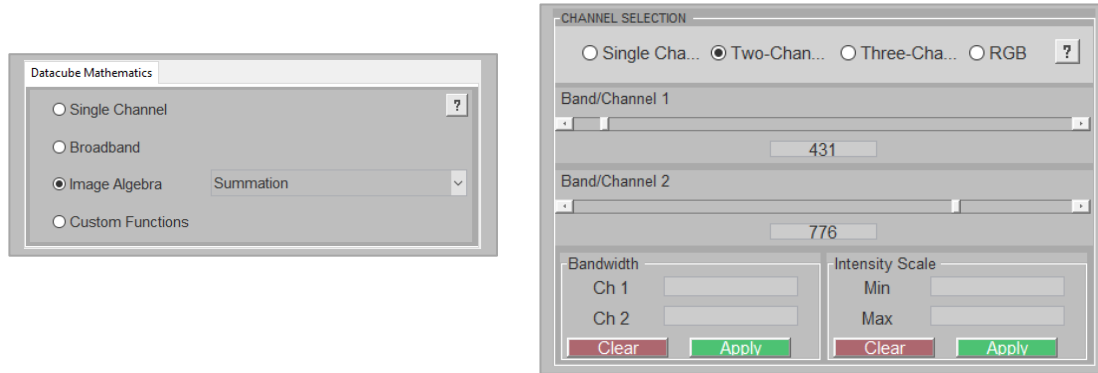
Steps:

1. Open a file. The default view is monochromatic using a randomly selected single channel. Select **Two-Channel** from the CHANNEL SELECTION panels. DATACUBE MATHEMATICS panel should automatically select the **Image Algebra** radio button. Alternatively, you can select the **Image Algebra** radio button first.
2. Apply any mathematics available from the **Image Algebra** dropdown menu in the Databcube Mathematics.

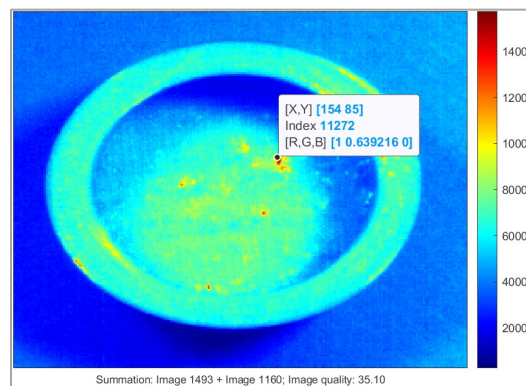


| Preset functions | Number of channels | Description |
|-----------------------|--------------------|---------------------------|
| None | 1 | <i>No math is applied</i> |
| Inverse image | 1 | $1/w1$ |
| Image complement | 1 | $imcomplement(w1)$ |
| Log10 | 1 | $Log10(w1)$ |
| First derivative | 1 | $diff(w1)$ |
| Second derivatives | 1 | $diff(diff(w1))$ |
| Summation | 2 | $w1 + w2$ |
| Subtraction | 2 | $w1 - w2$ |
| Simple Ratio | 2 | $w1 / w2$ |
| Normalized Ratio | 2 | $(w1 - w2)/(w1 + w2)$ |
| Weber ratio | 2 | $(w1 - w2)/w2$ |
| Log10(Ratio) | 2 | $Log10(w1 / w2)$ |
| Multiplication | 2 | $w1 \times w2$ |
| Log10(Multiplication) | 2 | $Log10(w1 \times w2)$ |
| Logical AND | 2 | $w1 AND w2$ |
| Logical OR | 2 | $w1 OR w2$ |
| Logical XOR | 2 | $w1 XOR w2$ |

3. Change the values of **Bands/Channels 1** and **Bands/Channels 2** by either entering values in the boxes or using sliders. The main image will be automatically updated. The input values along with other information will be added to the caption under the main image.

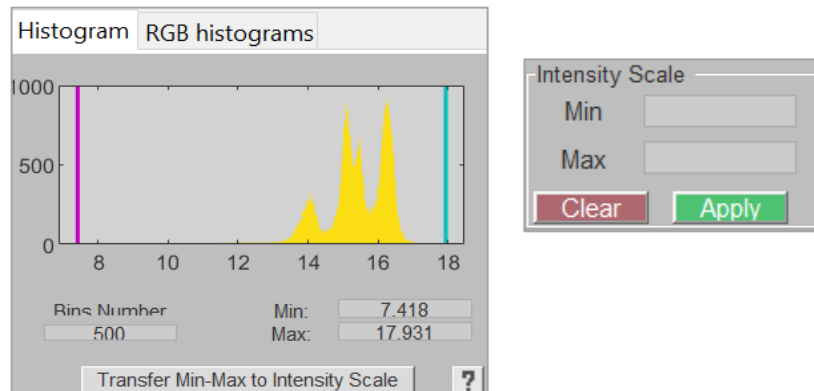


4. The values for each pixel can be visualized by clicking a **Data Tips** icon on the **Strip Toolbar** and pointing to the pixel of interest. **Data Tip shows the coordinate**, the intensity of the pixel (index), and the assigned color using the RGB notation (normalized to 0 -1).



Pressing the **Reset** button will return the image to the original unprocessed state in a monochromatic mode.

You can increase the number of bands assigned to each channel by entering values in the **BANDWIDTH** panel. You can fine-tune the image by adjusting histograms in the **HISTOGRAM** panel or changing the range of the intensities by entering numbers in the **Intensity Scale**.



Large datasets might cause a delay in updating the slider value and the image. Click the green **Get Image** button to ensure the effect. The sliders work well for a relatively large number of bands that are uniformly distributed. For a small number of bands (10 or less, i.e., in multispectral imaging) adding the values manually may be necessary.

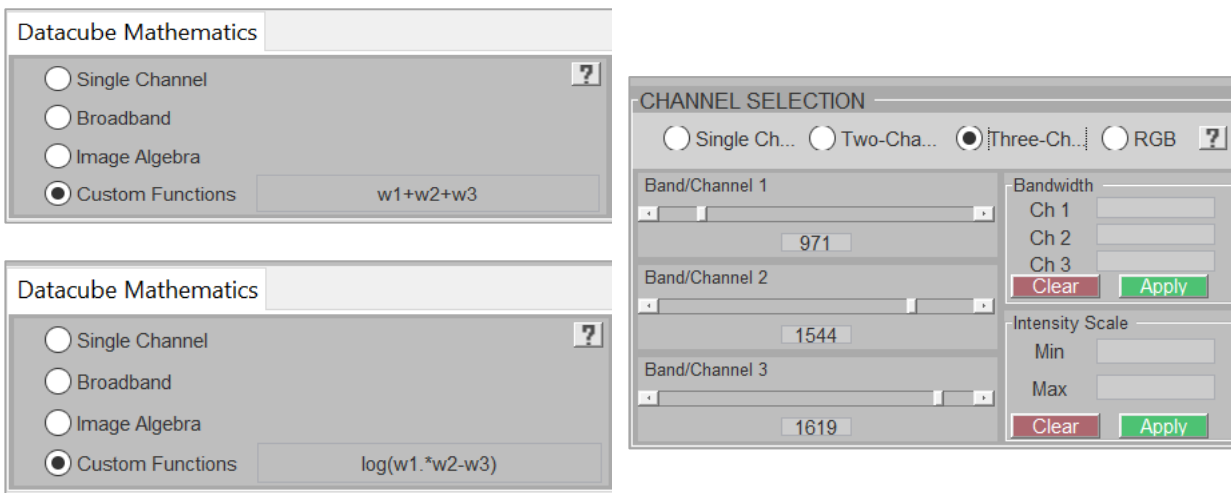
Three-Channel Visualization (Custom Functions)

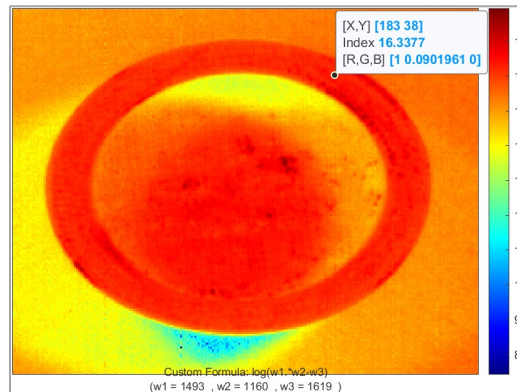
NOTE: Plastic and Coin dataset (cropped) is used as an example.

Features: Use this option to visualize the image of any combinations of one, two, or three bands/channels using many preset Custom Functions. The functions should be typed into the interactive field. The resulting image will be monochromatic.

Steps:

1. Open a file. The default view is monochromatic using a randomly selected single channel. Select **Three-Channel** from the CHANNEL SELECTION panel. DATACUBE MATHEMATICS panel should automatically select the **Custom Functions** radio button and activate an interactive field for entering an equation.
2. Type a valid equation using an appropriate notation from the list of functions or their combinations from the list of available functions. You can use one, two, or three bands denoted as **w1 (Band/Channel 1)**, **w2 (Band/Channel 2)**, and **w3 (Band/Channel 3)**.

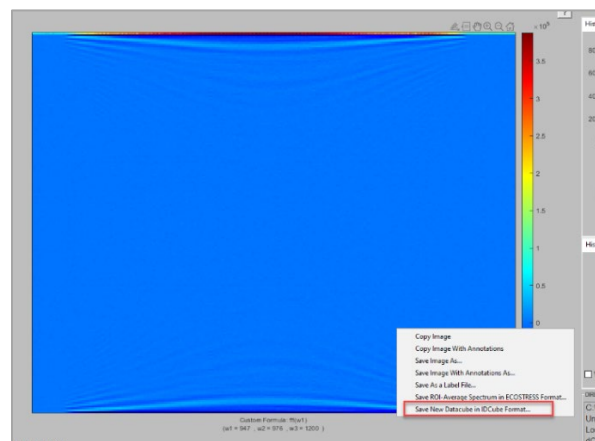




1. Change the values in **Bands/Channels 1 - 3** by either entering a value in the box or using sliders. The main image will be automatically updated. The input values along with other information will be added to the caption under the main image.
2. The values for each pixel on the Image can be visualized by clicking a **Data Tips** icon on the **Strip Toolbar** and pointing to the pixel of interest. **Data Tips** show the coordinate, the intensity of the pixel (index), and the assigned color using the RGB notation (normalized to 0 - 1).
3. (Optional). You can increase the number of bands assigned to each channel by entering values in the **BANDWIDTHS** panel.
4. (Optional). You can fine-tune the image by adjusting a histogram in the **HISTOGRAM** panel or changing the range of the intensities by entering numbers in the **INTENSITY SCALE** panel.

Saving: Custom Function only changes the current image and does not generate a new datacube like some other functions. IDCube Pro enables the user to save the entire datacube after the results of the custom function. If more than one variable ($w1$, $w2$, $w3$) is selected, only $w1$ will be used as a spectral variable. Other variables such as $w2$ and $w3$ will be used as constants. The image below shows the effect of the *fft* function (Fourier transform) on the image.

5. To save the datacube, **Right click** on the **Image Display** and select **Save New Dataset in IDCube format**. You can then open the new datacube through the **File** → **Open Dataset in IDCube format** (**Ctrl+O**).



Pressing the **Reset** button will return the image to the original unprocessed state in the monochromatic mode. The RGB channel values will be remembered.

Notes:

Large datasets might cause a delay in updating the slider value and the image. Click the green **Get Image** button to ensure the effect.

The sliders work well for a relatively large number of bands that are uniformly distributed. For a small number of bands (10 or less, i.e., in multispectral imaging) adding the values manually might be necessary.

You can increase the number of bands assigned to each channel by entering values in the BANDWIDTHS panel. You can adjust the **Contrast Saturation** of the image by entering the number from 0 (default) to 49. You can fine-tune the image by adjusting histograms in the RGB HISTOGRAM panel.

Additional Information:

For the list of Functions and Expressions that can be used in IDCubePro® see section **Appendix 1**.

Visualization with Pseudo RGB

NOTE: Plastic and Coin dataset (cropped) is used as an example.

Features:

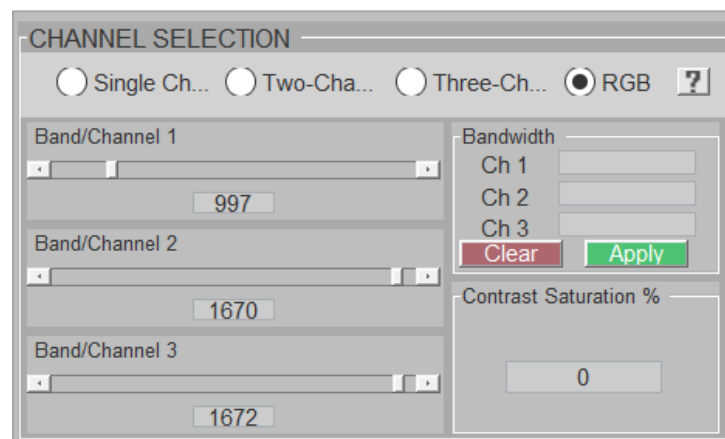
Use this option to visualize the image at any three different bands/channels as a pseudo-RGB image. In this mode, you can assign any band.

This feature is mostly for visualization and can work with other visualization functions (histogram, contrast saturation, cropping, etc.).



Steps:

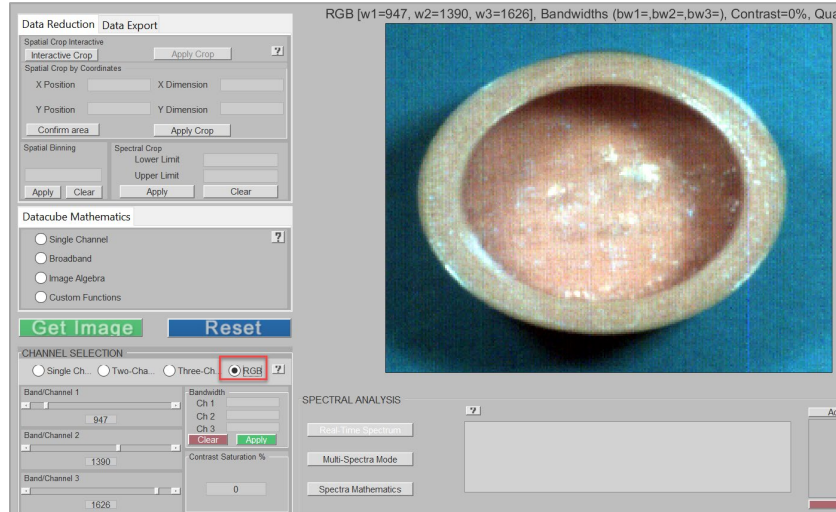
1. Open a file. The default view is monochromatic using a randomly selected single channel.
2. In the CHANNEL SELECTION panel selects **RGB** mode. IDCube automatically and randomly assigns values to all three channels.



Each **Band/Channel** is assigned to a specific true color.

| Band/Channel | Color |
|--------------|-------|
| #1 | red |
| #2 | green |
| #3 | blue |

- Change the values of **Bands/Channels** by either entering values in the boxes or using sliders. The main image will be automatically updated. The input values along with other information will be added to the caption under the main image.



The RGB values for each pixel can be visualized by clicking a **Data Tips** icon on the **Strip Toolbar** and pointing to the pixel of interest. The scale of the colors using a standardized 0 to 255 scale normalized between 0 and 1.



You can increase the number of bands assigned to each channel by entering values in the **BANDWIDTHS** panel.

You can adjust the **Contrast Saturation** of the image by entering the number from 0 (default) to 49. You can fine-tune the image by adjusting histograms in the **RGB HISTOGRAM** panel.

Pressing the **Reset** button will return the image to the original unprocessed state in the monochromatic mode but will remember the values for the RGB channels.

Additional Information:

Large datasets might cause a delay in updating the slider value and the image. Click the green **Get Image** button to ensure the effect.

The sliders work well for a relatively large number of bands that are uniformly distributed. For a small number of bands (10 or less, i.e., in multispectral imaging) adding the values manually might be necessary.

Bandwidths

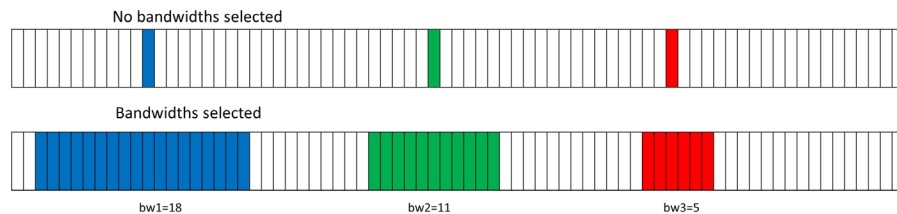
NOTE: Plastic and Coin dataset is used as an example. Example is given for the RGB mode.

Features:

Use this option to broaden the band as shown below and treat the resulting group as a single band. For example, in the RGB mode, you can include additional bands on every color channel.

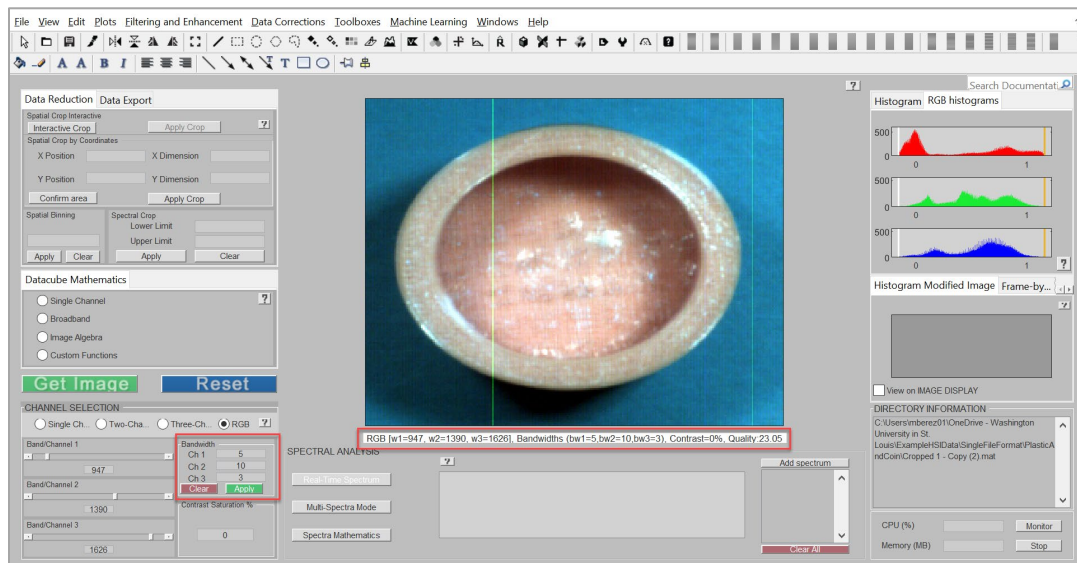
This function can be used with any Channel Selection: **Single Channel**, **Two-Channel**, **Three-Channel**, or **RGB**.

This feature is for visualization only and can work with visualization functions (histogram, colormaps, etc). The entered bandwidths do not pass to other functions that treat input as single bands.



Steps:

1. Load the file.
2. Select the bands of interest in **Band/Channels**. Those are the center bands.
3. Go to the **BANDWIDTH** panel and add values to Ch1 through Ch 3. The bandwidth indicates how many bands/channels will be combined to generate the image.
4. Click **Apply** and observe the image. The information about the bandwidths can be seen in the caption under the image.



Additional Information:

The current version of the software sums the signal from several bands grouped into one band.

Contrast Saturation

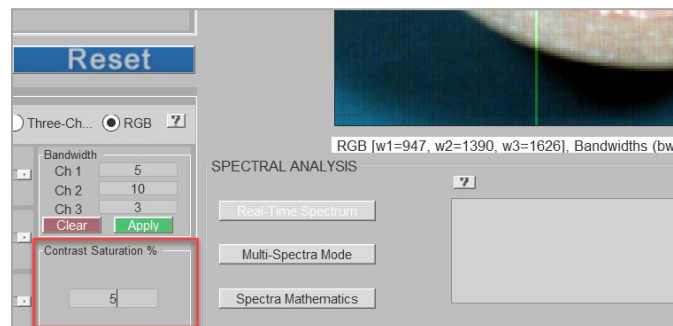
NOTE: PAVIA dataset is used as an example.

Features:

Enables the user to adjust the image visualization by changing the contrast saturation. Contrast saturation is preserved for any further changes activated from **Main Interface** but *is not transferred to Toolboxes*. Only available for the RGB mode. The original data are not affected.

Steps:

1. Load the image file and select **RGB** from the CHANNEL SELECTION panel:



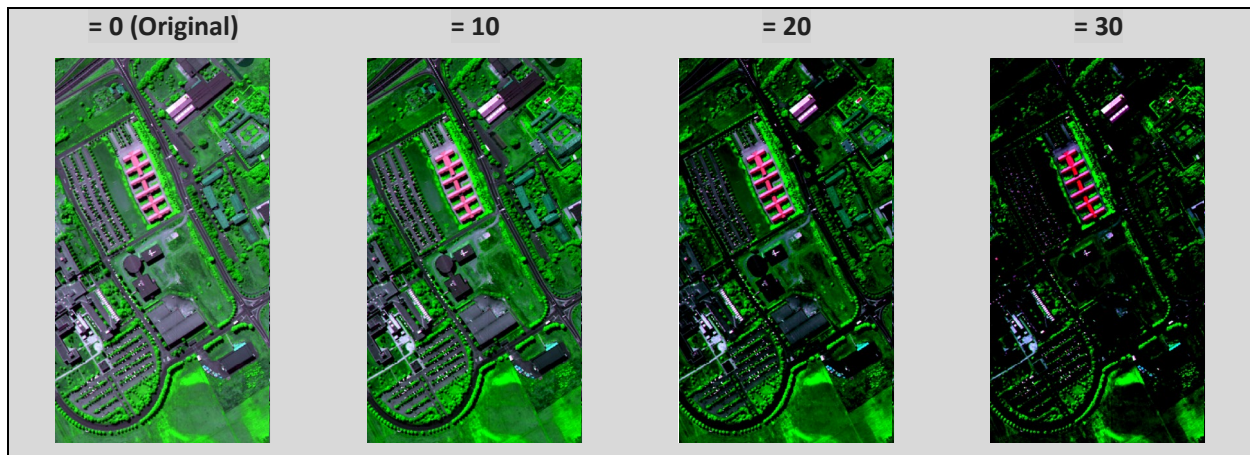
2. Put a value in **Contrast Saturation %** between 0 and 49.9 (default 0). A higher level of contrast saturation will make the image with higher contrast and often darker. To remove the contrast saturation, put a zero in the Contrast Saturation field.

Contrast Saturation

Contrast Saturation

Contrast Saturation

Contrast Saturation



Additional Information:

The algorithm maps the values in true-color image RGB to new values by saturating the bottom $N\%$ and the top $N\%$ of all pixel values, where N is the value inputted into the textbox. The same mapping is applied to each channel.

6.6. Histogram Image Adjustment Panel

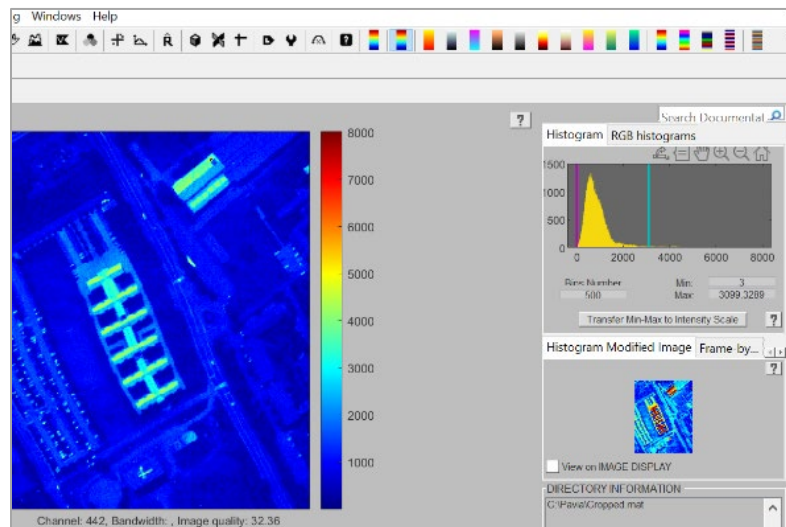
NOTE: PAVIA dataset is used as an example.

Features:

Enables the user to optimize the view of the image using an interactive HISTOGRAM panel. Works in both, monochromatic mode and an RGB mode.

Monochromatic mode

1. Select the **Monochromatic** tab in the HISTOGRAM panel. To adjust the image, move either a magenta (minimum) or cyan (maximum) boundary line. The changes can be seen in the **Min** and **Max** fields located under the histogram.
- a. The **Bins number** enables the user to change the number of the histogram bins. The default level is 500, this quantity depends on the spatial size of the image, and smaller files might need a lower number of bins.

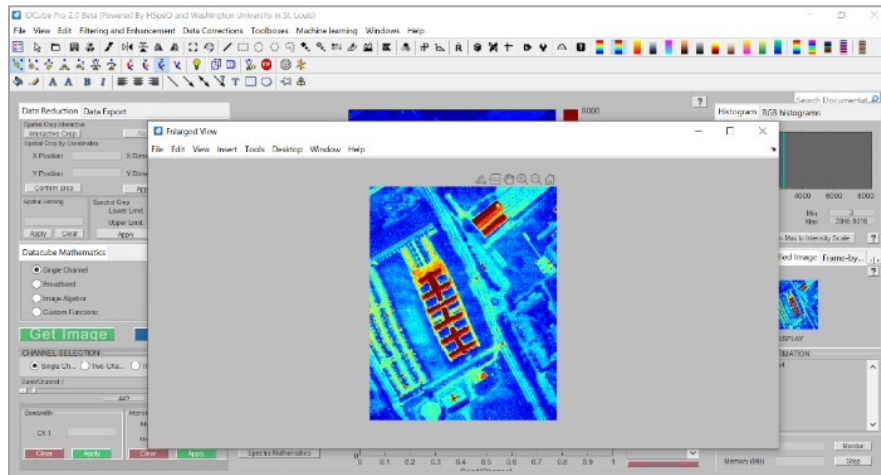


The changes in the images will be immediately visualized:

- a. In the HISTOGRAM MODIFIED IMAGE panel located below the HISTOGRAM PANEL (default).
- b. In the IMAGE DISPLAY panel if the **View on Image Display** checkbox is checked.



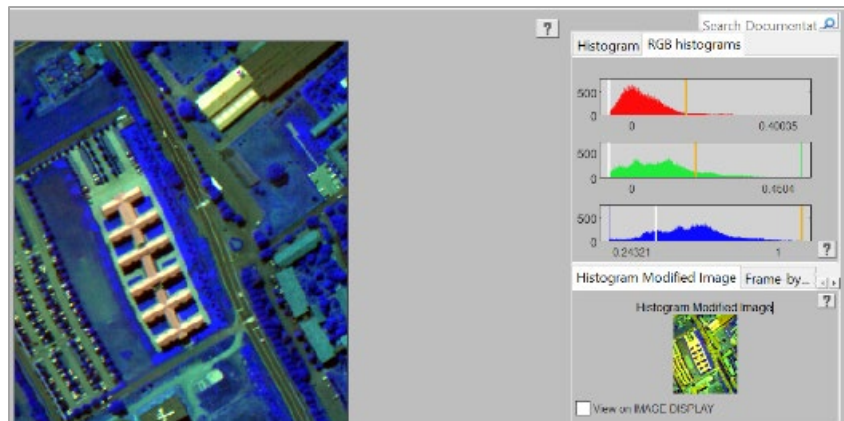
You can also expand the image by clicking on it.



NOTE: After adjustment the histogram you can save the entire dataset as a new file. Select **File** → **Save Histogram-Modified Dataset** and select a destination folder. By default, the current folder will be opened. You can create a different folder. Press **Select Folder**. For details see **Save Histogram-Modified Dataset** section).

RGB mode

Select the RGB histogram tab in the HISTOGRAM panel or select RGB in the CHANNEL SELECTION panel. To adjust the image, move either a white (minimum) or orange (maximum) boundary line in each of the channels (Red, Green, or Blue). The scale of the channels is between 0 and 1.



1. The changes in the images will be immediately visualized:
 - a. In the HISTOGRAM MODIFIED IMAGE panel located below the HISTOGRAM PANEL (default).
 - b. In the IMAGE DISPLAY panel if the **View on Image Display** checkbox is checked.
2. You can also expand the image by clicking on the image.

6.7. Image Enhancement Panel

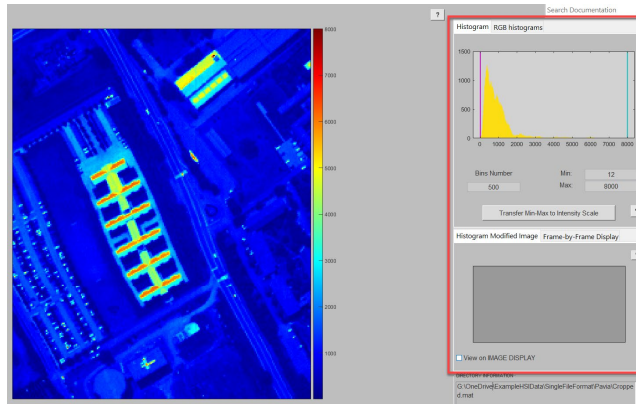
The main feature of the panel is to improve the visualization of the 2D representation of the datacube. This is performed using an image histogram.

An image histogram is a gray-scale value distribution showing the frequency of occurrence of each gray-level value. Modification of image histograms is commonly used in image enhancement procedures.

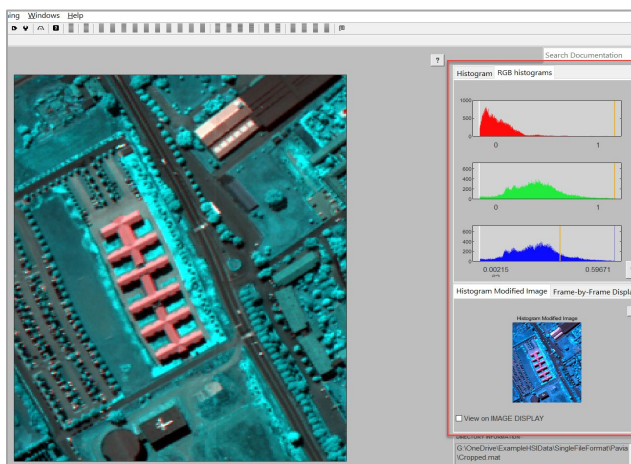
IDCube calculates the histogram for both the grayscale image and the RGB-type image. The number of bins in the histogram can be changed (default = 500) and is determined by the image type and size. Larger images might require a larger number of bins. IDCubePro® enables the user to control the number of bins.

IDCube also enables the user to modify the image by controlling the boundaries of the histogram. In the unprocessed image, all pixels have an intensity and are presented in the histogram. Moving boundaries in the HISTOGRAM panel allow you to remove some of the pixels with abnormally high or low intensities. These pixels are eliminated from the image. The boundaries can be controlled interactively by grabbing and moving the boundaries or by entering the values in the appropriate fields.

HISTOGRAM panel for monochromatic images:



HISTOGRAM panel for RGB images:



Monochromatic Histogram

NOTE: Plastic and Coin dataset is used as an example.

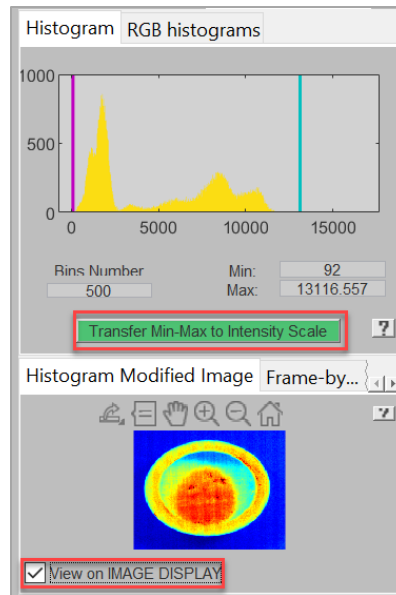
Features:

Enables adjustment of the monochromatic images via interactive histogram manipulation. The changes in the image are first observed in the HISTOGRAM MODIFIED IMAGE panel.

In the case of monochromatic images, you can set the range of intensities for all frames in the dataset.

Steps:

1. Open a file. The histogram will be generated automatically.
2. Select the 1st tab in the HISTOGRAM panel. To adjust the image, move either red (minimum) or green (maximum) boundaries. The changes can be seen in the **Min** and **Max** fields located under the histogram. The **Bins Number** enables the user to change the number of the histogram bins, default 500. This quantity depends on the spatial size of the image, and smaller files might need a lower number of bins.

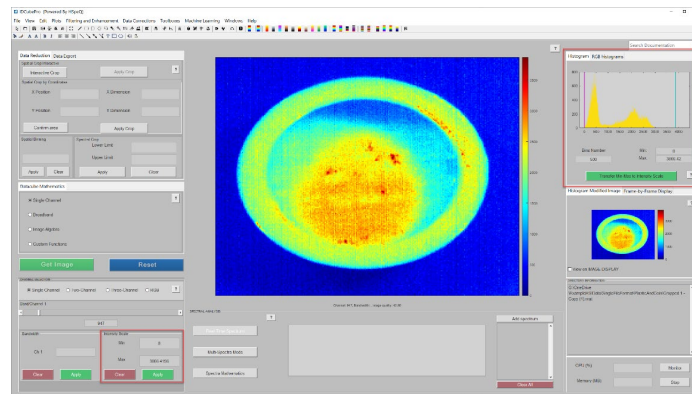


The changes in the images can be visualized in two windows:

- In the HISTOGRAM MODIFIED IMAGE panel located below the HISTOGRAM PANEL (default).
- In the main IMAGE DISPLAY panel, if the **View on Image Display** checkbox is checked.

The changes induced by the monochromatic histogram can be applied globally to the entire dataset.

3. For that click **Transfer Min-Max to Intensity scale**. The INTENSITY SCALE panel located on the bottom left will display the new values.
4. Click **Apply**. You will see that the colorbar on the IMAGE DISPLAY panel will reflect the new boundaries. Click **Clear** to remove values and clear the fields.



RGB Histograms

NOTE: PAVIA dataset is used as an example.

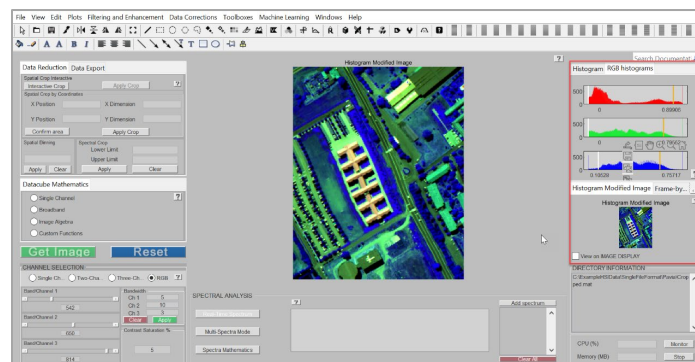
Features: Enables adjustment of RGB images via manipulation of the interactive histogram.

The changes in the image are first observed in the HISTOGRAM MODIFIED IMAGE panel. The changes are only applied to the shown image. Changes in the wavelengths will bring the histogram's min and max values back to the default values.

Steps:

Select the **RGB histograms** tab in the HISTOGRAM panel. To adjust the image, move white (minimum) or orange (maximum) boundaries on any of the three-histogram panels corresponding to three color channels (Red, Green, and Blue). The default scale for each color histogram is from 0 to 1.

Move the boundaries to change the values. In contrast to the monochromatic images, the Bins number is fixed at 500.



The changes in the images can be visualized in two panels:

- In the HISTOGRAM MODIFIED IMAGE panel located below the HISTOGRAM panel (default).
- In the main IMAGE DISPLAY panel by clicking the textbox **View on Image Display** to change the visualization panel.

Click **Reset** to change the histograms and entire image back to the default level.

6.8. Spectral Analysis Panel

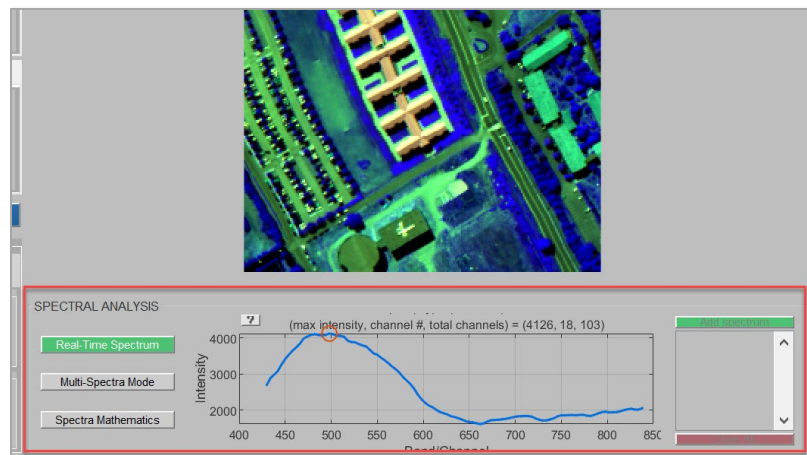
NOTE: PAVIA dataset is used as an example.

Features:

1. Interactively presents spectra at individual pixels.
2. Shows spectra from the selected region of interest (with or without standard deviation).
3. Calculates interactions between the selected spectra that are related to a specific region of interest.
4. Performs mathematics over the spectra (log, derivatives, etc).
5. Saves selected spectra as images, in Excel, or ECOSTRSESS format.

Steps: (could be used in random order)

The spectral analysis toolbox is located at the bottom of the **Main Interface**.

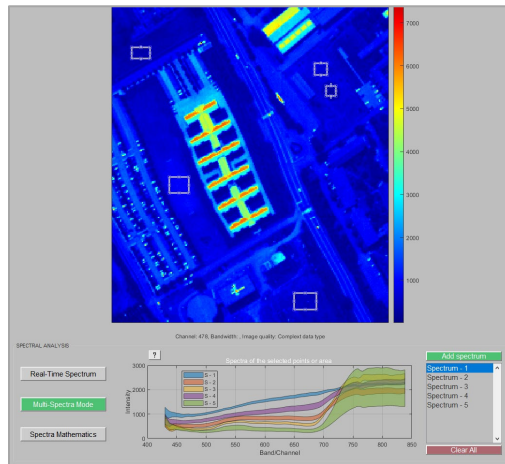


Real-Time Spectrum: In the SPECTRAL ANALYSIS panel click **Real-Time Spectrum** and place the cursor on the image. The spectrum will be generated with its maximum marked with a red circle. The position of the cursor, maximum intensity value, and the total number of channels will be shown above the graph.

Multi-Spectra Mode enables the selection of several regions of interest to visualize their spectra. The default presentation is the standard deviation spectrum. The function enables several spectra to be visualized.

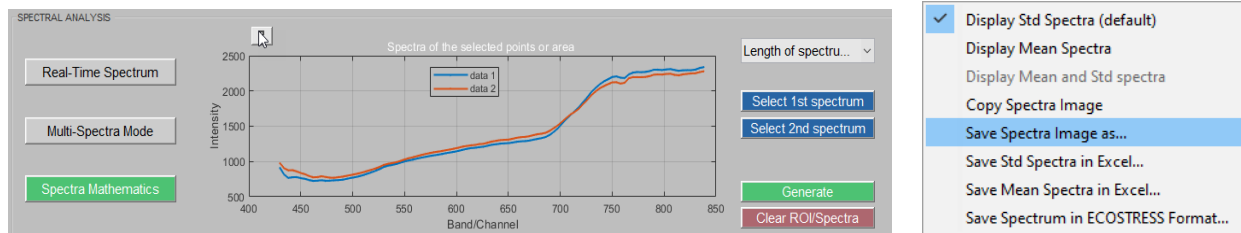
To visualize spectra in a different mode, **Right Click** and select one of the options:

- Standard deviation spectrum (default)
- Mean spectrum



Spectral Mathematics: This mode enables both single-spectrum math as well as a spectral comparison between the selected region of interest and the entire dataset. Click the **Spectra Mathematics** button. A new panel with the available options will appear. Select the method from the drop-down menu. Available options are listed in the table:

| Group | Mathematical function |
|---|---------------------------------------|
| Information | Length of the spectrum (default) |
| | Normalization of one or two spectra |
| Spectral algebra | Subtraction of two spectra |
| | Simple Ratio between two spectra |
| | Log10 |
| | Derivatives of spectra |
| | First Derivative |
| | Second Derivative |
| Fourier transform of spectra | Low pass Fourier transform filtering |
| | High pass Fourier transform filtering |
| Spectral Correlation between two regions of interest | Spectral Correlation value |
| | Spectral Divergence value |
| | Spectral Angle Value |
| Spectral Correlation between the selected region of interest and the rest of the image (correlation maps) | Spectral Correlation Map |
| | Spectral Divergence Map |
| | Spectral Angle Map |
| Spectra smoothing | Savitzky – Golay smoothing |
| Background removal | Continuum Hull Removal |
| | Polynomial Baseline Removal |




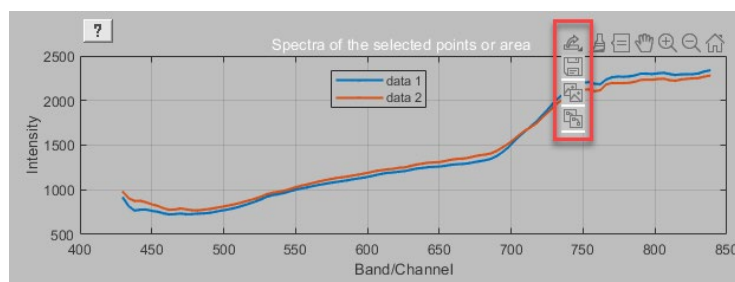
Press the **Select 1st spectrum** button and draw a region of interest.

Whenever applicable, press the **Select 2nd spectrum** button and draw another region of interest.

Click **Generate** to visualize the results. **NOTE:** if Correlation Maps are selected, a new interactive pop-up window will appear.

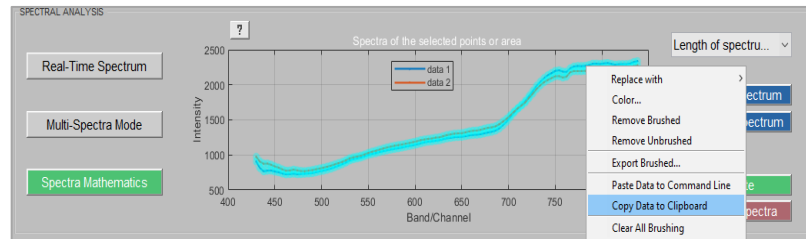
Saving options. The software enables several methods for saving data. Available options include:

1. **Right-click** the mouse on the area outside of the spectra. The options enable the user to save all spectra as images, in Excel and ECOSTRESS format (see below).
 - a. Click **Copy Spectra Image** to generate an image that can be pasted elsewhere. (**NOTE:** this option does not include legends).
 - b. Click **Save Spectra Image as...** to save an image as a *png*, *jpeg*, or *tiff* format. (**NOTE:** this option does not include legends).
 - c. Click **Save Std spectra in Excel...** to save standard deviation spectra derived from a region of interest.
 - d. Click **Save Mean Spectra in Excel...** to save mean spectra from the spectra derived from a region of interest.
2. Hover over the spectral window to activate a small toolbar and point to the **Save** icon. When pointed, the icon further splits into the following icons (options):
 - a. Save As...
 - b. Copy as Image
 - c. Copy as Vector Graphic
3. Saving spectra in Excel format using a brush. Click the **Brush icon** in the **Main Toolbar**  or hover over the spectral window to activate a small toolbar and point to the **Brush** icon. When clicked, the Brush icon will turn blue.



Brush the entire or part of the spectra on the graph and **Right click**. Select **Copy Data to Clipboard** or activate a pop-up by clicking **Export brushed...** and the **Identify Brushed Data** table comes up. The lowest row in the Table corresponds to the first spectrum, the second from the bottom to the second

spectrum and so on. Select the row and the spectrum and the legends will become thicker indicating the spectrum you selected. Click OK and paste the numbers into Excel or other text file. If you need to select another spectrum, you will have to repeat the process: **right-click** on the spectra, select **Copy Data to Clipboard** and select another row. At the end, click the **Brush** button from the small toolbar to deactivate it.





Identify Brushed Data

Select the brushed data to export.

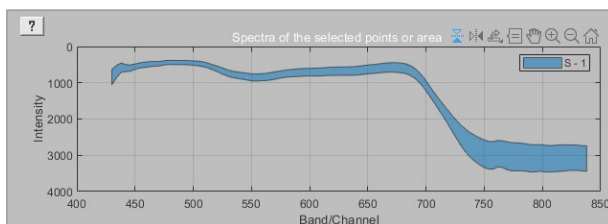
| Number of Brushed Points | Type | Tag |
|--------------------------|------|-----|
| 412 | line | |
| 412 | line | |

OK

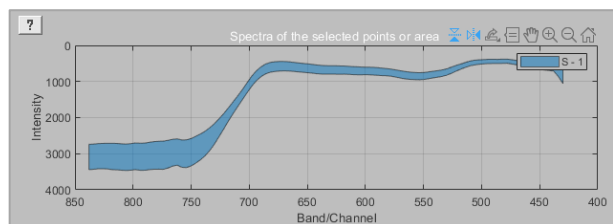
5. Flip spectral axes

The direction of the axes in the spectral windows can be reversed. The default direction is from low to high values. Pressing 'flip' buttons  reverse the directions of axes. Blue color of the flip icon  indicate 'reverse' direction as shown in the spectral images below. The spectral view can be returned to the original by pressing the buttons again.

Y axes is reversed

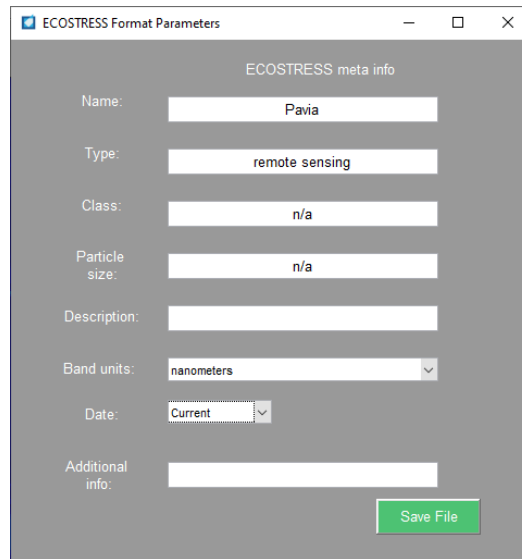


X and Y axes are reversed



NOTE: Many functions on the software will stop responding if one of the icons from the **Strip Toolbar** is activated (blue-colored) except the flip functions. Before you go to the next task, please make sure activated (blue) icons are turned off.

Saving in the ECOSTRESS format. The ECOSTRESS spectral library is a compilation of over 3,400 spectra of natural and manmade materials. These libraries were developed as part of the ASTER and ECOSTRESS projects. IDCubePro® supports the format of the library and allows spectra to be saved in the standard ECOSTRESS format that can be used in the Spectral Matching Toolbox. A new pop-up ECOSTRESS Format Parameters will offer an ECOSTRESS META INFO form to be filled. Submitting any information is optional. This information will be used as a header. Feel free to add the information or leave the fields blank.



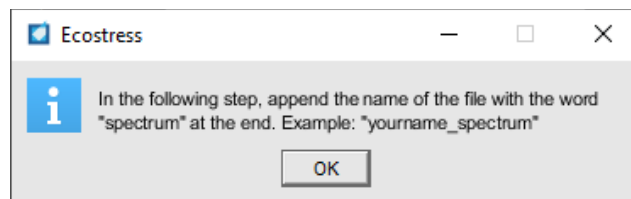
The dialog box titled "ECOSTRESS Format Parameters" contains a section for "ECOSTRESS meta info". It includes the following fields:

- Name: Pavia
- Type: remote sensing
- Class: n/a
- Particle size: n/a
- Description: (empty)
- Band units: nanometers (dropdown menu)
- Date: Current (dropdown menu)
- Additional info: (empty)

A green "Save File" button is located at the bottom right of the dialog.

Click **Save File** and select the folder to store the spectrum.

IMPORTANT: the name of the file must be followed a specific format: yourname_spectrum.txt (i.e., pavia_spectrum.txt) where **spectrum.txt** is mandatory and cannot be changed.



Notes: Some of the advanced spectral functions are also available from other toolboxes.

References:

ECOSTRESS library downloads: <https://speclib.jpl.nasa.gov/>;

ECOSTRESS Library MATLAB format:

<https://www.mathworks.com/help/images/ref/readecostresssig.html>

Length of Spectrum

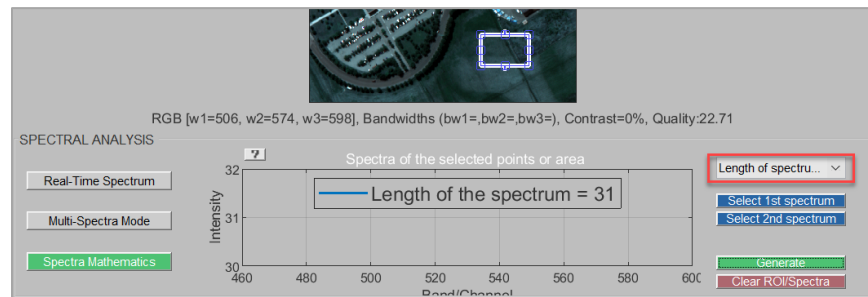
NOTE: PAVIA dataset is used as an example.

Features:

Provides information about the length of the z-dimension. For most of the datacubes, this information is independent of the regions of interest (ROI), but ROI is still required to operate the function.

Steps:

1. Click **Spectra Mathematics**.
2. Select the ROI on the image using a mouse.
3. Select **Length of Spectrum** from the dropdown menu.
4. Click **Select 1st Spectrum**.
5. Click **Generate**. The information will be given in the spectral plot window.



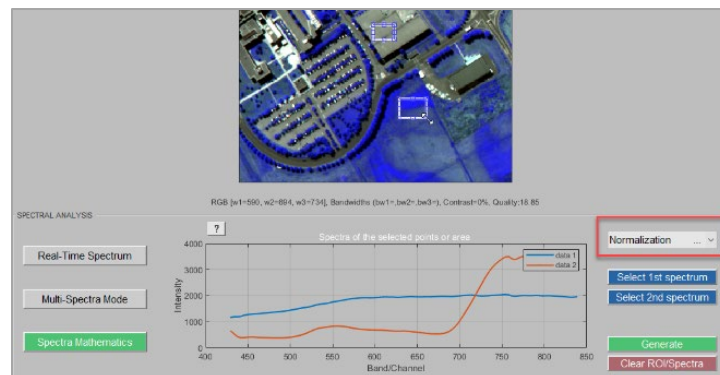
Normalization of Spectra to [0 1]

NOTE: PAVIA dataset is used as an example.

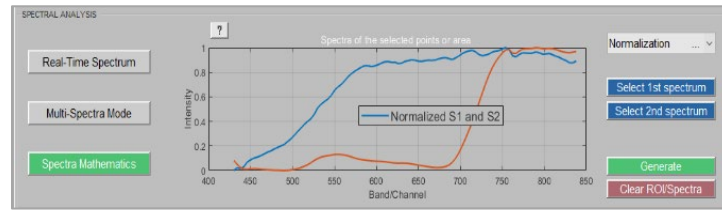
Features: Normalizes up to two spectra from two corresponding regions of interest.

Steps:

1. Click **Spectra Mathematics**.
2. Select **Normalization** from the dropdown menu.
3. Click **Select 1st Spectrum** and draw a region of interest. The spectrum should appear in the SPECTRAL ANALYSIS panel.
4. Click **Select 2nd Spectrum** and draw a region of interest. The second spectrum should appear in the SPECTRAL ANALYSIS panel.



5. Click **Generate**. Both spectra will be normalized to [0, 1].



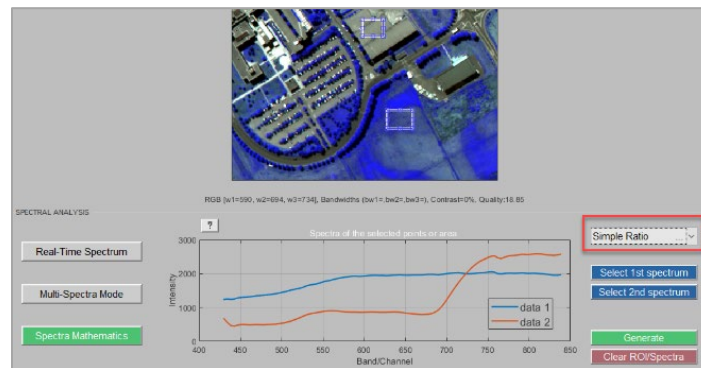
Simple Ratio of Two Spectra

NOTE: PAVIA dataset is used as an example.

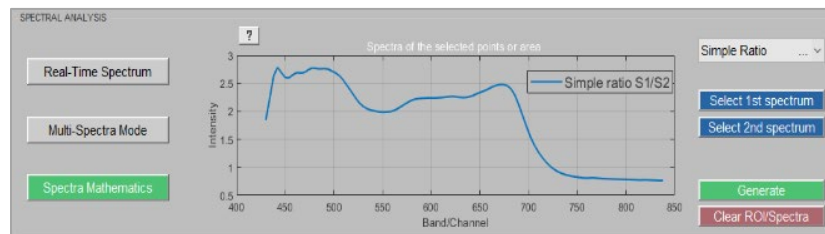
Features: Divides two spectra from two corresponding regions of interest.

Steps:

1. Click **Spectra Mathematics**.
2. Select **Simple Ratio** from the dropdown menu.
3. Click **Select 1st Spectrum** and draw a region of interest. The spectrum should appear in the SPECTRAL ANALYSIS panel.
4. Click **Select 2nd Spectrum** and draw a region of interest. The second spectrum should appear in the SPECTRAL ANALYSIS panel.



5. Click **Generate**. The resulting spectrum will be a result = $S1/S2$.



Log10 of Spectra

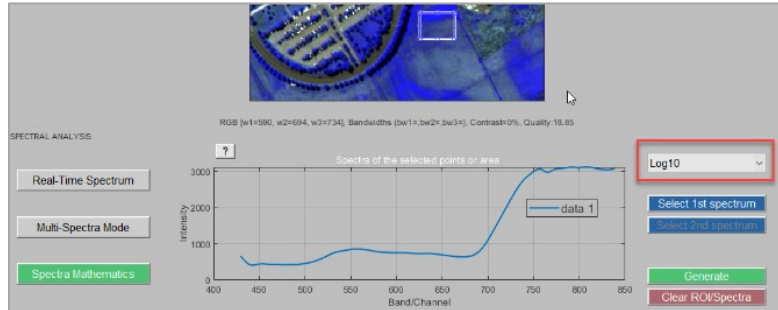
NOTE: PAVIA dataset is used as an example.

Features: Calculates the Log10 of a spectrum.

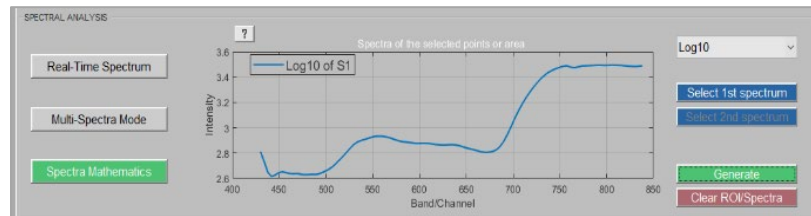
Steps:

1. Click **Spectra Mathematics**.

2. Select **Log10** from the dropdown menu.
3. Click **Select 1st Spectrum** and draw a region of interest. The spectrum should appear in the SPECTRAL ANALYSIS panel.



4. Click **Generate**. The resulting spectrum will be a result = $\log_{10}(S1)$.



First Derivative

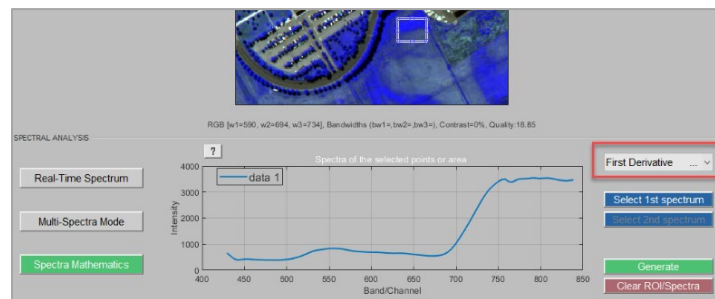
NOTE: PAVIA dataset is used as an example.

Features: Generates the first derivative of the spectra.

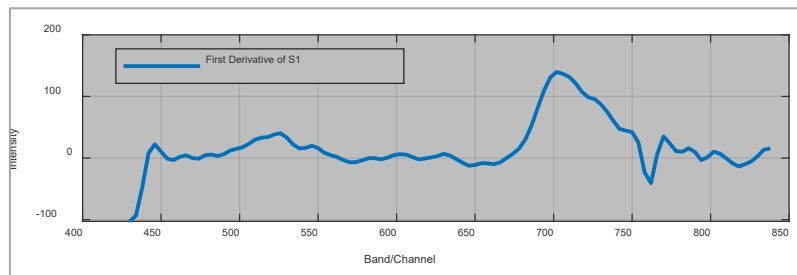
The first derivative of the spectrum from the region of interest is performed in two steps. First, the function averages the spectra from the region of interest. Second, the algorithm performs derivation of the spectrum, converting the mean spectrum into its corresponding first derivative spectrum.

Steps:

1. Load the file. Select **Spectra Mathematics** and select **First Derivative**.
2. Press **Select 1st spectrum**. Draw a region of interest. A spectrum corresponding to the average spectrum of the selected region will appear in the SPECTRAL ANALYSIS panel.



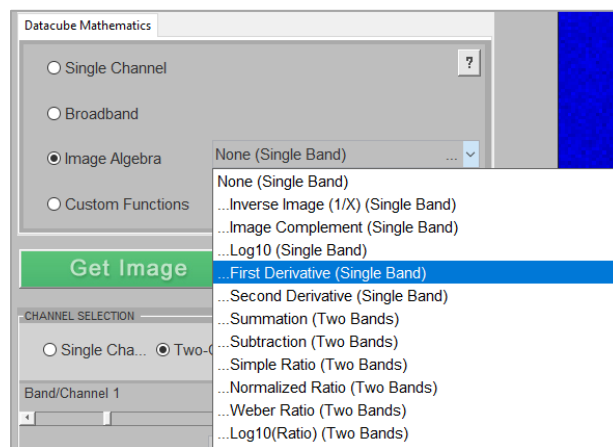
3. Press **Generate** and observe a new spectrum.



NOTE: You can save the spectra using the brushing mode available from the **Strip Toolbar**.

Alternative:

You can also execute the first derivative of the entire dataset selecting the **First Derivative** from **Image Algebra** available from the DATACUBE MATHEMATICS panel.



Additional Information:

A first-order derivative is the rate of change of intensity with respect to the band/channel number. A first-order derivative starts and finishes at zero. It also passes through zero at the same wavelength as the max of the band. Either side of this point is positive and negative bands with maximum and minimum at the same wavelengths as the inflection points in the band. This bipolar function is characteristic of all odd-order derivatives.

Second Derivative

NOTE: PAVIA dataset is used as an example

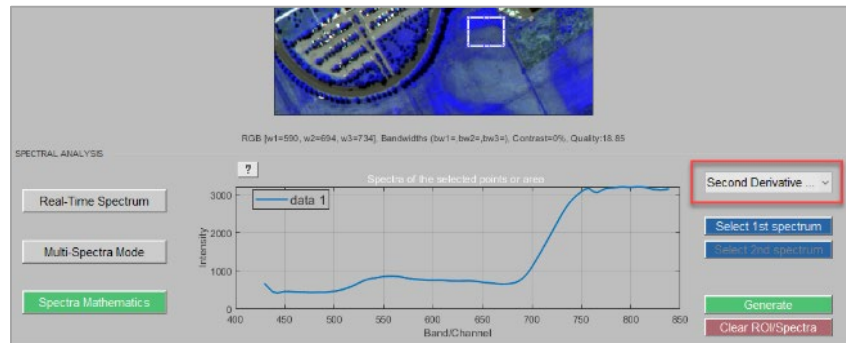
Features:

- Generate the second derivative of the spectra.
- Second derivative spectroscopy is a technique that enhances the separation of overlapping peaks. The second derivative measures the instantaneous rate of change of the first derivative. The sign of the second derivative tells us whether the slope of the tangent line is increasing or decreasing.

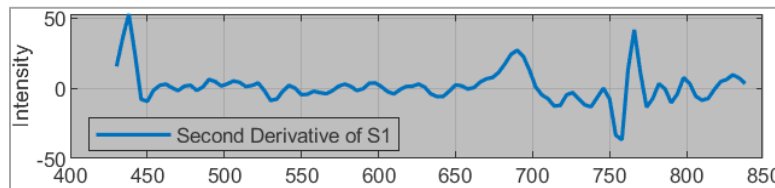
Steps:

1. Load the file. Select **Spectra Mathematics** and select **Second Derivative** from the dropdown menu.

- Click **Select 1st** spectrum. Draw a region of interest. A spectrum corresponding to the average spectrum of the selected region will appear in the SPECTRAL ANALYSIS panel.

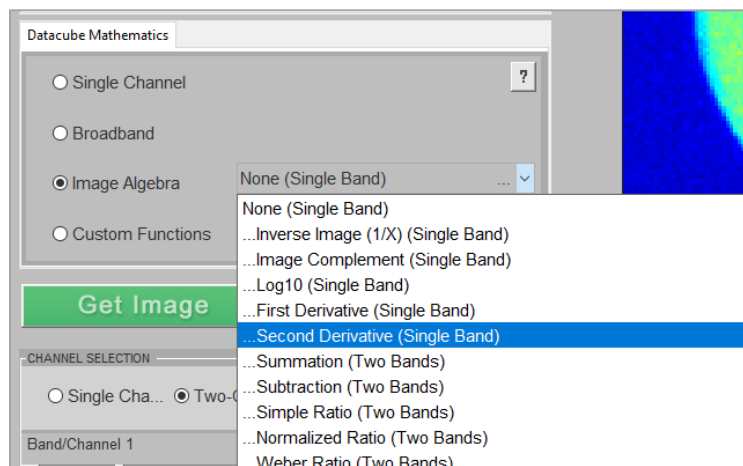


- Press **Generate** and observe a new spectrum.



Tip: You can save the spectra using the brushing mode available from the **Strip Toolbar**.

NOTE: You can also execute the second derivative of the entire dataset by selecting **Second Derivative** from **Image Algebra** available from the **DATA CUBE MATHEMATICS** panel.



Low Pass Fourier Transform Spectral Analysis

NOTE: PAVIA dataset is used as an example. Can be used in conjunction with **Filtering and Enhancement Tab** → **Low Pass FFT Filter**.

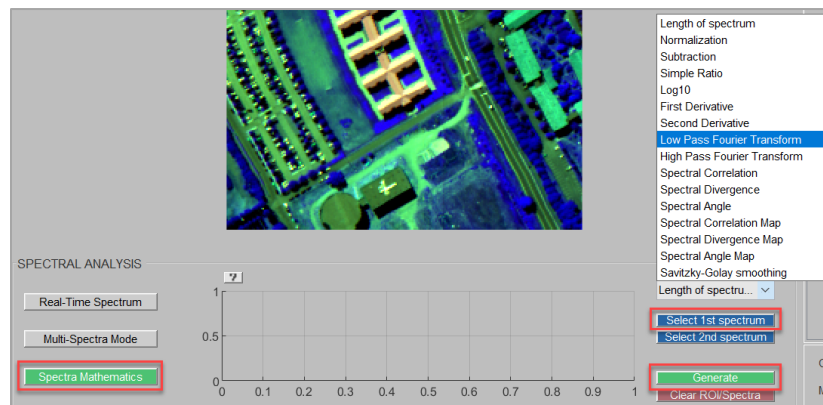
Features: Performs FFT of the spectrum and removes high-frequency data.

The Low Pass FFT of the spectrum from the region of interest is performed in several steps automatically after several inputs from the user. First, the function averages the spectra from the region of interest. Second,

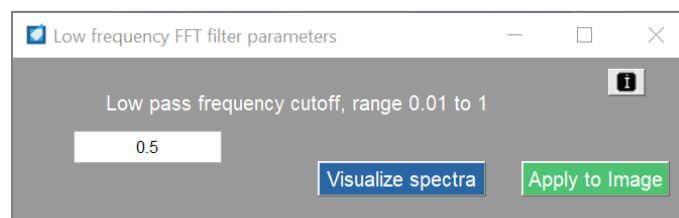
the algorithm performs a Fourier transform of the spectrum, converting the mean spectrum into its corresponding frequency domain spectrum. Third, the algorithm executes a low pass filter with a specified user cut-off frequency. In the final step, the inverted Fourier transform algorithm is performed to generate a new dataset with only low frequencies remaining.

Steps:

1. Optimize and visualize the performance of FFT on an individual spectrum from the selected region of interest using **Fourier Transform**.
 - a. Load the file.
 - b. Select **Spectra Mathematics**.
 - c. Select **Low Pass Fourier Transform**.
2. Click **Select 1st Spectrum** and draw a region of interest. A spectrum corresponding to the region will appear in the SPECTRAL ANALYSIS window.



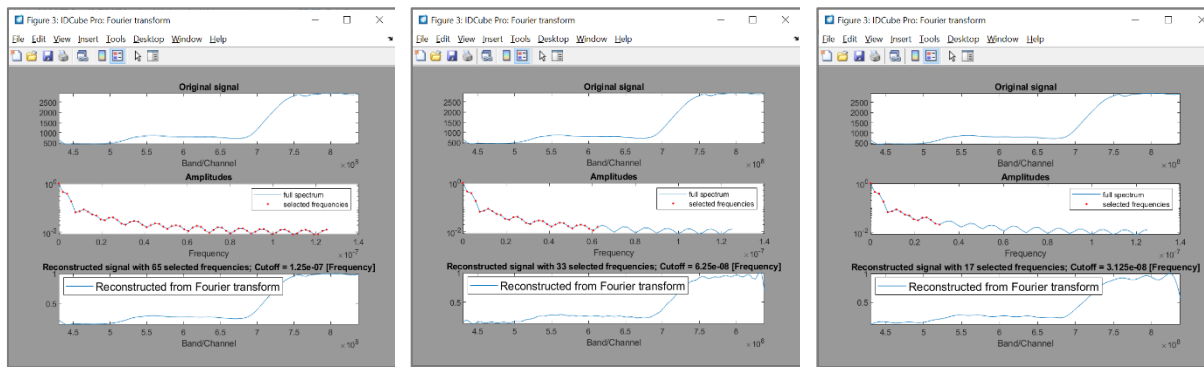
3. Press **Generate** and enter a **Cutoff** value number in the pop-up dialog. The number reflects the % of Nyquist frequency in the range between 0 and 1.



4. Press **Visualize Spectra**.

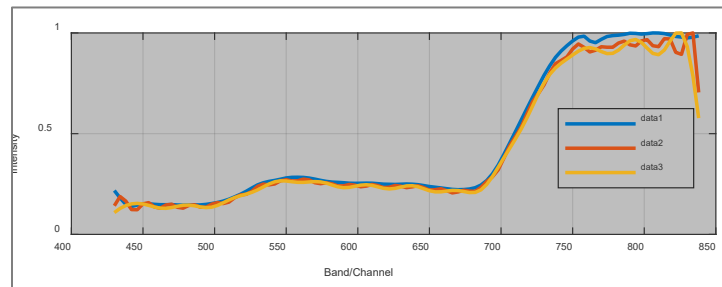
Observe a new window that shows the following spectra: the original spectrum, FFT transformed spectrum, and a reconstructed spectrum as shown in the figure below. From top to bottom: i) original spectrum, ii) frequency domain spectrum, with red dots showing the frequencies that are preserved for subsequent inverse Fourier transform, iii) the spectrum after the inverse Fourier transform.

| | | |
|---|--|--|
| Cutoff =1.0 (Preserves 100% frequencies) | Cutoff =0.5 (Keeps 50% low frequencies) | Cutoff=0.25 (Keeps 25% low frequencies) |
|---|--|--|

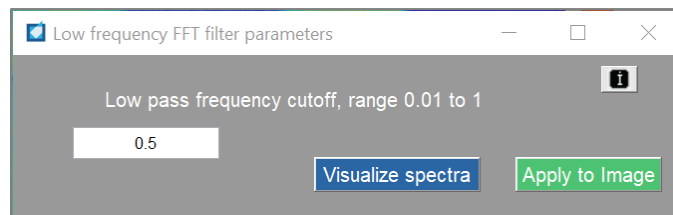


NOTE: the intensity scale of the reconstructed spectra automatically changes and ranges from 0 to 1.

The results of these transformations can be also seen in the SPECTRAL ANALYSIS panel. Multiple reconstructed spectra from several cutoffs can be visualized.



(Optional) After the cutoff value of the FFT filter is optimized, press **Apply to Image** to visualize the resulting filtered image.



References:

The algorithm is built using part of the *fftl* library developed by Shmuel Ben-Ezra in 2009:

https://www.mathworks.com/matlabcentral/fileexchange/25017-fft-filter-clean-your-signals-and-display-results?s_tid=srchtitle

High Pass Fourier Transform Spectral Analysis

NOTE: PAVIA dataset is used as an example. Can be used in conjunction with **Filtering and Enhancement Tab** → **High Pass FFT Filter**

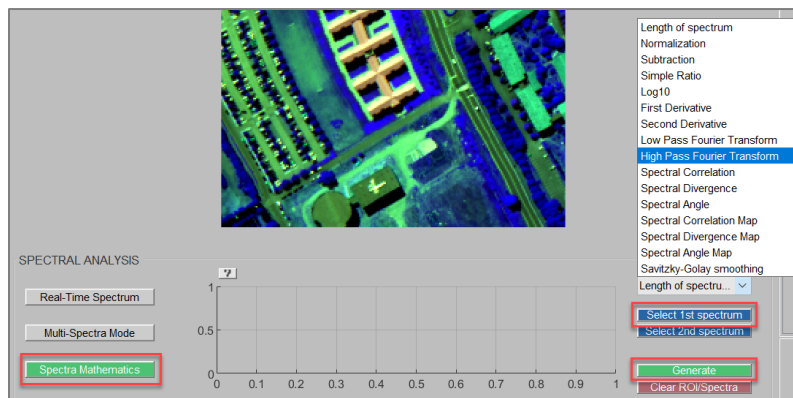
Features: Performs FFT of the spectrum and removes low-frequency data.

The High Pass FFT of the spectrum from the region of interest is performed in several steps, automatically with several inputs from the user. First, the function averages the spectra from the region of interest. Second,

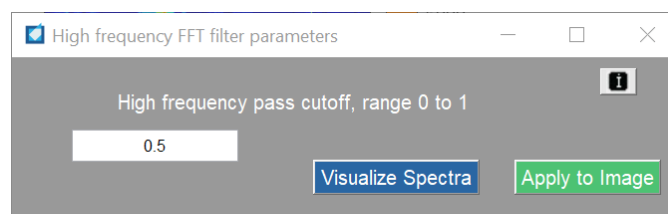
the algorithm performs a Fourier transform of the spectrum, converting the mean spectrum into its corresponding frequency domain spectrum. Third, the algorithm executes a high pass filter with a specified user cut-off frequency. In the final step, the inverted Fourier transform algorithm is performed to generate a new dataset with only high frequencies remaining.

Steps:

1. Optimize and visualize the performance of FFT on an individual spectrum from the selected region of interest using **Fourier Transform**.
 - a. Load the file.
 - b. Select **Spectra Mathematics**.
 - c. Select **High Pass Fourier**.
 - d. Click **Select 1st Spectrum** and draw a region of interest. A spectrum corresponding to the region will appear in the SPECTRAL ANALYSIS panel.



2. Press **Generate** and enter a **Cutoff** value number in the pop-up dialog. The number reflects the % of Nyquist frequency in the range between 0 and 1.



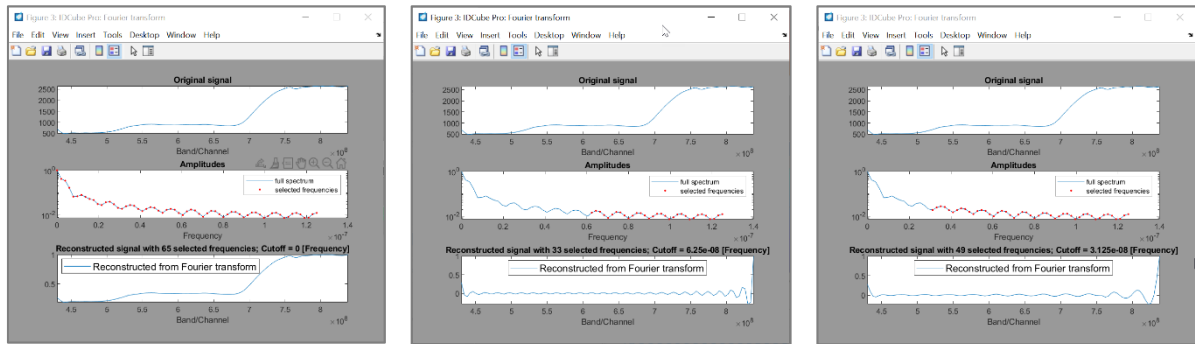
3. Press **Visualize Spectra**.
4. Observe a new window that shows the original spectrum, FFT transformed spectrum, and a reconstructed spectrum as shown in the figure below. From top to bottom: i) original spectrum, ii) frequency domain spectrum, with red dots showing the frequencies that are preserved for subsequent inverse Fourier transform, iii) the spectrum after the inverse Fourier transform.

NOTE: the intensity scale of the reconstructed spectra ranges from 0 to 1.

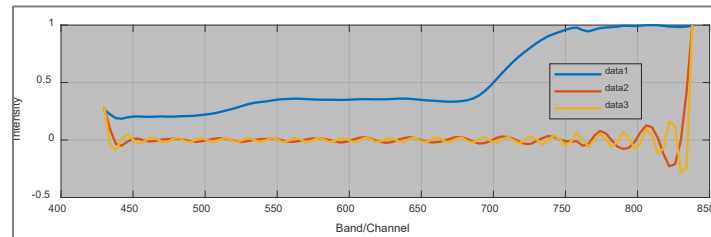
Cutoff=0.0
(preserves 100% frequencies)

Cutoff=0.5
(keeps 50% high frequencies)

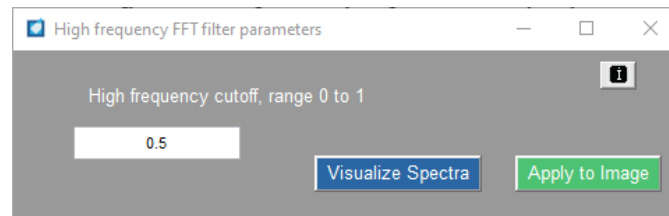
Cutoff=0.25
(keeps 75% high frequencies)



The results of these transformations can be also seen in the SPECTRAL ANALYSIS panel. Multiple reconstructed spectra from several cutoffs can be visualized.



(Optional) After the cutoff value of the FFT filter is optimized, press **Apply to Image** to visualize the resulting filtered image.



References:

The algorithm is built using part of the fftl library developed by Shmuel Ben-Ezra in 2009:

https://www.mathworks.com/matlabcentral/fileexchange/25017-fft-filter-clean-your-signals-and-display-results?s_tid=srchtitle

Spectral Correlation

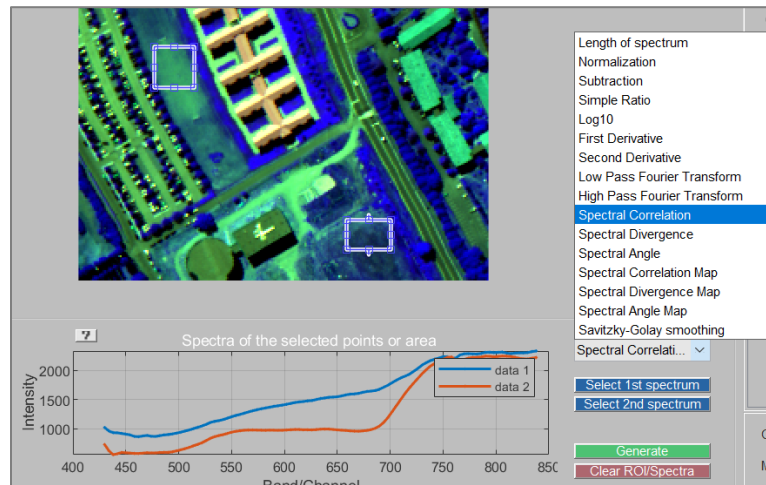
NOTE: PAVIA dataset is used as an example.

Features: Generates comparison between any two regions of interest interactively selected on the image using spectral correlation algorithm.

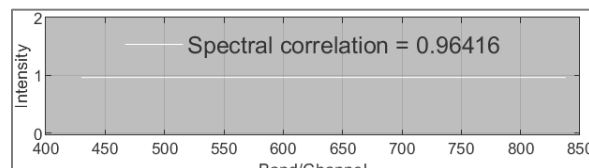
Steps:

1. Load the file. Select **Spectra Mathematics** and select **Spectral Correlation** from the dropdown menu.

2. Click **Select 1st Spectrum**. Draw a region of interest. A spectrum corresponding to the average spectrum of the selected region will appear in the SPECTRAL ANALYSIS panel.
3. Click **Select 2nd Spectrum**. Draw a region of interest. A spectrum corresponding to the average spectrum of the selected region will appear in the SPECTRAL ANALYSIS panel.



4. Press **Generate** to measure the spectral correlation between two objects. Correlation coefficient scores can range from -1 to $+1$. A score of -1 indicates a perfect negative correlation, while a score of $+1$ indicates a perfect positive correlation. Higher scores correspond to stronger spectral correlation. A score of 0 indicates no correlation between the two selected areas.



In the shown case where two areas (purple boxes) were selected, the spectral correlation score is 0.964. For comparison, the correlation score between the roof and the grass is 0.672.

Press **Clear ROI/Spectra** to start another correlation analysis or any other spectral tasks.

The function is based on a spectral cross-correlation algorithm that computes the p -scores for Pearson's correlation using a Student's t distribution for a transformation of the correlation.

References

Gibbons, J.D. *Nonparametric Statistical Inference*. 2nd ed. M. Dekker, 1985.

Hollander, M., and D.A. Wolfe. *Nonparametric Statistical Methods*. Wiley, 1973.

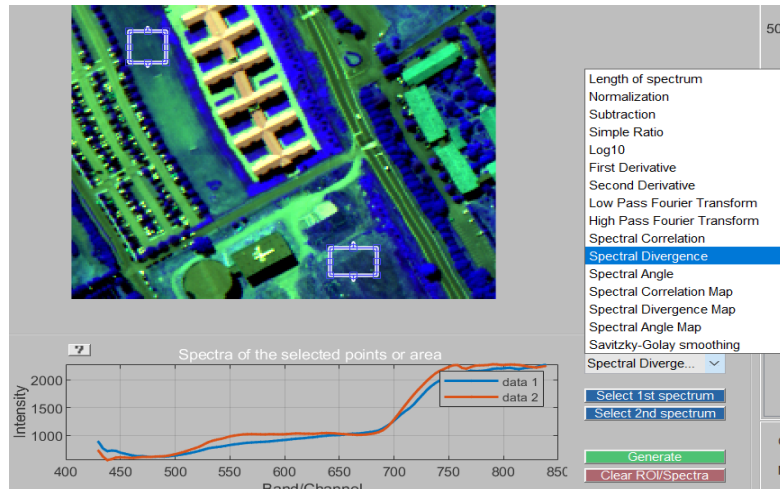
Spectral Divergence

NOTE: PAVIA dataset is used as an example.

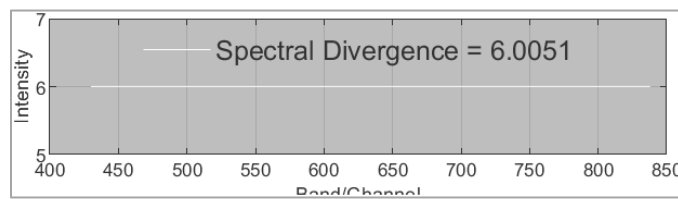
Features: Generates comparison between any two regions of interest interactively selected on the image using spectral information divergence (SID) algorithm.

Steps:

1. Load the file. Select **Spectra Mathematics** and select **Spectral Divergence**.
2. Click **Select 1st spectrum**. Draw a region of interest. A spectrum corresponding to the average spectrum of the selected region will appear in the SPECTRAL ANALYSIS panel.
3. Click **Select 2nd spectrum**. Draw a region of interest. A spectrum corresponding to the average spectrum of the selected region will appear in the SPECTRAL ANALYSIS panel.



4. Press **Generate** to measure the spectral information divergence score between two objects. A lower score corresponds to a stronger similarity between the areas. A value of 0 indicates no divergence between the two areas.



In the shown case where two areas (purple boxes) were selected, the SID score is 3.9382. For comparison, the SID score between the roof and the canopy is 38.43.

Press **Clear ROI/Spectra** to start another analysis or to perform any other spectral tasks.

Additional Information:

The method measures the spectral similarity between the two mean spectra from the selected ROIs by using the spectral information divergence (SID) algorithm. This method might also be used to compare the spectral signature of an unknown material against the reference area. The smaller the divergence, the more likely the pixels are similar.

The method computes spectral similarity scores based on the divergence between the probability distributions of the two spectra.

References:

Chein-I Chang, "An Information-Theoretic Approach to Spectral Variability, Similarity, and Discrimination for Hyperspectral Image Analysis." *IEEE Transactions on Information Theory* 46, no. 5 (August 2000): 1927–32. <https://doi.org/10.1109/18.857802>.

Du, H., C.-I. Chang, H. Ren, F. M. D'Amico, and J. O. Jensen, J. "New Hyperspectral Discrimination Measure for Spectral Characterization." *Optical Engineering* 43, No. 8 (2004): 1777-1786.

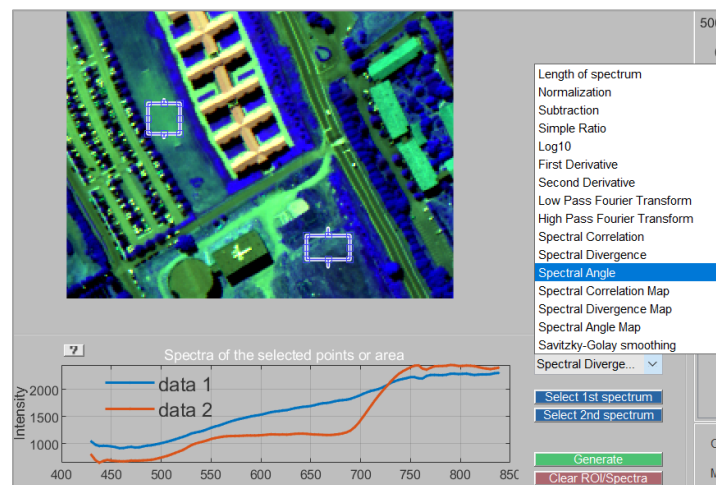
Spectral Angle

NOTE: PAVIA dataset is used as an example.

Features: Generates comparison between any two regions of interest interactively selected on the image using a spectral angle algorithm.

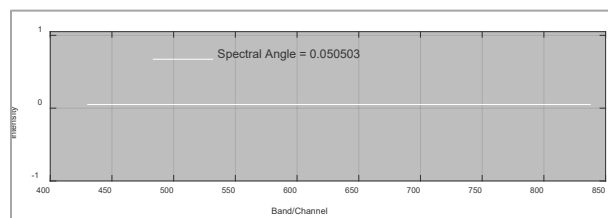
Steps:

1. Load the file. Select **Spectra Mathematics** and select **Spectral Angle** from the dropdown menu.
2. Click **Select 1st spectrum**. Draw a region of interest. A spectrum corresponding to the average spectrum of the selected region will appear in the SPECTRAL ANALYSIS panel.
3. Click **Select 2nd spectrum**. Draw another region of interest. A spectrum corresponding to the average spectrum of the selected region will appear in the SPECTRAL ANALYSIS panel.



4. Press **Generate** to measure the spectral angle between two objects.

A lower score corresponds to stronger spectral similarity. A score of 0 indicates perfect similarity. Usually, a score > 0.1 radians indicate no similarity.



5. In the shown case where two objects were selected, the spectral angle is 0.05. For comparison, the spectral angle between the roof and the canopy is much higher 0.405 (not shown) indicating a low spectral correlation between the two subjects.
6. Press **Clear ROI/Spectra** to start another spectral angle analysis or any other spectral tasks.

Additional Information:

The spectral angle algorithm determines the spectral similarity between two spectra by calculating the angle between the spectra. Smaller angles represent closer matches between the two selected areas.

References:

Kruse, F.A., A.B. Lefkoff, J.W. Boardman, K.B. Heidebrecht, A.T. Shapiro, P.J. Barloon, and A.F.H. Goetz. "The Spectral Image Processing System (SIPS)—Interactive Visualization and Analysis of Imaging Spectrometer Data." *Remote Sensing of Environment* 44, no. 2–3 (May 1993): 145–63. [https://doi.org/10.1016/0034-4257\(93\)90013-N](https://doi.org/10.1016/0034-4257(93)90013-N).

Spectral Cross-Correlation Map

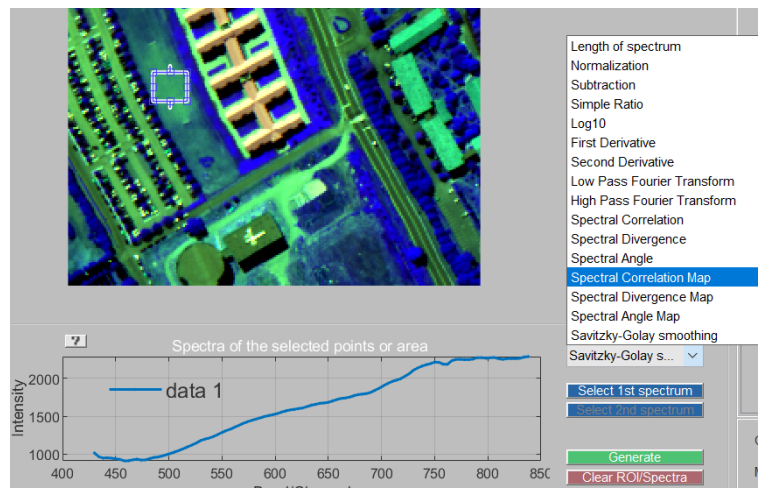
NOTE: PAVIA dataset is used as an example.

Features:

- Enables to draw a seed and cross-correlate with the rest of the image.
- Identifies the area of the highest/lowest cross-correlation.
- Quantifies the area correlated with the seed.

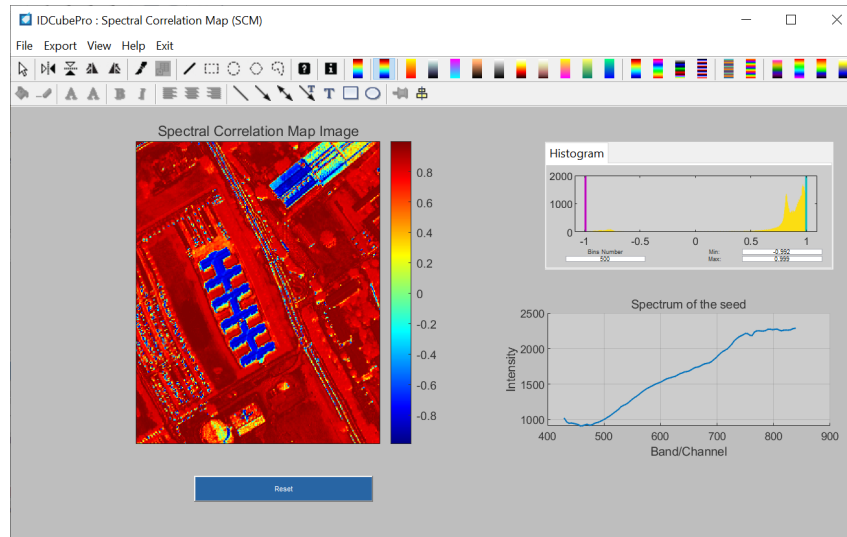
Steps:

1. Press the button **Spectral Mathematics** on the **Main Interface** under SPECTRAL ANALYSIS.
2. Select **Spectral Correlation Map** from a dropdown menu.
3. Select 1st spectrum.
4. Draw a region of interest that can be used as a reference point (seed) and visualize the mean spectrum.



5. Click **Generate** to open another window Spectral Correlation Map.
6. Visualize and quantify a Spectral Cross-Correlation Map.

Higher cross-correlation corresponds to a closer match between the seed and each pixel in the image. Use a slider on the histogram to visualize the images with the highest or lowest correlation. The area of the matched cross-correlation (high cross-correlation) is shown in the title.



The **Reset button** can be used to revert the image to the original.

Additional Information:

The toolbox is based on a spectral cross-correlation algorithm that computes the p -values for Pearson's correlation using a Student's t distribution for a transformation of the correlation.

Values of the correlation coefficient can range from -1 to $+1$. A value of -1 indicates a perfect negative correlation, while a value of $+1$ indicates a perfect positive correlation. A value of 0 indicates no correlation between the seed and the pixel.

References:

Gibbons, J.D. *Nonparametric Statistical Inference*. 2nd ed. M. Dekker, 1985.

Hollander, M., and D.A. Wolfe. *Nonparametric Statistical Methods*. Wiley, 1973.

Spectral Information Divergence Map

NOTE: PAVIA dataset is used as an example.

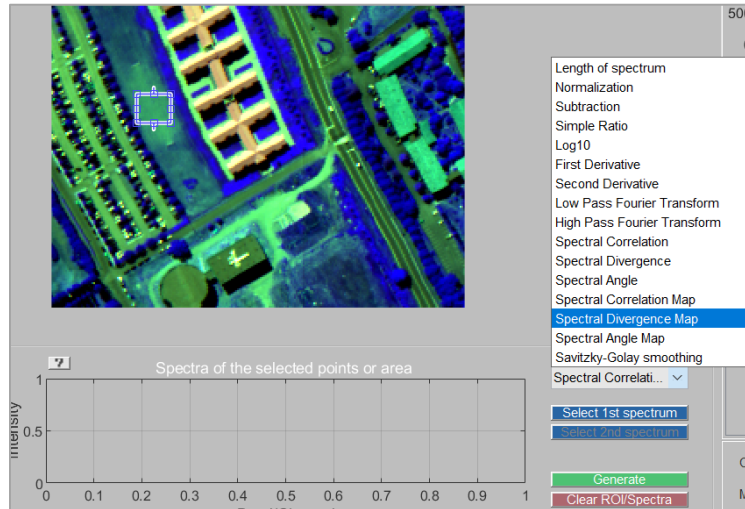
Features:

- Interactively selects a seed.
- Show a divergence between the seed and the rest of the image.
- Identifies the area of the highest/lowest divergence.
- Quantifies the area correlated with the seed.

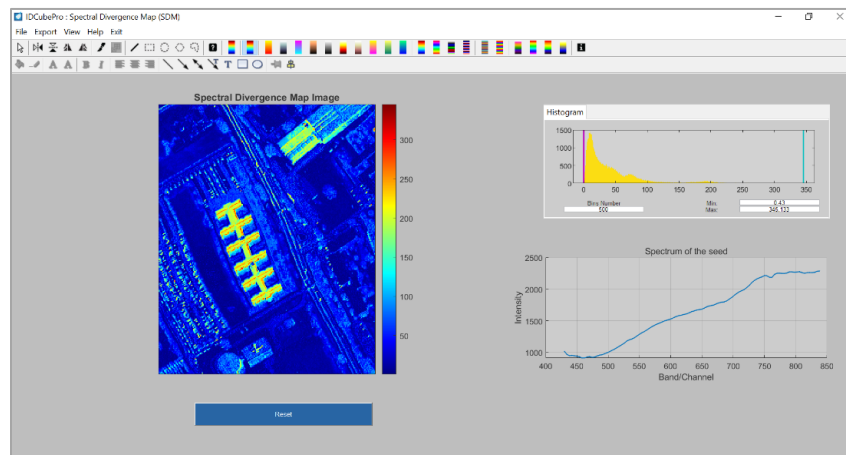
Steps:

2. Press the button **Spectral Mathematics** under Spectral Analysis on the **Main Interface**.
3. Select **Spectral Divergence Map** from a dropdown menu.

4. Select **1st spectrum**.
5. Draw a region of interest and visualize the mean spectrum.



6. Click **Generate** to open another window **Spectral Divergence Map**. The mapping calculations will start.
7. Visualize and quantify a spectral information divergence map.



Lower divergence corresponds to a closer match between the seed and each pixel in the image. Use a slider on the histogram to visualize the images with the highest or lowest correlation. The total area of the matched divergence (low values) is shown in the title.

Using the **Reset** button below the image, revert the image to the original.

NOTE: For this calculation, only values between the cyan line and the left edge of the histogram are counted.

Additional Information:

Spectral Information Divergence (SID) measures the spectral similarity between the specified test spectra (pixels in the image) and reference spectra (mean spectrum) from the selected ROI by using the SID

method. This method is used to compare the spectral signature of an unknown material against the seed reference spectra or to compute spectral variability between two spectral signatures.

SID: measures the spectral similarity between the spectra of each pixel in the hyperspectral data and the specified reference by using the spectral information divergence (SID) technique. The method computes spectral similarity based on the divergence between the probability distributions of the two spectra.

References:

SID: Chein-I Chang. "An Information-Theoretic Approach to Spectral Variability, Similarity, and Discrimination for Hyperspectral Image Analysis." *IEEE Transactions on Information Theory* 46, no. 5 (August 2000): 1927–32. <https://doi.org/10.1109/18.857802>.

Spectral Angle Map

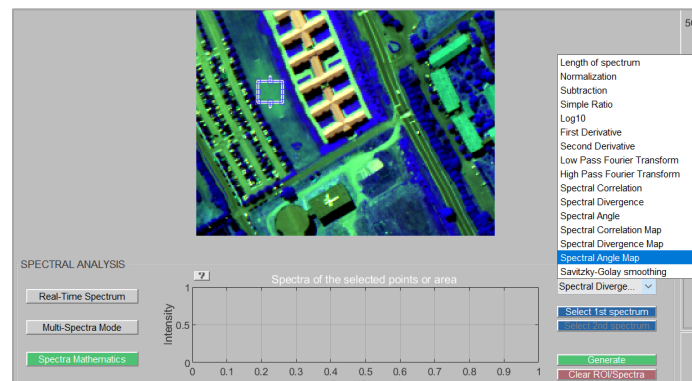
NOTE: PAVIA dataset is used as an example.

Features:

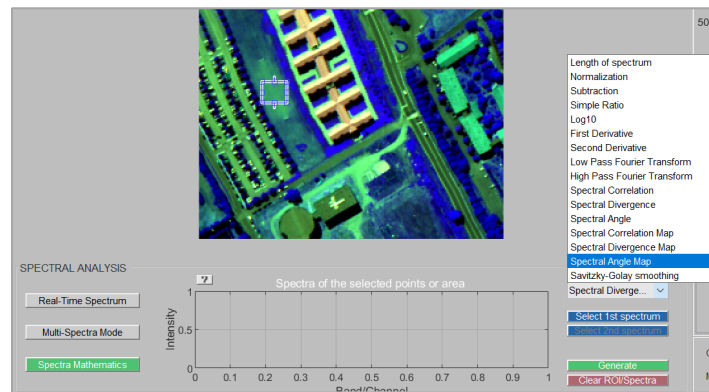
Measures the spectral similarity between the spectra of each pixel in the hyperspectral data and the specified reference spectra (seed) by using the spectral angle mapper (SAM) classification algorithm. A lower score corresponds to stronger spectral similarity. A score of 0 indicates perfect similarity. Usually, a score > 0.1 indicate no similarity between the pixels. A static similarity threshold will have to be applied to recognize similar and dissimilar areas.

- The user can interactively select a seed area.
- Shows a spectral angle map between the seed and the rest of the image.
- Identifies the area of the highest/lowest angle.
- Quantifies the area correlated with the seed.

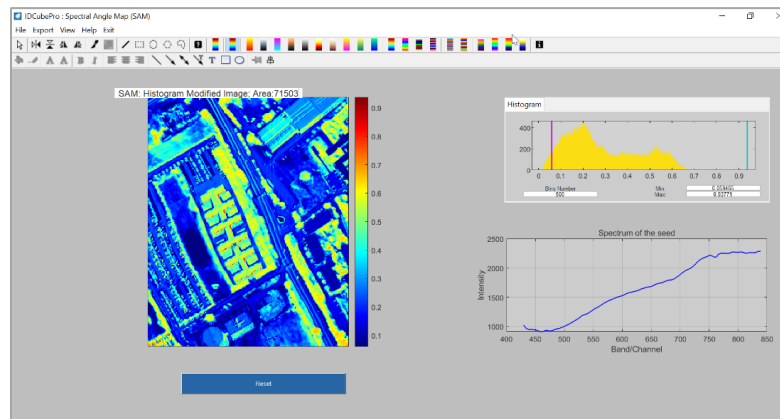
Steps:



Draw an area in the **Image Display** that you would like to use as a reference. This area is called a *seed area*.



1. Press the button **Spectra Mathematics** on the **Main Interface** under the SPECTRAL ANALYSIS panel.
2. Select **Spectral Angle Map** from a dropdown menu.
3. Select the **1st Spectrum** button.
4. Draw a region of interest and visualize the mean spectrum.
5. Click **Generate** to activate the calculation of the map. A new pop-up window **Spectral Angle Map** appears after the calculation is performed.
6. Visualize and quantify a **Spectral Angle Map**.



1. The mapper has three panels:
 - a. Spectrum of the Seed area shows the average spectrum across the selected seed area.
 - b. Histogram of the image where each value is a spectral angle score.
 - c. A monochromatic image of the map where each pixel value is a spectral angle score.
2. The lower angle value corresponds to a closer match between the spectrum from the seed and the pixel in the image.
3. Use a slider on the histogram to set a threshold to visualize the images with the highest or the lowest similarity. For example, to see the regions on the image with the highest similarity to the seed, move the green boundary on the histogram to the left. The modified image of the map will show the highest similarity.

4. The total area of similar objects with the defined threshold (low values) is shown in the title above the map.
5. Press the **Reset** button to cancel changes and return the spectral angle map image to the original.

NOTE: For these calculations, only values between the green line and the left edge of the histogram are counted.

References:

Kruse, F.A., A.B. Lefkoff, J.W. Boardman, K.B. Heidebrecht, A.T. Shapiro, P.J. Barloon, and A.F.H. Goetz. "The Spectral Image Processing System (SIPS)—Interactive Visualization and Analysis of Imaging Spectrometer Data." *Remote Sensing of Environment* 44, no. 2–3 (May 1993): 145–63. [https://doi.org/10.1016/0034-4257\(93\)90013-N](https://doi.org/10.1016/0034-4257(93)90013-N).

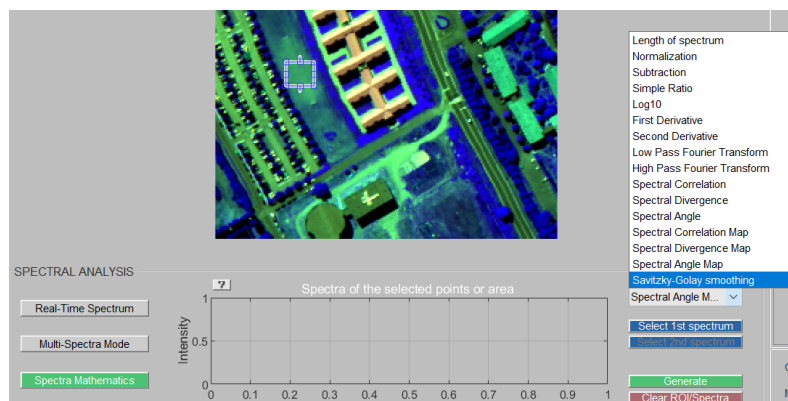
Savitzky-Golay (S-G) Smoothing

NOTE: PAVIA dataset is used as an example.

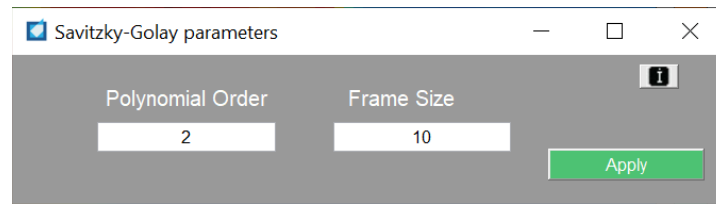
Features: S-G smooths noisy signal data using a least-squares digital polynomial filter. Optimizes and visualizes the performance of the S-G smoothing algorithm on an individual spectrum from the selected region of interest using Savitzky-Golay smoothing.

Steps:

1. Load the file.
2. Select **Spectra Mathematics** → **Savitzky-Golay smoothing**.
3. Press **Select 1st Spectrum** and draw a region of interest. A spectrum corresponding to the region will appear in the SPECTRAL ANALYSIS panel.



4. Press **Generate**. A pop-up dialogue window will ask for additional parameters, **Polynomial Order** and **Frame Size**.



Polynomial Order corresponds to the degree of the polynomial fitted to the points in the moving frame. The default value is 2. Polynomial Order value must be smaller than Frame Size if the frame size is a positive integer. The default value is 10.

Frame Size modifies the frame size for the smoothing function. If the **Frame Size** value is greater than 1, the rolling window is the size of the input number (i.e., 10) and independent of the number of bands/channels. Higher values smooth the signal more with an increase in computation time. If the **Frame Size** is less than 1, the window size is a fraction of the number of points in the total number of channels. For example, if the **Frame Size** value is 0.05, the window size is equal to 5% of the number of points in the total number of channels.

When the process is complete, the new spectrum will replace the original image. We suggest clearing the spectrum by pressing **Clear ROI/Spectra** before drawing a new area of interest.

(Optional) The optimized parameters can be applied to the **Savitzky-Golay filter**.

Additional Information:

IDCube uses a modified version of the Savitzky-Golay algorithm. The original algorithm developed by Savitzky and Golay assumes the input vector corresponding to the band/channel dimension has uniformly spaced separation units, while the current algorithm also allows one that is not uniformly spaced.

When the input bands/channels vector is evenly spaced, the least-squares fitting is performed once so that the signal is filtered with the same coefficients, and the speed of the algorithm increases considerably.

The algorithm specifies the degree of the polynomial fitted to the points in the moving frame. The default order of the polynomial fitted to the points in the moving frame is equal to 2. The default frame size is 10 samples. Both parameters can be modified in the IDCube.

Continuum Hull Removal from Spectrum

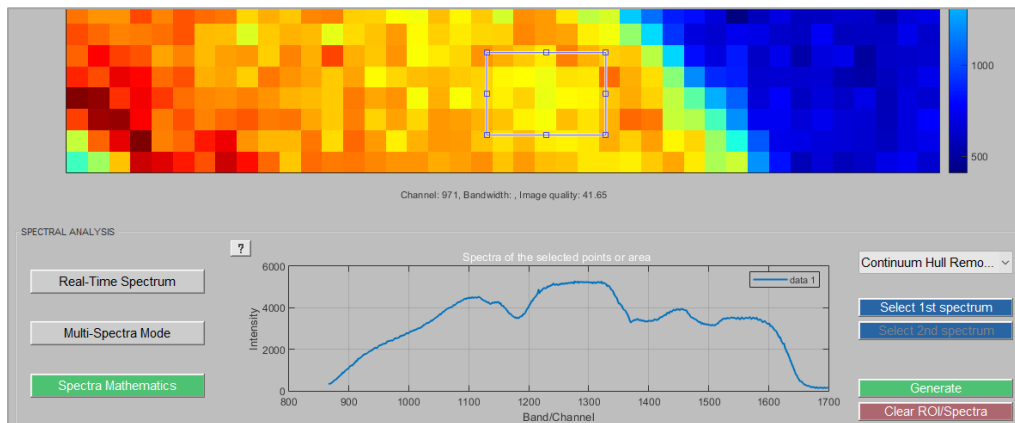
NOTE: Plastic and Coin dataset is used as an example.

Features: Enables rapid removal of continuum hull from the spectra across the entire dataset. See also **Continuum hull removal from spectrum** section.

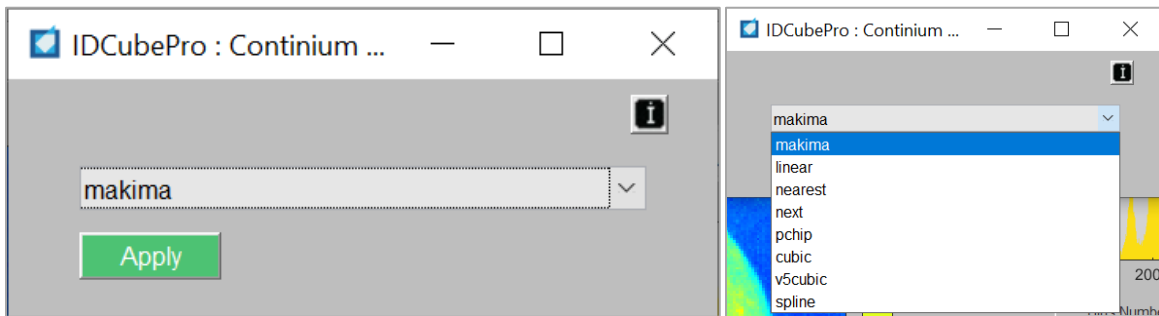
Continuum hull removal is a pre-processing technique used in hyperspectral image analysis to remove the spectral continuum from the data. The spectral continuum refers to the background signal in the image that is not associated with any specific spectral features or information. This background signal can obscure or distort the spectral information of interest, making it more difficult to analyze and interpret the data.

Step 1. In the SPECTRAL ANALYSIS panel click **Spectra Mathematics** button and select **Continuum Hull Removal** from the right menu.

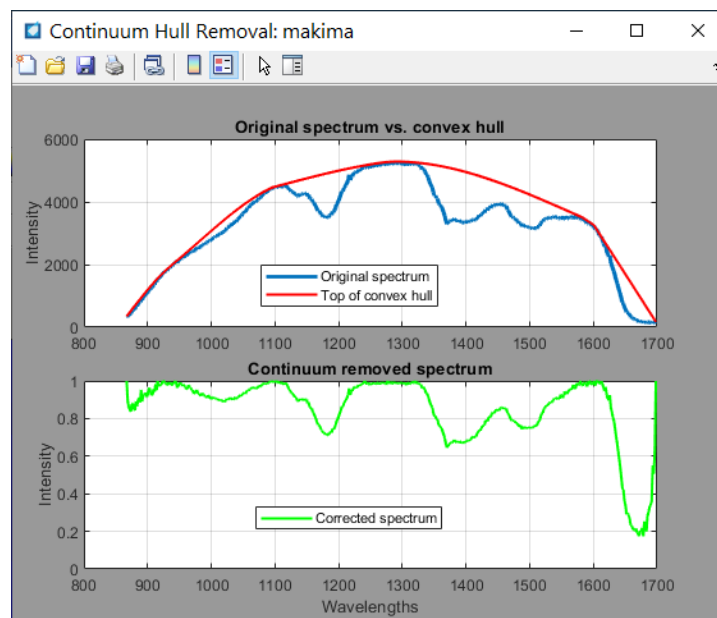
Step 2. Select **1st spectrum** button and draw a region of interest on the image.



Step 3. Click Generate and a popup dialogue IDCubePro : Continuum window with methods will popup. Select the method and press **Apply**.



A new window with the original spectrum, convex hull and continuum removed corrected spectrum will appear.



Additional Information

The continuum hull removal technique involves estimating the continuum spectrum and subtracting it from the original hyperspectral data. The goal is to remove the background signal while preserving the spectral information of interest. The specific method used for continuum hull removal may depend on the characteristics of the data and the analysis goals. After the continuum is estimated and subtracted, the resulting data is referred to as the "continuum-removed" spectrum. This spectrum represents the spectral features of the image without the background signal, making it easier to identify and analyze the specific spectral signatures associated with different materials or phenomena.

The algorithm performs three steps: **1.** Identifies a continuum hull using one of the methods (see a Table below). **2.** Subtracts the original spectrum from the continuum hull. **3** Repeats the procedure 1-2 for each pixel.

| Method | Description | Comments |
|-----------|---|---|
| 'makima' | Modified Akima cubic Hermite interpolation. The data is modeled using a cubic polynomial that is based on a set of Hermite basis functions, which are used to interpolate the data. The Modified Akima method improves upon the Akima method by adding a smoothing factor that reduces the impact of any noisy or erratic data points on the interpolation results. | Particularly useful in situations where the data is noisy or contains outliers, as it is able to provide a smooth interpolation. Memory requirements are similar to those of 'spline'. |
| 'linear' | Linear interpolation. The interpolated value at a query point is based on linear interpolation of the values at neighboring grid points in each respective dimension. This is the most common interpolation method. | Requires more memory and computation time than nearest neighbor. |
| 'nearest' | Nearest neighbor interpolation. The interpolated value at a query point is the value at the nearest sample grid point. | Modest memory requirements. Fastest computation time. |
| 'next' | Next neighbor interpolation. The interpolated value at a query point is the value at the next sample grid point. | Same memory requirements and computation time as 'nearest'. |
| 'pchip' | Shape-preserving piecewise cubic interpolation. The interpolated value at a query point is based on a shape-preserving piecewise cubic interpolation of the values at neighboring grid points. | Requires more memory and computation time than 'linear'. |
| 'cubic' | Cubic convolution used in MATLAB. | Points must be uniformly spaced |
| 'v5cubic' | Same as 'cubic'. | This method falls back to 'spline' interpolation for irregularly spaced data. Similar memory requirements and computation time as 'pchip'. |
| 'spline' | A spline is a piecewise polynomial function that is defined by a set of control points, which are the known data points in the case of spline interpolation. The spline curve is constructed by fitting a series of polynomial segments to the control points, with the requirement that the curve is smooth and continuous at each control point. | Uses the cubic spline as it provides a good balance between smoothness and accuracy Requires more memory and computation time than 'pchip'. |

Acknowledgement

The code in part was developed by Marian-Daniel Iordache, Copyright (April 14, 2016):

Polynomial Baseline Removal in the Spectrum

NOTE: Plastic and Coin dataset is used as an example. Also see **Polynomial Baseline Removal** from the **Data Correction** tab.

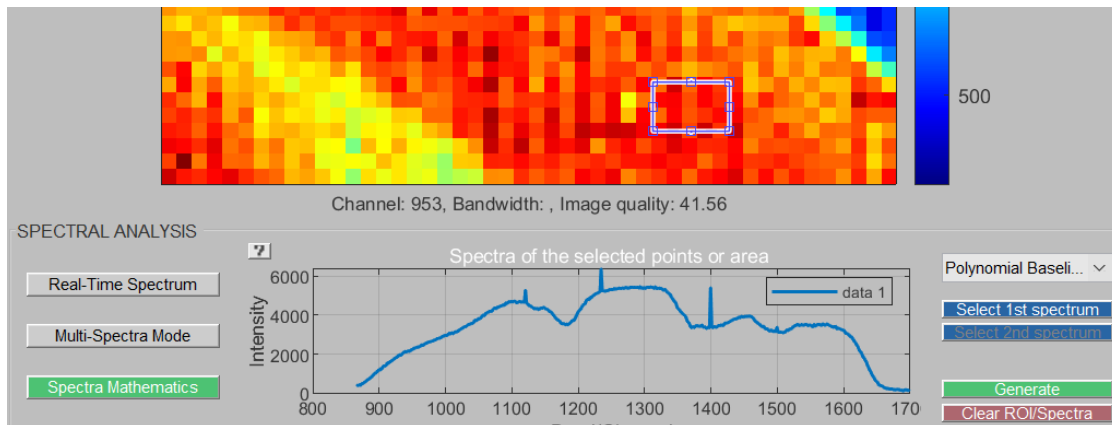
Features: Enables removal of the baseline from the spectrum from the selected region of interest.

Polynomial baseline removal is a pre-processing technique used in hyperspectral image analysis to remove the baseline from the data. The idea behind Polynomial Baseline Removal is to fit a polynomial function to the baseline of the signal and then subtract it from the original signal to obtain the corrected signal.

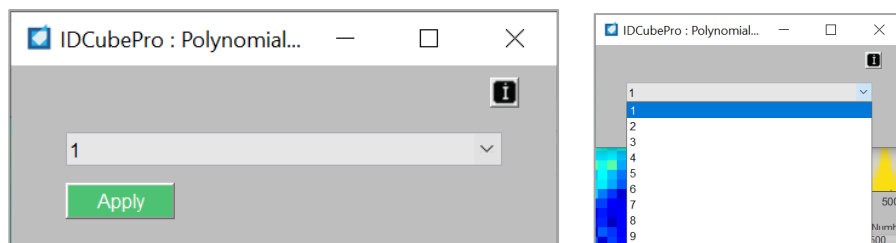
Step 1. In the SPECTRAL ANALYSIS panel click **Spectra Mathematics** button and select **Polynomial Baseline Removal** from the right menu.

Step 2. Select **1st spectrum** button and draw a region of interest on the image.

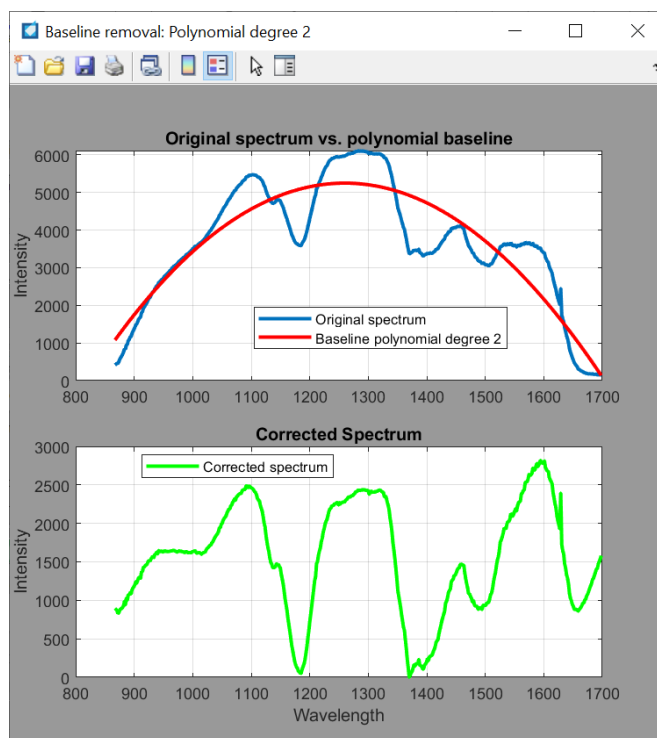
Step 3. Click **Generate**.



Select the degree of polynomial (from 1 to 9) and click **Apply** to perform fitting, subtraction and shifting.



A new window with the original spectrum, baseline and corrected spectrum will appear.



Additional Information

The algorithm performs three steps: **1.** Fits a polynomial function to the baseline with the selected degree of the polynomial function depends on the complexity of the baseline simple linear function (degree=1) or a higher-degree polynomial function (degree > 1). **2.** Subtracts the polynomial function from the original signal. **3.** Shifts the spectrum to have minimum values at zerois.

The choice of the degree of the polynomial function is usually made by trial and error. The presented method will help you to visualize and optimize baseline removal on a specific region of interest. Once satisfied, you can perform removal of the baseline using **Polynomial Baseline Removal** from the **Data Correction** tab.

The polynomial function fits to the spectrum using a least-squares regression algorithm. The polynomial order is typically chosen based on the noise level and complexity of the data, with higher-order polynomials providing more accurate fits but also increasing the risk of overfitting. After the baseline is estimated and subtracted, the resulting spectrum data are shifted to have minimum value at zerois. The final spectrum is referred to as the "baseline-removed" spectrum. The entire algorithm is performed over all pixels in the image. This spectrum represents the spectral features of the image without the background signal, making it easier to identify and analyze the specific spectral signatures associated with different materials or phenomena.

7.10. Frame-By-Frame Panel

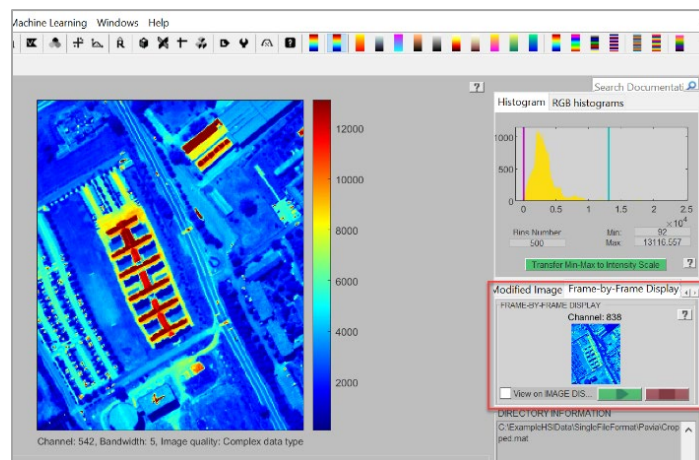
NOTE: PAVIA dataset is used as an example.

Features:

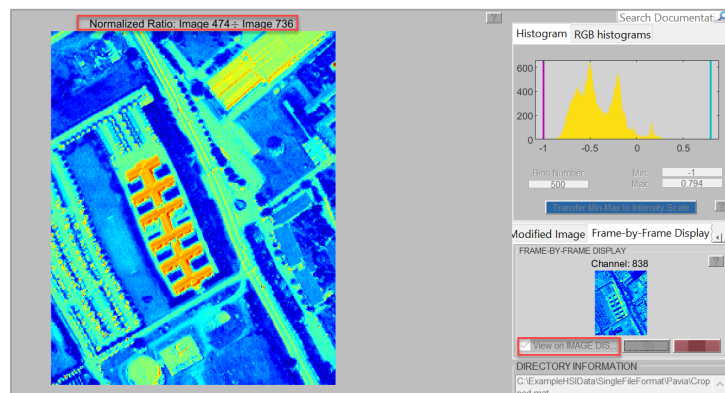
Presents images in a movie-type fashion. Can be combined with any other functions including mathematics. The movie can be saved as a movie file (*avi*) (via **File - Save As...→Video**).

Steps:

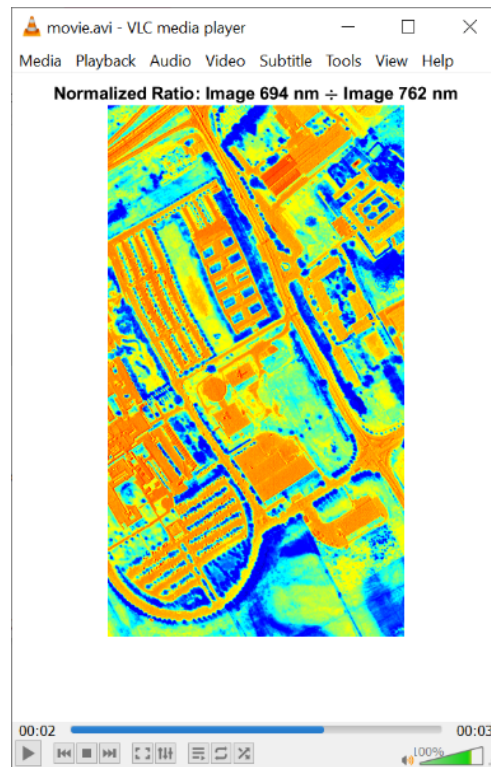
1. Select **Frame-by-Frame Display** and press the green **Play** button. Press the red **Stop** button to stop the movie.



2. The movie can be visualized in two windows. Click **View on Image Display** to change the visualization panel.
3. The movie can be combined with many functions available in IDCube. In the example shown in the figure below, **Frame-to-Frame Display** is combined with **Mathematics** where the image is calculated via the **Normalized Ratio** between two channels. In that case, **Image Display** will show the resulting images with the first channel scanning while the second channel remains stable.



The movie can be saved through **Save As...** from the **File menu** and selecting **Video (.avi)**. The movie will be saved in the *avi* format in the folder.

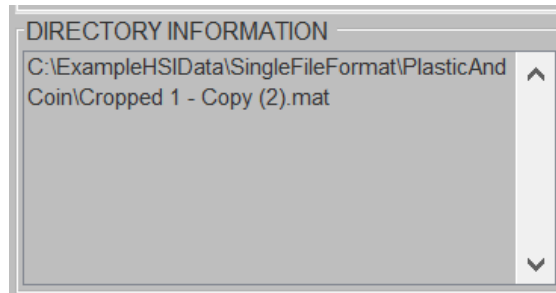


7.11. Directory Information Panel

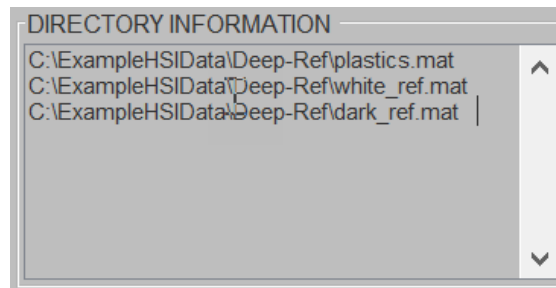
NOTE: The panel is interactive and allows the user to copy/paste/edit the information.

Features: Generates a list of opened files with the pathways.

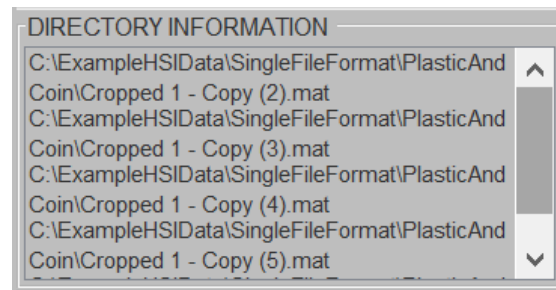
Opening a single file: When the single file is open, the information about the file can be seen in the DIRECTORY INFORMATION panel in the lower right corner of the software.



Opening a single file with references generates a list of the main file and references



Opening multiple files generate the list of files opened.

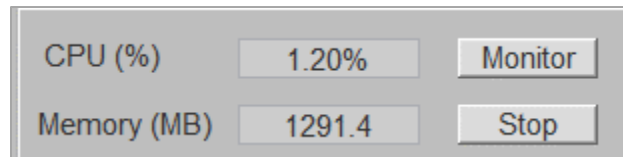


NOTE: In the current configuration IDCube does not support **Concatenated files**. Instead, only the last opened file is shown

7.12. Computer Information Panel

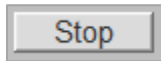
Features:

4. The COMPUTER INFORMATION panel provides real-time information about the user's PC CPU and memory usage.
5. CPU data is displayed as a percentage (%) of the PC's capacity.
6. Memory is displayed in megabytes (MB).



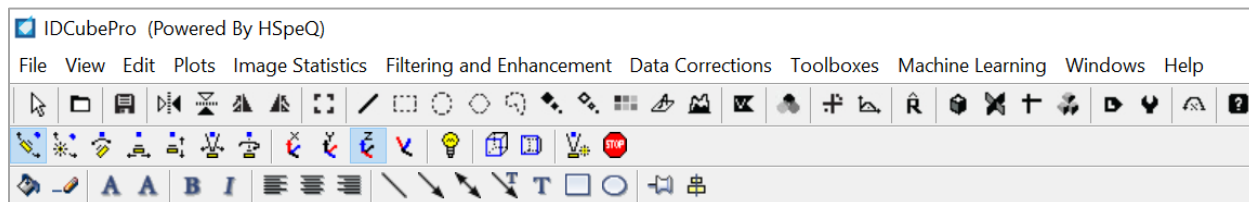
The “Monitor” button starts/resumes the information collecting process.

The “Stop” button pauses the information-collecting process. Functionality can be resumed by pressing the “Monitor” button.



7. Tabs

IDCubePro® offers many functions organized in tabs in the following categories



| Tabs | Function | Additional info |
|----------|--|---------------------|
| File Tab | Open Dataset in IDCube Format | |
| | Add References in IDCube Format | Additional menu |
| | Add Multiple Datasets in IDCube Format | |
| | Concatenate IDCube Dataset | Additional menu |
| | Import Other Formats and Convert to IDCube | Additional menu |
| | Open Legacy Format Datasets (MATLAB) | |
| | Open Color Image (BMP/JPEG/TIFF) | |
| | Convert Images to Stack (JPEG/PNG/TIFF) | |
| | Recent IDCube Datasets | Generated menu |
| | Download Example Files in IDCube Format | Additional menu |
| | Export Setup... | |
| | Copy Interface View | |
| | Save Interface View As... | |
| | Save Data As... | Additional menu |
| | Save Histogram-Modified Dataset | |
| | Print Preview As... | Pop-up window |
| | Print | Pop-up window |
| | Exit | |
| | Generate Report | Saved as a txt file |

| Tabs | Function | Additional info |
|----------|---------------------------------|-----------------|
| View Tab | Colortheme of the software | Additional menu |
| | Close/Open Color LUT Toolbar | |
| | Close/Open Color Camera Toolbar | |
| | Generatorator | Pop-up GUI |
| | List of Bands/Channels | Pop-up window |
| | Image Scale | |
| | Expanded View | |
| | View Header Information | Pop-up window |
| | View Image Information | Pop-up window |
| | View Heatmap | Pop-up plot |
| | Edit Plot | |
| | Turn Instructions Off | |

| Tabs | Function | Additional info |
|----------|-----------------------------|-----------------|
| Edit tab | Rotate and Flip | Additional menu |
| | Crop (spatial and spectral) | Additional menu |
| | Bin (spatial and spectral) | Additional menu |
| | Spectral Crop | Dialogue window |
| | Change Bands | Pop-up window |
| | Annotations | Additional menu |
| | Edit Plot Mode | |

| Tabs | Function | Additional info |
|-----------|------------------------|-----------------|
| Plots Tab | Contour 2D plot | |
| | Contour-filled 2D plot | |
| | Mesh 3D plot | |
| | Surface 3D plot | |
| | Contour 3D plot | |
| | Remove all plots | |

| Tabs | Function | Additional info |
|------------------|--|-----------------|
| Image Statistics | Image Quality Plot | Additional menu |
| | Anomaly Pixels | Pop-up window |
| | Texture features | Pop-up window |
| | Hausdorff (Box-Counting) Fractal Dimension | Pop-up value |

| Tabs | Function | Additional info |
|-------------------------------|---|---------------------------|
| Filtering and Enhancement Tab | Mean Spatial Filter | Dialogue window |
| | Mean Spectral Filter | Directly applies to Image |
| | 3D Gaussian Filter | Directly applies to Image |
| | NGmeet Filter | Directly applies to Image |
| | Spatio-Spectral Total Variation (SSTV) Filter | Dialogue window |
| | FFT Filters | Dialogue window |
| | Savitzky-Golay Smoothing | Dialogue window |
| | Asymmetric Least Square Smoothing | Dialogue window |
| | Standard Deviation | Directly applies to Image |
| | Decorrelation Stretch | Directly applies to Image |
| | Color Inversion | Directly applies to Image |
| | Normalization | Additional menu |
| | Contrast Enhancement | Additional menu |
| | Structure Similarity Index | Pop-up value |
| | Remove all filters and enhancements | Equivalent to Reset |

| Tabs | Function | Additional info |
|----------------------|---|---------------------|
| Data Corrections Tab | Background Data Correction | Interactive menu |
| | Flatfield Correction | Interactive menu |
| | Multiplicative Scatter Correction (MSC) | Interactive menu |
| | Standard Normal Variate (SNV) | Interactive menu |
| | Remove all filters and enhancements | Equivalent to Reset |

| Tabs | Function | Additional info |
|-----------|---|-----------------|
| Toolboxes | Principal Component Analysis (PCA) | Pop-up toolbox |
| | Maximum Noise Fraction (MNF) | Pop-up toolbox |
| | Image Classification | Pop-up toolbox |
| | Spectral Signature Matching | Pop-up toolbox |
| | Endmembers Extraction | Pop-up toolbox |
| | Image Indices | Pop-up toolbox |
| | Contrast Maximization | Pop-up toolbox |
| | Correlation Matrix (R-Squared) | Pop-up toolbox |
| | t-SNE Clustering | Pop-up toolbox |
| | Spectral Phasor Clustering | Pop-up toolbox |
| | 3D Viewer | Pop-up toolbox |
| | Feature Finder | Pop-up toolbox |
| | Fusion MSI and HIS in IDCube format (Pansharpening) | Pop-up toolbox |

| Tabs | Function | Additional info |
|------------------|---------------------------------|-----------------|
| Machine learning | Create Label(s) | Pop-up window |
| | Create Mask(s) | Pop-up window |
| | Create Binary Image | Pop-up window |
| | k-Means Classifier | Dialogue window |
| | Machine Learn Classifier | Pop-up toolbox |
| | Deep Learning (future releases) | Pop-up toolbox |

| Tabs | Function | Additional info |
|---------------|---|-----------------|
| Macros Editor | Generate a sequence of commands for automatic run | Generated menu |

| Tabs | Function | Additional info |
|--------|--|-----------------|
| Window | Automatically populates with every open window | Generated menu |

| Tabs | Function | Additional info |
|------|--|----------------------|
| Help | About IDCubePro® | Online link |
| | Tutorials | Online videos |
| | Report Bug | Online form |
| | Terms of Use | Pop-up document |
| | Error Log | Generated document |
| | About HSpeQ | Online (idcubes.com) |
| | Contact Us | Online form |
| | Visit IDCube website and check for updates | Online |
| | | |

7.1. File Tab

The File tab includes the following functions

| Tabs | Function | Additional info |
|----------|--|----------------------|
| File Tab | Open Dataset in IDCube Format | |
| | Add References in IDCube Format | Additional menu |
| | Add Multiple Datasets in IDCube Format | |
| | Concatenate Image | Additional menu |
| | Import Other Formats and Convert to IDCube | Additional menu |
| | Open Legacy Format Datasets (MATLAB) | |
| | Open Color Image (BMP/JPEG/TIFF) | |
| | Convert Images to Stack (JPEG/PNG/TIFF) | |
| | Recent IDCube Datasets | Generated menu |
| | Download Example Files in IDCube Format | Additional menu |
| | Export Setup | |
| | Copy Interface View | |
| | Save Interface View As... | Additional menu |
| | Save and Close Data | Pop-up window |
| | Save Data As... | Additional menu |
| | Print Preview | Pop-up window |
| | Print | Pop-up window |
| | Exit | |
| | Generate Report | Saves as a text file |

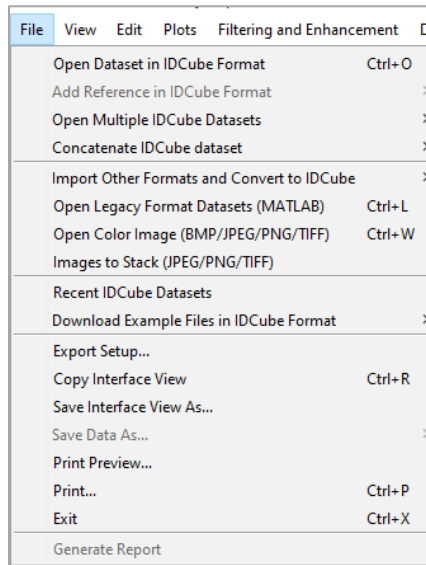
Open Dataset in IDCube Format

Features:

Open a file that has already been converted and saved in the IDCube format

Steps:

1. Go to **File** and select **Open Dataset in IDCube format** from the drop-down menu. You can also use **Ctrl+O** as a shortcut
2. Find your file in the directory and select **Open**.
3. The file will load and open on the IMAGE DISPLAY panel.



Add References

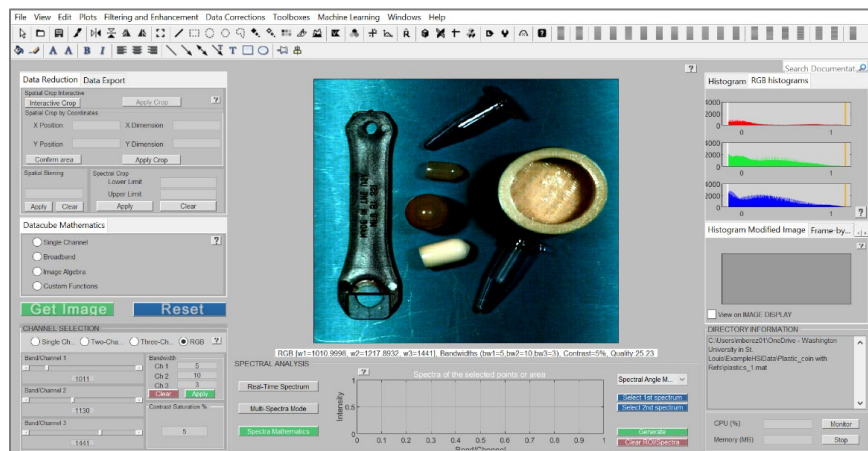
NOTE: This function is only available for data in the IDCube format. For other formats, the user needs to first convert the data files and reference files into the IDCube format.

Features:

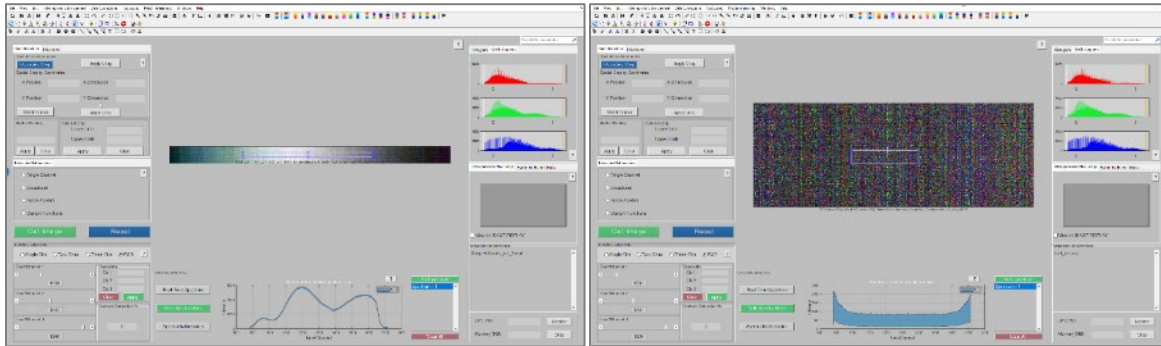
- Removes artifacts related to the illumination and noise from the detector.
- Provides a pure spectrum of the sample

Steps:

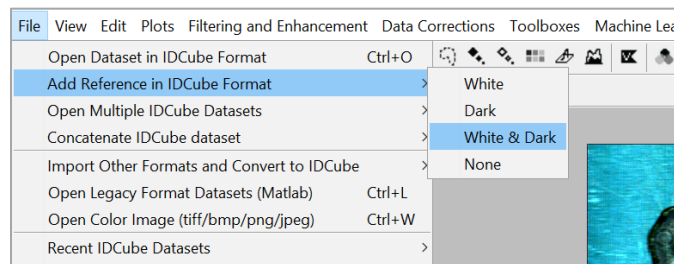
1. Open a folder file in IDCube format. Switch to the RGB mode and adjust band/channels /wavelengths. Visualize the spectra of the object. The reflection spectra are severely affected by specular reflection from the light source and to some degree by the dark noise from the detector.



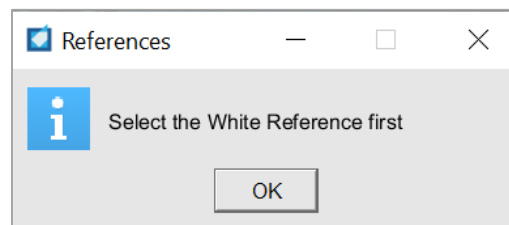
2. To correct the image, you will need to have control images recorded under similar conditions. The example folder has two correction files. The **white_ref** image shown below is recorded from a strip of white reflective material made of Spectralon®. The **dark_ref** image is recorded in the same setting as the closed lens of the imaging system.

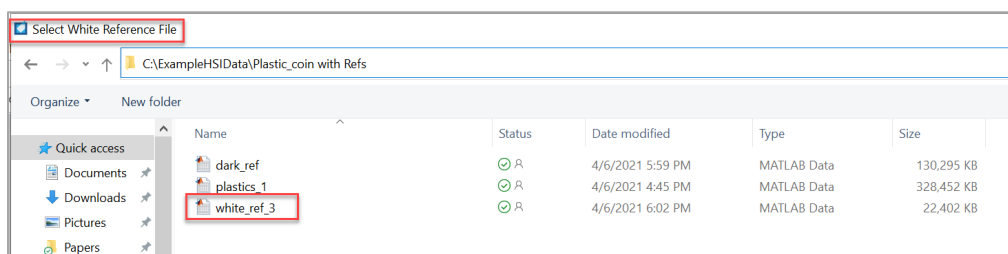


3. To apply the correction files select **File → Add reference in IDCube format** and select one of the three options **White**, **Dark**, or **White and Dark**.
 - **White** – corrects for white reflection only.
 - **Dark** – corrects for the dark count only.
 - **White and Dark** - correct for white reflection and dark count.
 - **Remove corrections** – deletes all corrections.

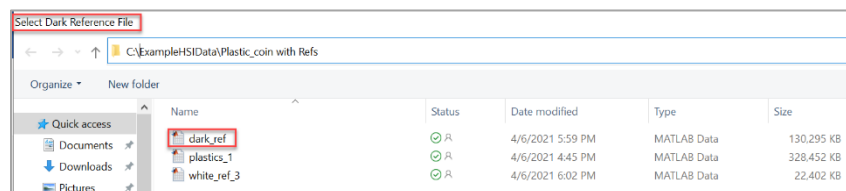
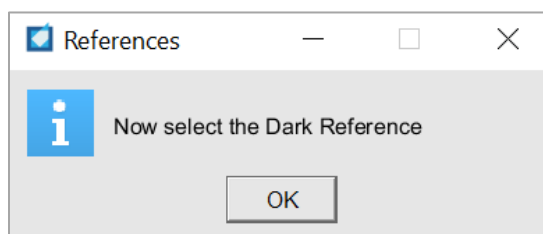


When the **White and Dark** option is selected, a message box **Select the White Reference First** will appear. After clicking **OK**, a pop-up dialog window **Select White Reference File** will appear. Choose the **white_ref** correction file and click **Open**.

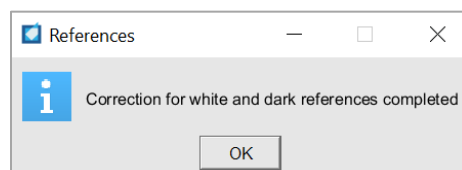




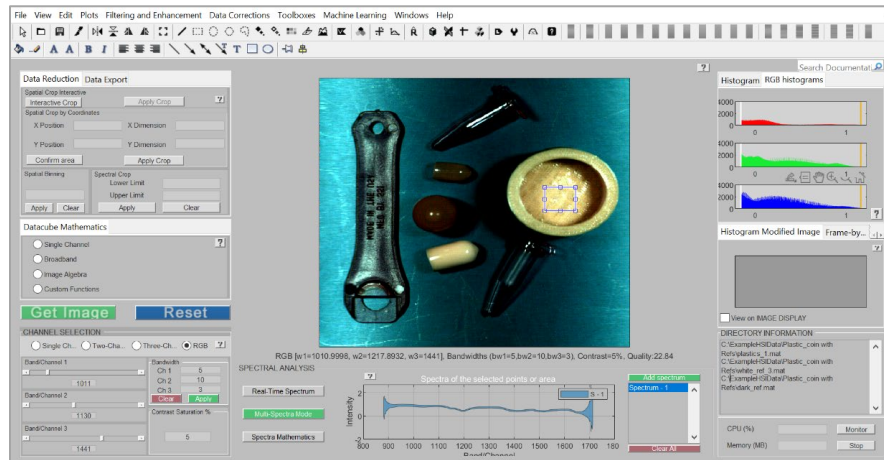
After selecting a white ref file, a message box **Now Select the Dark Reference** will appear. You will be prompted to select a Dark Reference file after clicking OK. Choose the *dark_ref* correction file and click **Open**.



The completion of the task will be confirmed by a message box.



The IMAGE DISPLAY and the DIRECTORY INFORMATION panel will be automatically updated. To visualize the spectra, click **multispectral mode** and select the region of interest. The corrected spectrum shown as a mean spectrum +/- standard deviation is drastically different from the non- corrected (see above). One of the features of the corrected spectrum is a relatively high standard deviation at both ends of the spectrum. This is caused by the limited sensitivity of the detector at wavelengths shorter than 950 nm and longer than 1650 nm.



NOTE: A new dataset corrected for the white and dark noise can be treated as a typical IDCube dataset.

Additional Information:

Illumination in hyperspectral imaging systems is often not uniform across the image, generating potential artifacts. This problem can be eliminated by calibrating the image with the white object. Currently, the widely used standard reflectance surface is made of Spectralon[®] white diffuse reflectance target, although other materials especially in remote sensing can also be used. In addition, imaging detectors used in HSI systems generally have dark currents. Dark current is dependent on temperature and is proportional to integration time. To convert raw intensity into reflectance, reference and dark images are taken before or after acquiring sample images. The reference image is taken with a standard reflectance surface placed in the scene, and the dark current is measured by keeping the camera shutter closed. The raw data are then corrected using the following equation.

$$I = \frac{I_{raw} - I_{dark}}{I_{white} - I_{dark}}$$

where I is the calculated reflectance value, I_{raw} is the raw data of a given pixel, and I_{dark} and I_{white} are the dark current and the white reference intensity of the given pixel, respectively.

References:

Lu, Guolan, and Baowei Fei. "Medical hyperspectral imaging: a review." *Journal of biomedical optics* 19.1 (2014): 010901.

Add Multiple Datasets in IDCube Format

NOTE: This function is only available for data recorded or converted to the IDCube format. For other formats, the user needs to first convert the data file and the reference files into the IDCube format. The files might have different spatial (X-Y) coordinates but must have the same spectral (Z) coordinate.

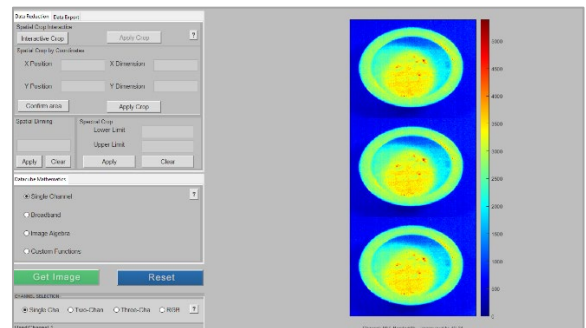
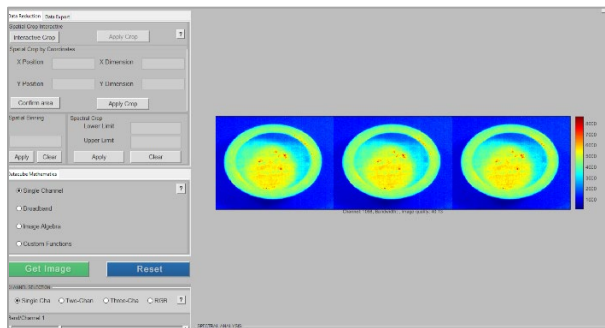
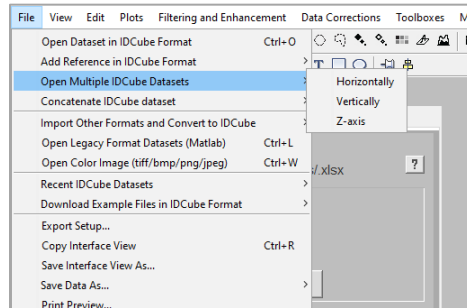
Features:

Enables the users to open several datasets and treat them as a single file.

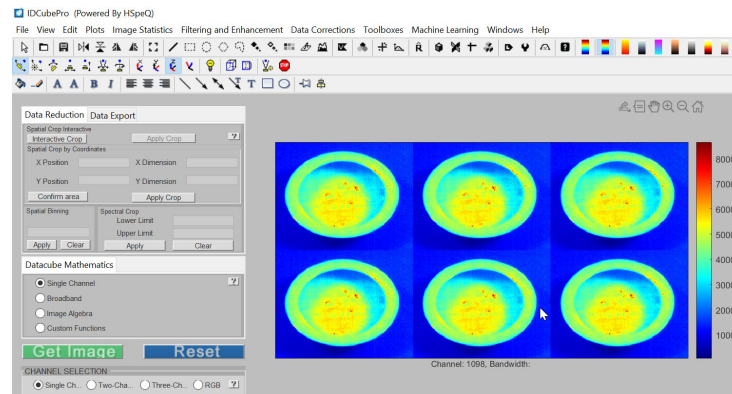
Steps:

1. Select **File** → **Open Multiple IDCube Datasets** and select one of the options. The available options are:

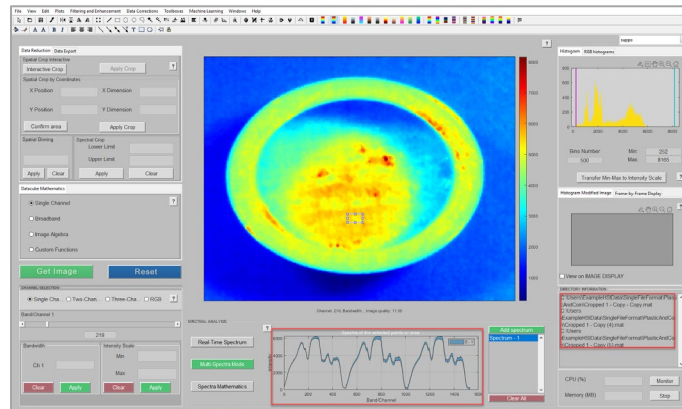
- a. **Horizontally** – adds files horizontally (up to 7 files). Spatial coordinates might be different, but the spectral coordinates should be the same.
 - b. **Vertically** – adds files vertically (up to 7 files). Spatial coordinates might be different, but the spectral coordinates should be the same.
 - c. **Z-axis** – adds file along the spectral (Z) axis.
2. Select **Multiple IDCube Datasets** (the files must be in the same folder).



If six or more files are selected, then the files are arranged in the most compact form such as 3 x 3 for six files.



When the **Z-axis** is selected, the files are open stacking in the Z direction as shown below. **NOTE:** that spectra of the new dataset in the SPECTRAL ANALYSIS panel reflect three files.



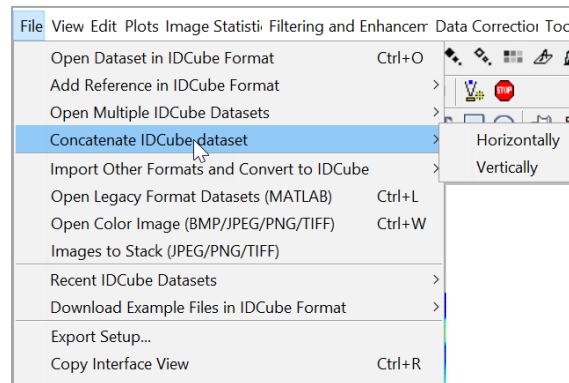
Concatenate Images

NOTE: PAVIA dataset is used as an example. The maximum number of files to be concatenated is 5.

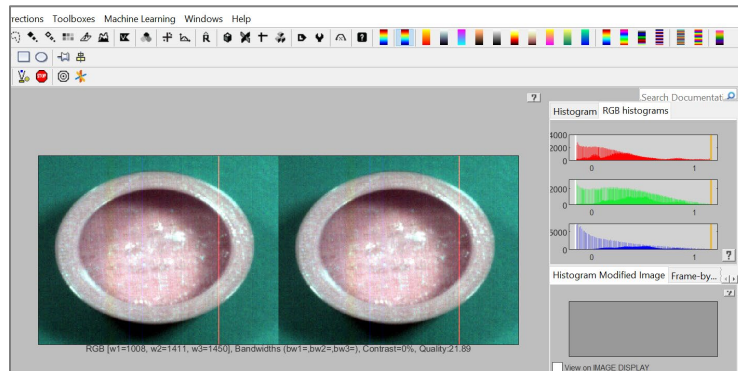
Features: Allows to open maximum of four images and position them next to each other. The images do not have to be the same spatial dimension but must have the same spectral dimension.

Steps:

1. Load the data using **File, Open...** or using an icon and open a file in the IDCube format
2. Go to **File** → **Concatenate IDCube dataset** to add a new image. Two options are available:
 - a. Concatenate Horizontally
 - b. Concatenate Vertically

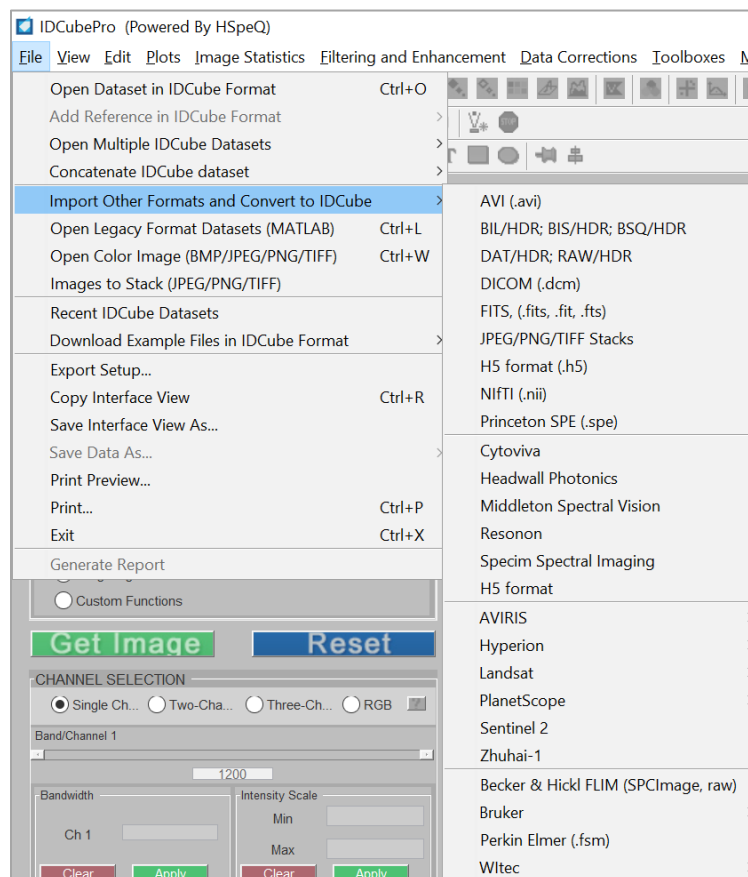


The procedure can be repeated with up to five files concatenated.



Import Other Formats

IDCubePro® allows the conversion of different file formats to the IDCube format. This functionality can be accessed under the file menu and hovering the **Import other formats and Convert to IDCube** menu option.



The following imports and conversions to the IDCube format are available:

| General type of files | Instruments/platform | Comments |
|-----------------------------------|--|---|
| AVI (.avi) | Movies | Imported and converted directly to IDCube format, no spectral information |
| BIL/HDR (.bil/.hdr) | Resonon | Imported and converted directly to IDCube format |
| BIP/HDR (.bip/.hdr) | Resonon | Imported and converted directly to IDCube format |
| BSQ/HDR (.bsq/.hdr) | Resonon | Imported and converted directly to IDCube format |
| DAT/HDR (.dat/hdr) | Cytoviva, Arion Optics | Imported and converted directly to IDCube format |
| DICOM (.dcm) | Medical imaging | Imported and converted directly to IDCube format No metadata |
| FILE/HDR | Aviris, Aviris NG | Imported and converted directly to IDCube format |
| FITS (.fits, .fit, .fts) | Flexible Image Transport System, used by Andor, SensIR | Imported and converted directly to IDCube format, no spectral information |
| FSM (.fsm) | Perkin Elmer (IR imager) | Imported and converted directly to IDCube format |
| JPEG (.jpeg, .jpg) single | various | Requires conversion Images to Stack first |
| PNG files (.png), single | various | Requires conversion from Images to Stack first |
| TIF/TIFF (.tif, .tiff), single | Landsat 8, Landsat 9 | Requires conversion from Images to Stack first |
| H5 (.h5) | various | Imported directly to IDCube format |
| JP2 (.jp2) | Sentinel 2 | Imported and converted directly to IDCube format |
| JPEG (.jpeg, .jpg), stack | Various | Imported and converted directly to IDCube format |
| L1R/HDR (.l1r, .hdr) | Hyperion | Imported and converted directly to IDCube format |
| MAT (.mat, m) | Bruker (Lumos) | Requires additional input (image dimension) |
| NIFTI (.nii) | Medical imaging | Imported to IDCube format |
| PNG (.png), stack | various | Imported and converted directly to IDCube format |
| raw data file | Becker&Hickl (FLIM system) | Imported and converted directly to IDCube format, no time information |
| RAW/HDR | Headwall Photonics, Middleton Spectral Vision | Imported and converted directly to IDCube format |
| SPC (.spc) | Witek | Requires additional input (image dimension) |
| SPE (.spe) | Princeton Photonics, also used by Andor and SensIR | Imported and converted directly to IDCube format, no spectral information |
| TIF/TIFF (.tif, .tiff), stack | PlanetScope | Imported and converted directly to IDCube format |
| .tiff and .jpg files with the hdr | Zhuhai-1 Satellite | Imported and converted directly to IDCube format |

Import AVI files (.avi)

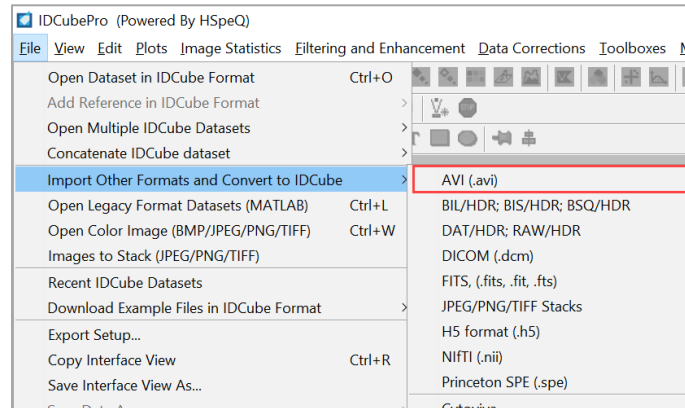
Features:

- .avi stands for **Audio Video Interleave**, a widely used video file format created by Microsoft. IDCubePro® enables the user to convert these types of files to the IDCube format.

- The .avi files contains only a three-dimensional structure ($m \times n \times l$), where m and n are spatial coordinates and l is the spectral coordinate.

Steps:

- Click **File** → **Import other formats and Convert to IDCube** → **Import AVI**.



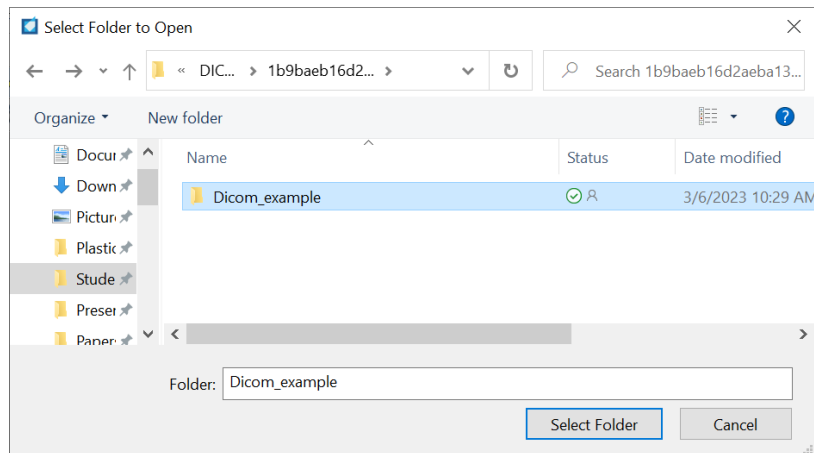
Import DICOM files (.dcm)

DICOM stands for Digital Imaging and Communications in Medicine, which is a standard file format used in the medical imaging industry to store and transfer medical images and related information. DICOM files are typically created by medical imaging devices, such as MRI or CT scanners, and they contain not only the images themselves but also metadata such as patient information, the imaging modality used, and the acquisition parameters. DICOM files are designed to be platform-independent, which means that they can be viewed and analyzed on different types of computer systems using specialized software programs.

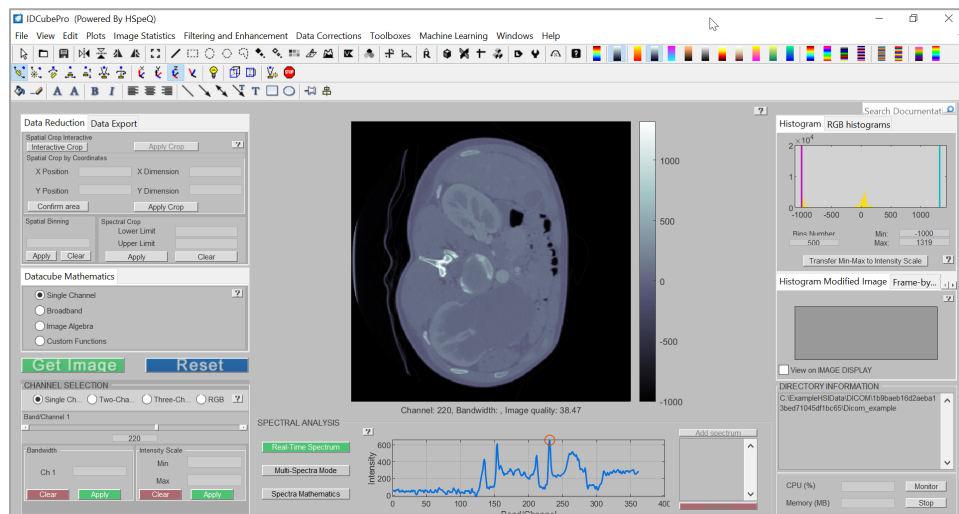
Structure of the DICOM folder:

| Name | Status | Date modified | Type | Size |
|------------------|--------|-------------------|----------|-------|
| image-000001.dcm | ✓ R | 1/12/2023 5:45 AM | DCM File | 90 KB |
| image-000002.dcm | ✓ R | 1/12/2023 5:45 AM | DCM File | 90 KB |
| image-000003.dcm | ✓ R | 1/12/2023 5:45 AM | DCM File | 93 KB |
| image-000004.dcm | ✓ R | 1/12/2023 5:45 AM | DCM File | 90 KB |
| image-000005.dcm | ✓ R | 1/12/2023 5:45 AM | DCM File | 90 KB |
| image-000006.dcm | ✓ R | 1/12/2023 5:45 AM | DCM File | 94 KB |
| image-000007.dcm | ✓ R | 1/12/2023 5:45 AM | DCM File | 90 KB |
| image-000008.dcm | ✓ R | 1/12/2023 5:45 AM | DCM File | 90 KB |
| image-000009.dcm | ✓ R | 1/12/2023 5:45 AM | DCM File | 90 KB |
| image-000010.dcm | ✓ R | 1/12/2023 5:45 AM | DCM File | 90 KB |
| image-000011.dcm | ✓ R | 1/12/2023 5:45 AM | DCM File | 90 KB |
| image-000012.dcm | ✓ R | 1/12/2023 5:45 AM | DCM File | 90 KB |
| image-000013.dcm | ✓ R | 1/12/2023 5:45 AM | DCM File | 92 KB |
| image-000014.dcm | ✓ R | 1/12/2023 5:45 AM | DCM File | 92 KB |
| image-000015.dcm | ✓ R | 1/12/2023 5:45 AM | DCM File | 90 KB |

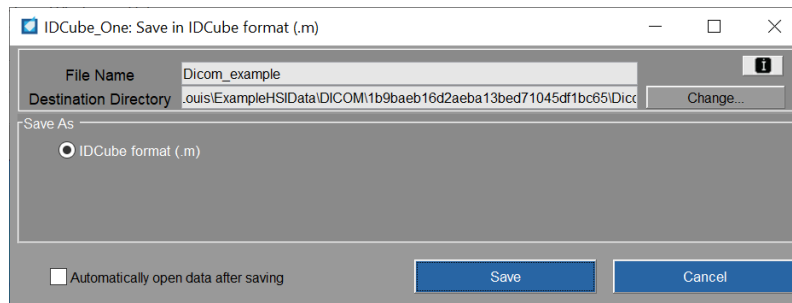
To import the files, click **File** → **Import other formats and Convert to IDCube** → **DICOM (.dcm)**



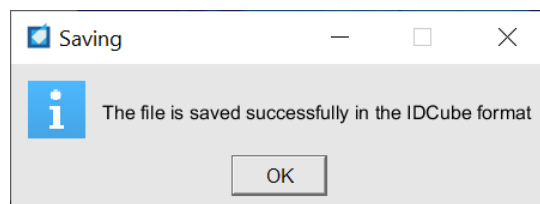
The *.dcm* files will be combined and converted to the IDCube format.



To save the converted file, click **File** → **Save as...**



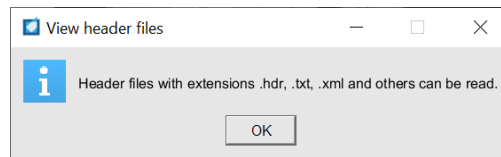
A message box will inform you when the conversion is complete.



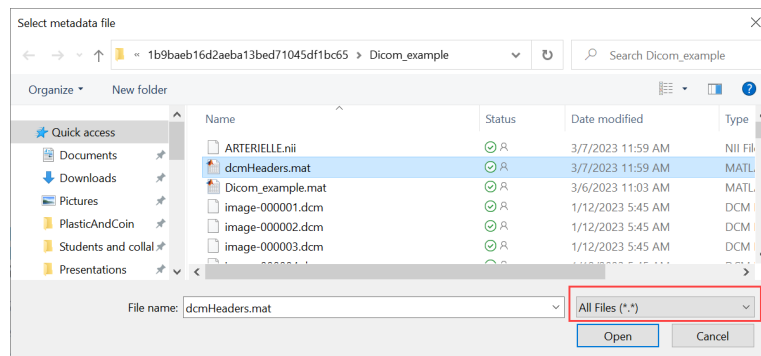
The conversion also generates a NIFTI type file (.nii) and extracts the header information *dcmHeaders.mat*.

| Name | Status | Date modified | Type | Size |
|-------------------|--------|-------------------|-------------|------------|
| ARTERIELLE.nii | ✓ R | 3/6/2023 10:58 AM | NII File | 184,833 KB |
| dcmHeaders.mat | ✓ R | 3/6/2023 10:58 AM | MATLAB Data | 4 KB |
| Dicom_example.mat | ✓ R | 3/6/2023 11:03 AM | MATLAB Data | 80,503 KB |
| image-000001.dcm | ✓ R | 1/12/2023 5:45 AM | DCM File | 90 KB |
| image-000002.dcm | ✓ R | 1/12/2023 5:45 AM | DCM File | 90 KB |
| image-000003.dcm | ✓ R | 1/12/2023 5:45 AM | DCM File | 93 KB |
| image-000004.dcm | ✓ R | 1/12/2023 5:45 AM | DCM File | 90 KB |
| image-000005.dcm | ✓ R | 1/12/2023 5:45 AM | DCM File | 90 KB |
| image-000006.dcm | ✓ R | 1/12/2023 5:45 AM | DCM File | 94 KB |
| image-000007.dcm | ✓ R | 1/12/2023 5:45 AM | DCM File | 90 KB |
| image-000008.dcm | ✓ R | 1/12/2023 5:45 AM | DCM File | 90 KB |

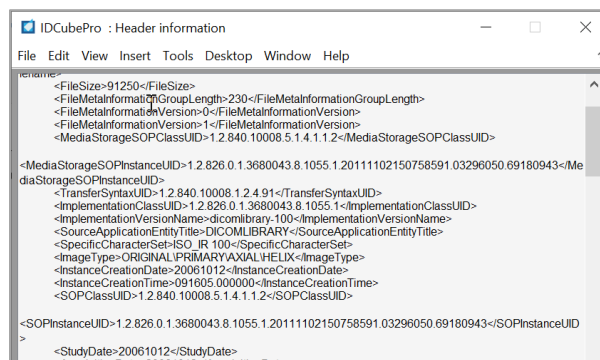
To visualize a header file, click **View → View Header Information...** select a *dcmHeaders.mat* file.



If you do not see this file, change the default .hdr type of files to .mat.



The header file will be opened in a new window.



Import FITS files (.fits)

FITS (Flexible Image Transport System) files are a type of file format commonly used in astronomy to store and exchange data. These files can contain a wide range of information, including astronomical images, spectra, and data tables. One of the key features of FITS files is their ability to store metadata about the data they contain. This metadata can include information about the instrument used to acquire the data, the location of the observation, and the processing steps that have been applied to the data.

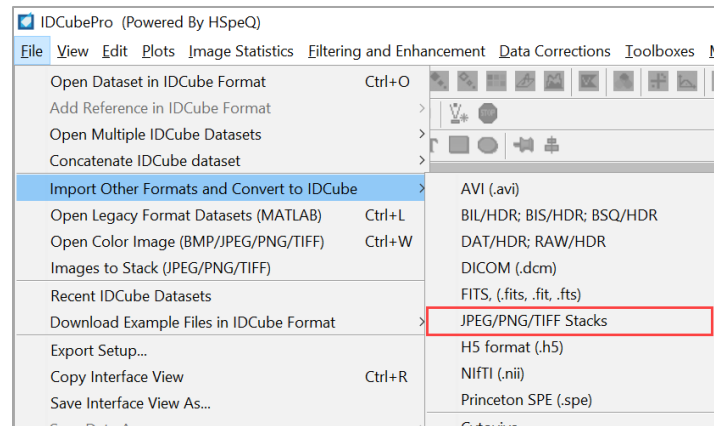
To import the file, click **File** → **Import other formats and Convert to IDCube** → **FITS (.fits)**

Import Stack of .tif/tiff, .png, and .jpeg files

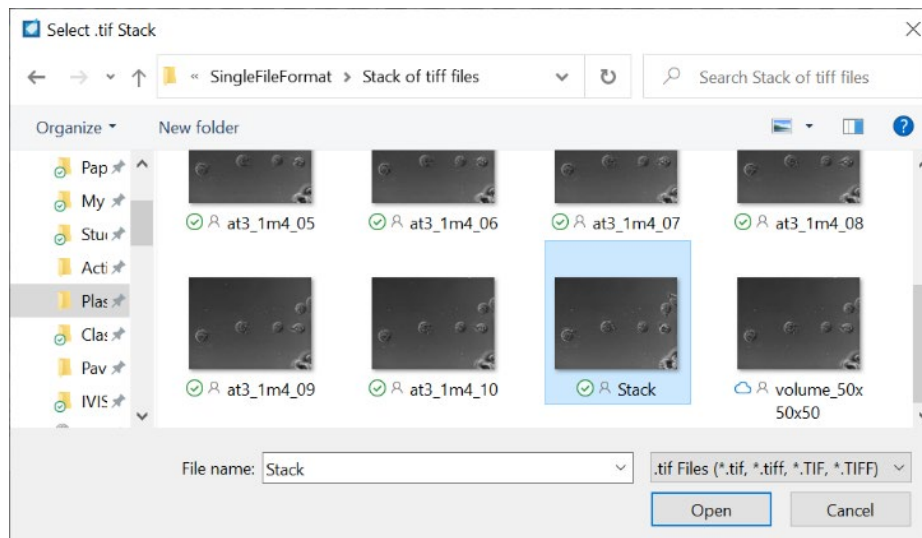
Features: IDCube directly imports a stack with .tif/tiff, .png, and .jpeg files. Cells_tiff_stack dataset is used as an example. To form a stack, see a previous section **Convert individual JPEG/PNG/TIF files to Stack**.

Steps:

1. Click **File** → **Import other formats and convert to IDCube** → **Import JPEG/PNG/TIF Stack**.



2. Select a stack of *tif/tiff* files from the directory.



Click **Open**. The stack file will be converted to the IDCube format and ready to use for any other operations. You can also save the tiff stack into the IDCube format using **Save As...** option from the **File** menu.

Import Raw/HDR and Dat/HDR files

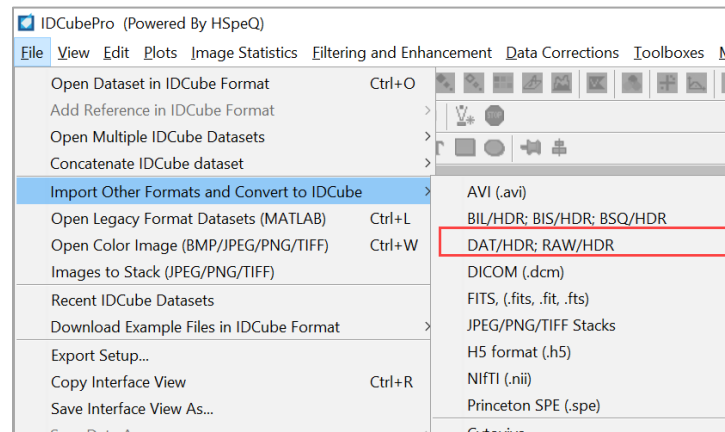
NOTE: Kootenai river dataset is used as an example (available from <https://www.sciencebase.gov/catalog/item/5bf48b00e4b045bfcae252d6>).

Features:

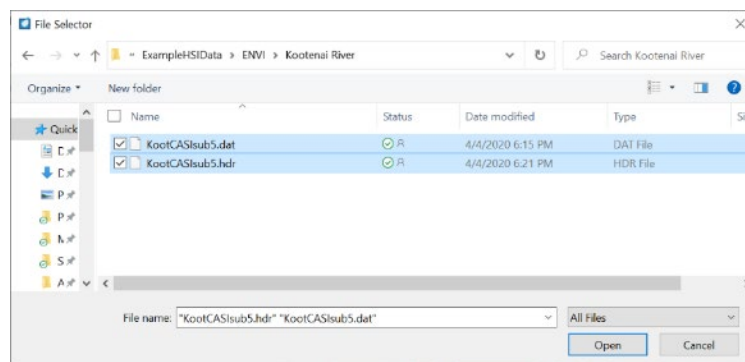
- *raw/hdr* and *dat/hdr* files are commonly used by commercial data acquisition systems. IDCubePro® enables the user to import and convert these types of files to the IDCube format
- Hyperspectral datasets often use *raw/hdr* or *dat/hdr* format. These formats have at least two files.
- The *.raw* or *.dat* files contains all relevant data and have a three-dimensional structure ($m \times n \times l$), where m and n are spatial coordinates and l is the spectral coordinate.
- The *.hdr* is a header file that contains metadata. The header file typically contains information about the type of sensor used to acquire the image, the date of the dataset collection, the number of discrete spectral bands, and the corresponding wavelengths or channels.
- Typically, the header file uses the same name as the image file and is located in the same folder.

Steps:

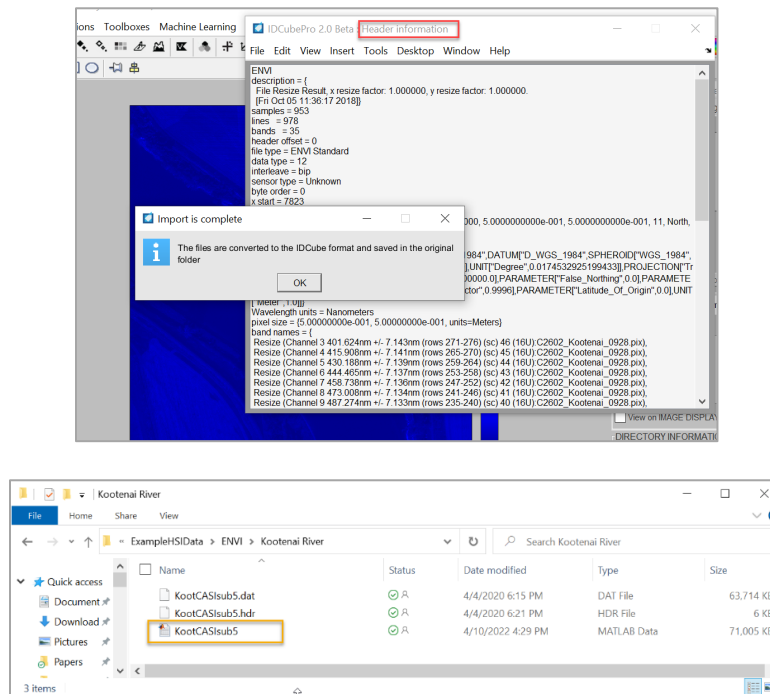
2. Click **File** → **Import other formats and Convert to IDCube** → **Import Raw/HDR or Dat/HDR**.



3. Select a folder that has both files. For example, folder Kootenai River has *.dat* and *.raw* files.



4. Select both *.dat* and *.hdr* files and click **Open**. The files will be opened in IDCubePro® and automatically converted to the IDCube format. After completion, metadata from the header file will be automatically shown. The file name will be preserved and saved in the original folder as shown below.

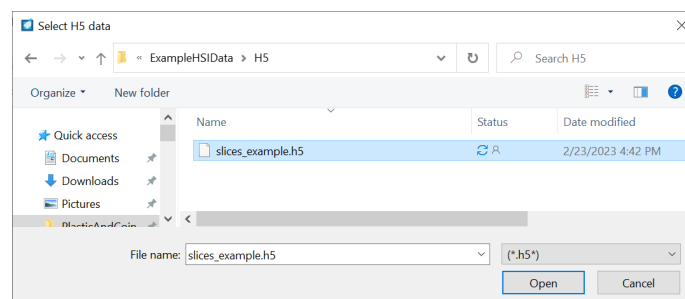


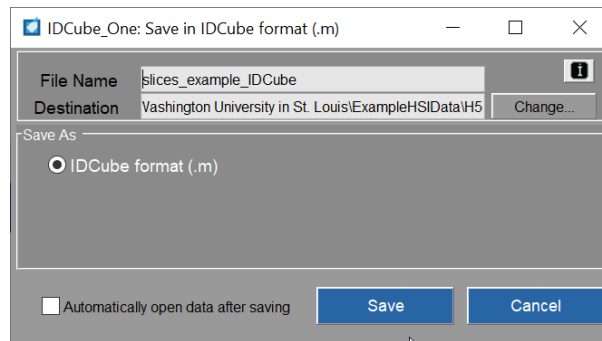
Import H5 files (.h5, .hdf5)

H5 or HDF5 (Hierarchical Data Format 5) is a file format designed to store and manage large and complex datasets. It is a data model, library, and file format for storing and managing data. HDF5 is organized as a hierarchical structure of groups and datasets. The data can be stored in a variety of data types such as integers, floats, strings, and arrays. The groups act as containers for datasets and other groups, and datasets can store data of any size and dimensionality. One of the key features of HDF5 is its ability to handle metadata, which is data that describes the attributes and characteristics of the dataset. This metadata can include information such as the creation date, author, and version of the dataset, as well as information about the data itself such as units and scaling factors. HDF5 is widely used in scientific research, engineering, and data analysis applications due to its ability to handle large and complex datasets, its flexibility, and its portability across different operating systems and platforms.

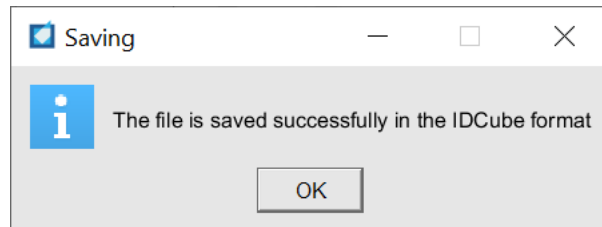
NOTE: The IDCube algorithm has been tested on several examples to open HDF5. IDCube might not be able to perform that for every HDF5 dataset because of the wide range of HDF5 formats.

Step 1. To import the files, click **File** → **Import other formats and Convert to IDCube** → **H5 (.h5)**

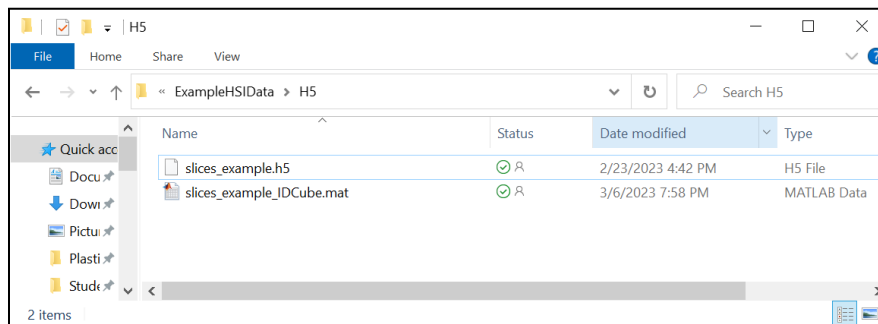




A message box will inform you when the conversion is complete.



The converted file can be found in the folder

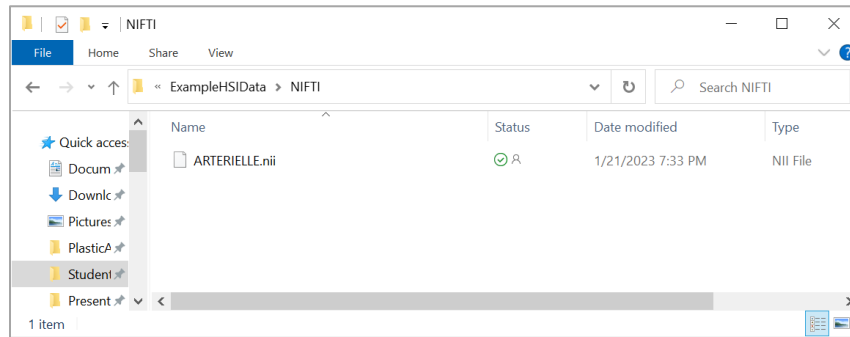


Import NIFTI files (.nii)

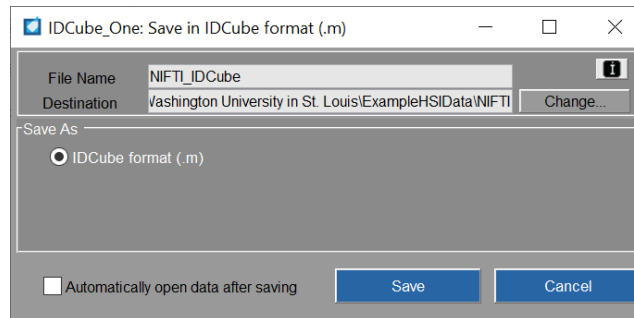
NIFTI (Neuroimaging Informatics Technology Initiative) files are a type of file format used in neuroimaging to store and share medical imaging data. They are a standard format for storing and distributing neuroimaging data and are widely used in the research community.

NIFTI files contain both image data and metadata, including information about the image dimensions, voxel size, and orientation, as well as the data type and any image transformations that have been applied. This metadata is important for ensuring that the data can be properly interpreted and analyzed by different software tools. In the IDCubePro® NIFTI files can also be generated from DICOM (see **Import DICOM (.dcm) files** section).

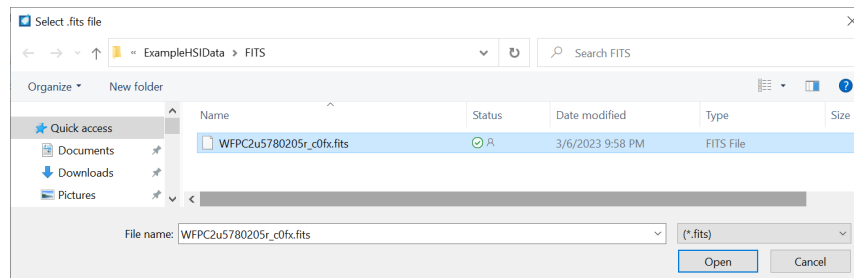
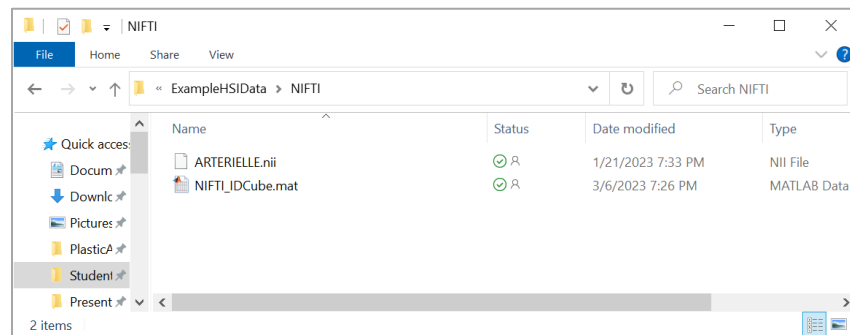
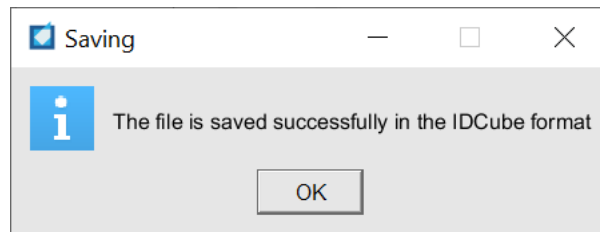
To import the file, click **File** → **Import other formats and Convert to IDCube** → **NIFTI (.nii)**



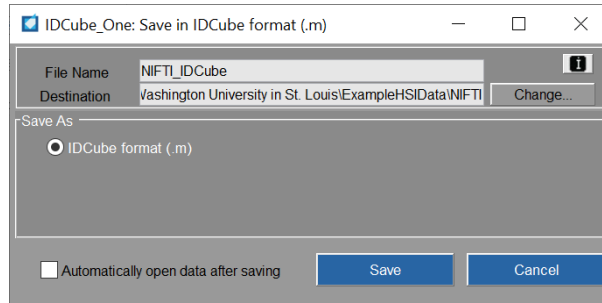
To save the converted file, click **File** → **Save as...**



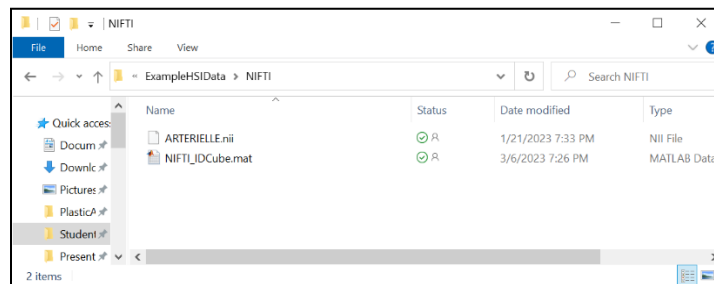
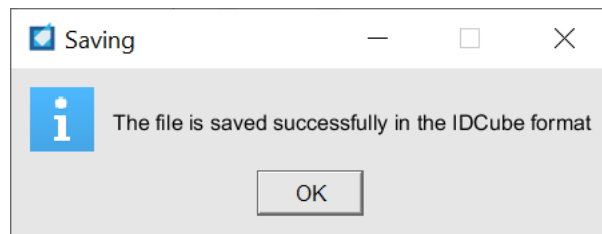
A message box will inform you when the conversion is complete.



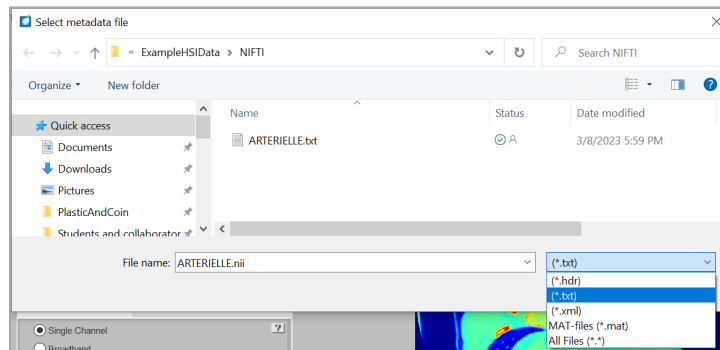
To save the converted file, click **File** → **Save as...**



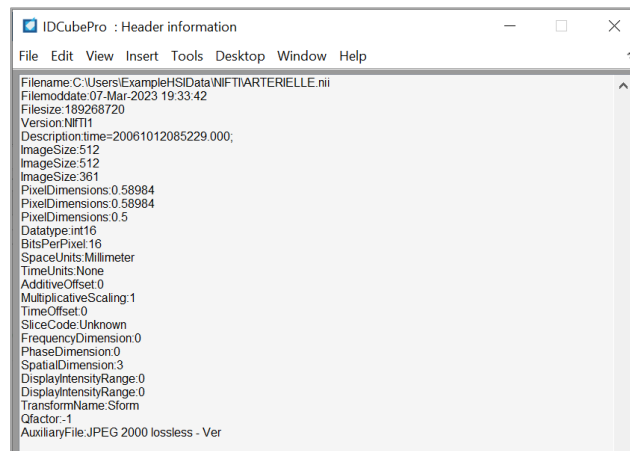
A message box will inform you when the conversion is complete.



The conversion also generates a header file. To open a header file click **View** → **Save as...**



The header file will be opened in a new window.



Import from different instruments

To save the converted file, click **File** → **Save as...**

IDCubePro® supports many formats and platforms.

For accessing data from satellites and other remote sensing platforms, see our video tutorials at <https://www.idcubes.com/tutorials>.

Examples of using platforms from several types of platforms are given below.

Aviris Classic

To find and download the file go to <https://aviris.jpl.nasa.gov/> and click on the panel **Search the Data Archive**. (Might require login in and not available for general public)



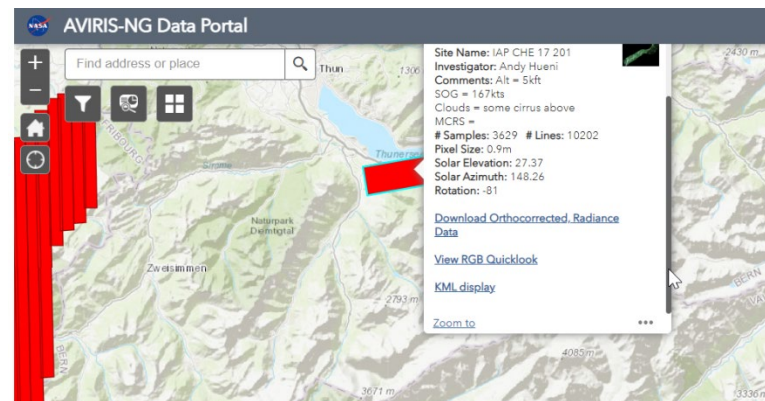
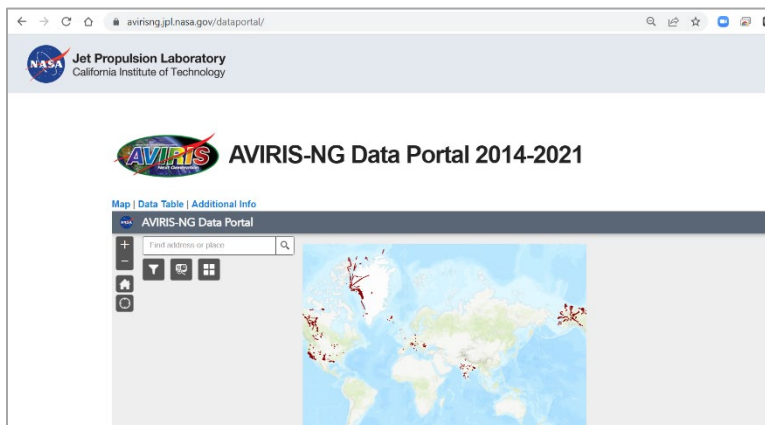
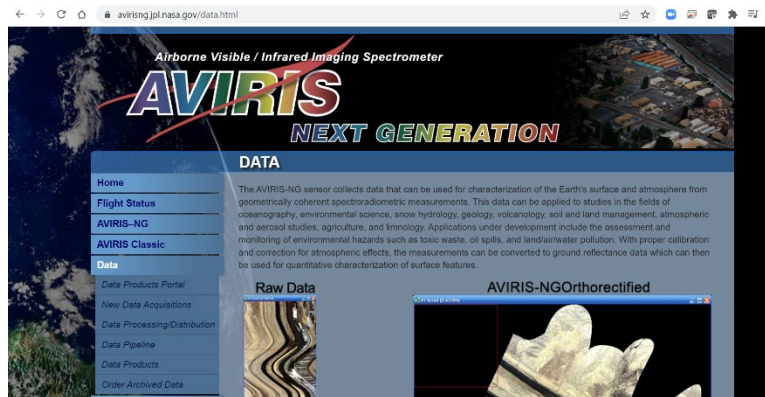
Aviris NG

AVIRIS NG stands for Aviris New Generation. AVIRIS-NG is an imaging spectrometer that measures reflected radiance at 5nm intervals in the Visible to Shortwave Infrared (VSWIR) spectral range from 380-2510nm.

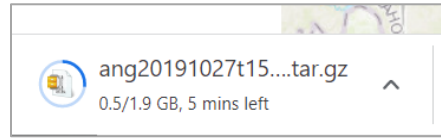
Step 1. Downloading data.

NOTE: Aviris NG operates by a company/governmental agency that is not affiliated with IDCube. The access to the data and the quality of the data are not controlled by IDCubePro.

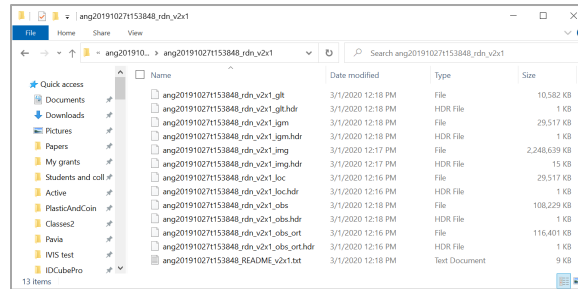
To find and download the file go to <https://avirisng.jpl.nasa.gov/data.html>. Red areas indicate available data.



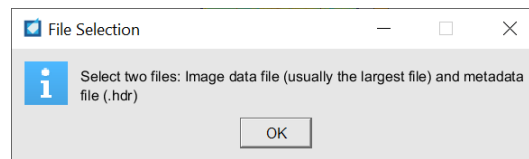
Find the data of your interest and click **Download Orthorectified Radiance Data**. The download will start.



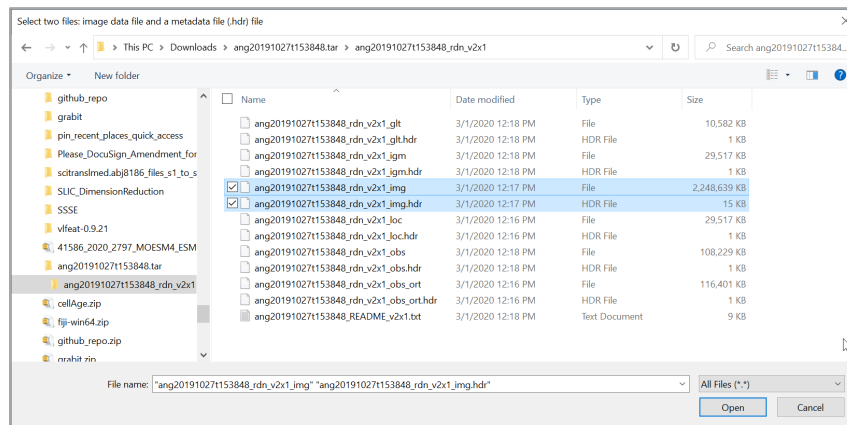
After the download is complete, unzip the file to see a folder with all files



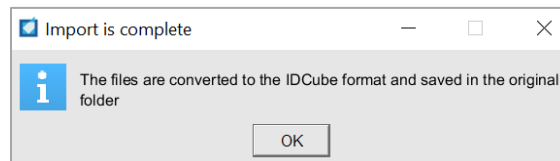
Step 2. To convert Aviris-NG files to IDCube, select **Import Other Formats and Convert to IDCube** → **Aviris** → **Aviris NG**



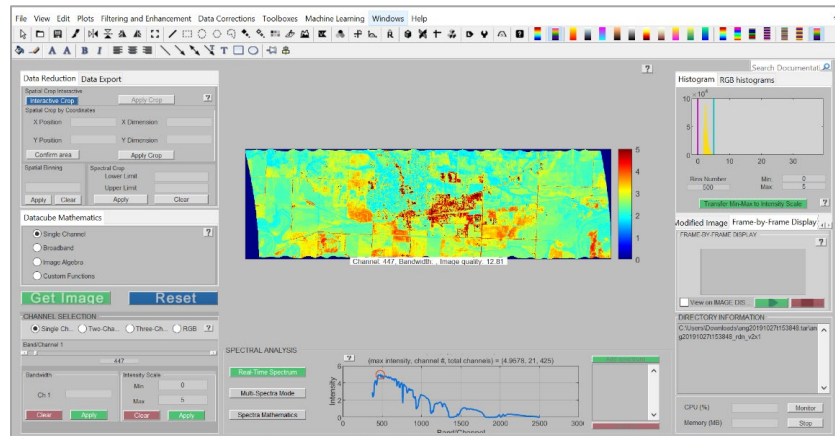
Navigate to the folder with the files and select an image datafile, usually the largest file, and a header file that has the same name as the datafile but with extension *.hdr*. Click **Open** to initiate the conversion.



Completion of the conversion will be notified with a message box.

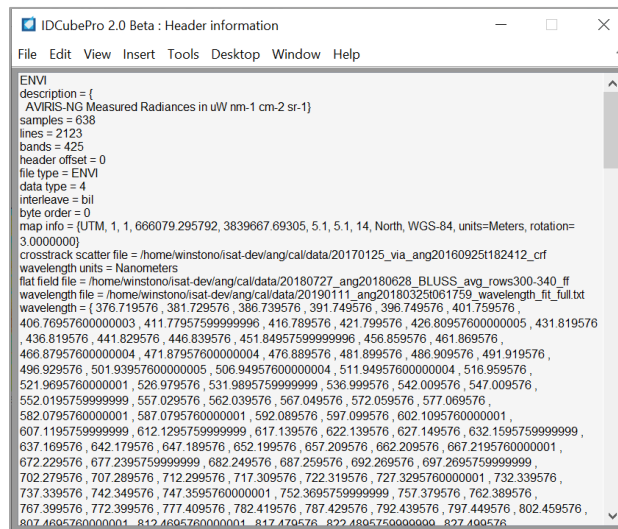


After the conversion is completed, the new imaging file in the IDCube format (with a *.mat* extension) will be generated and saved with the same name as the *.LIR* file.



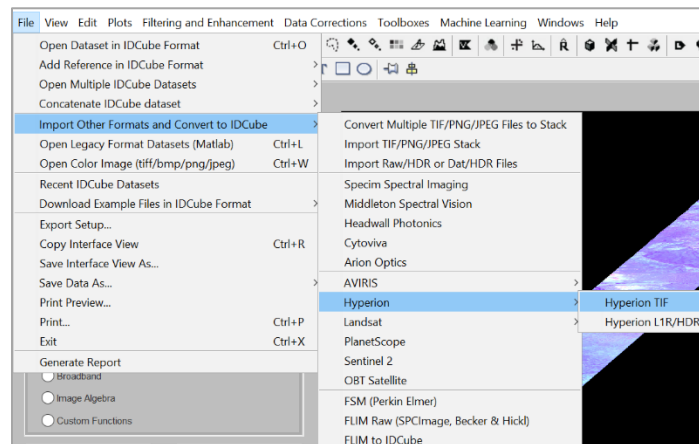
NOTE: AVIRIS-NG generates imaging data with values that are artificially low (highly negative). These data correspond to the edges of the image. If necessary, the best way to eliminate these data points is to crop the image.

Due to the presence of several header files, the header file will not open automatically. It can be opened via **View → View Header Information**. Any file with a *.hdr* or *.txt* extension can be opened this way.

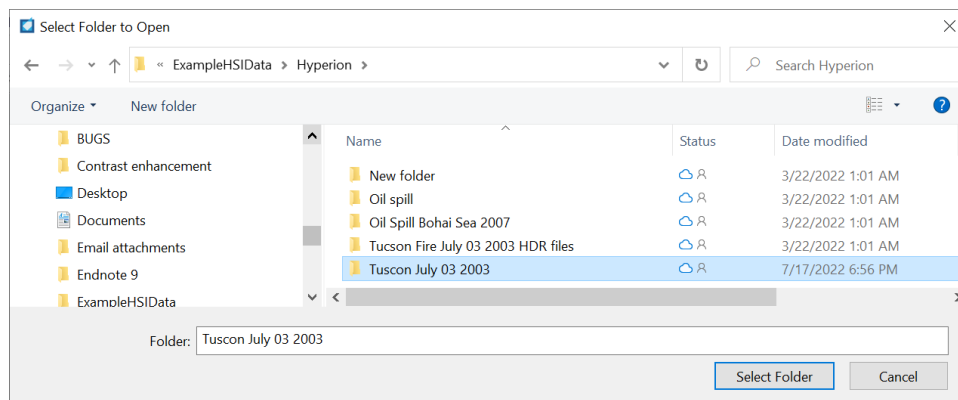
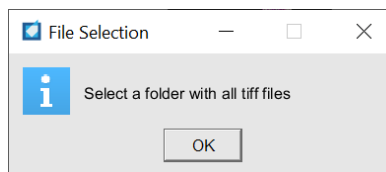


Hyperion (tiff format)

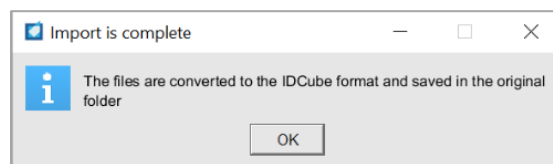
Hyperion generates files in two formats with *.tiff* and *.llr/hdr* extensions. In the case of *tiff* files, all *tiff* files are located within one folder. The folder has also a metadata file. To convert the *tiff* files to IDCube format, select **Import Other Formats and Convert to IDCube → Hyperion**.



A pop-up message will ask to select a folder where the *tiff* files are located.



Select the folder and click **Select Folder** where the *tiff* files are located. The conversion will start immediately. After the conversion is completed, the message will appear. The new imaging file in the IDCube format (with a *.mat* extension) will be generated and saved with the same name as the *tiff* files.



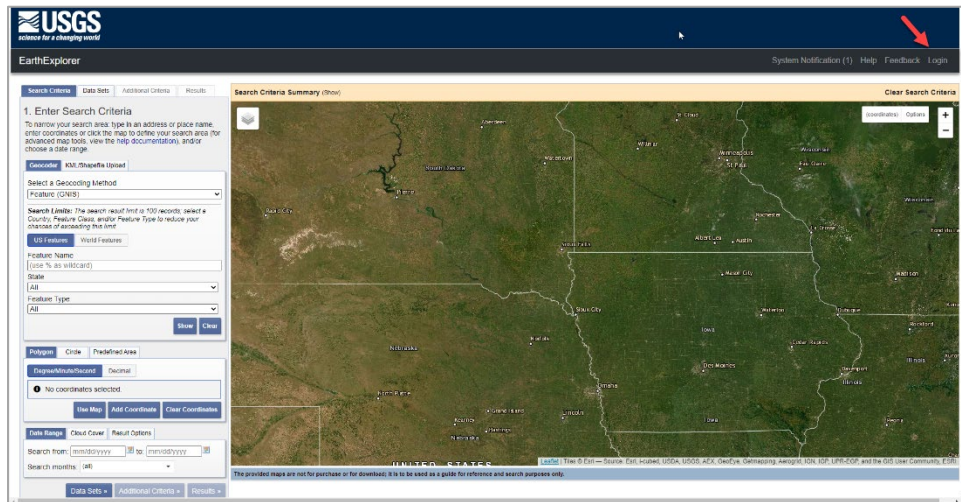
Hyperion (L1R/hdr format)

Hyperion generates files in two independent sets formats (*tiff* and *L1R/hdr*). This part of the manual describes how to download and process Hyperion files in the *L1R/hdr* format. The folder has also a metadata file.

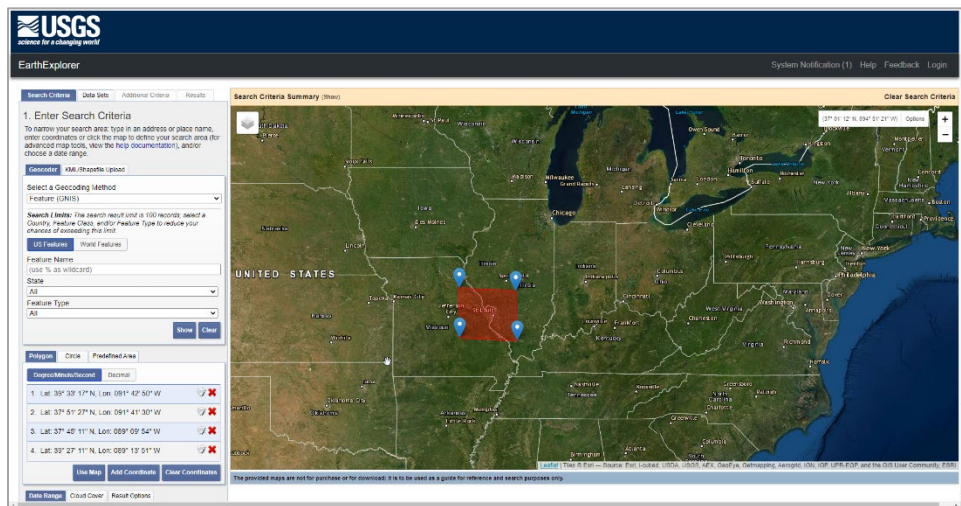
Step 1: Selecting the area and Landsat 9

v. 2.78

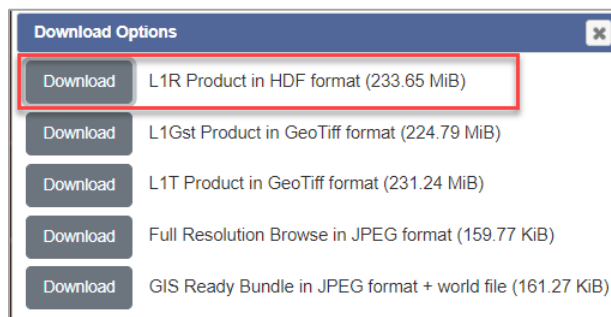
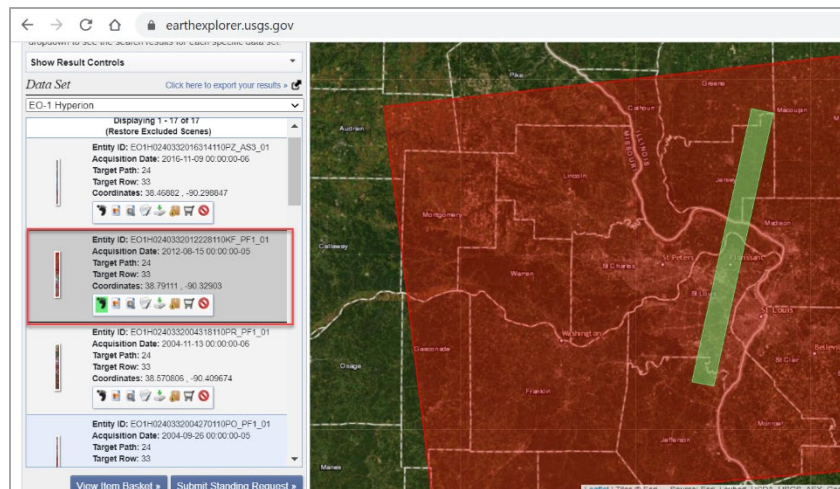
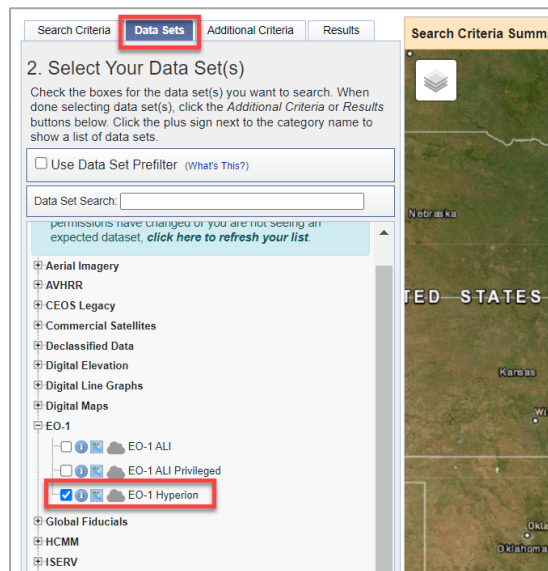
Landsat 9 data can be obtained by visiting <https://earthexplorer.usgs.gov/>. You will have to log in to the website in order to download the data.



Move to the location of interest and select the area by, for example, clicking on the map.

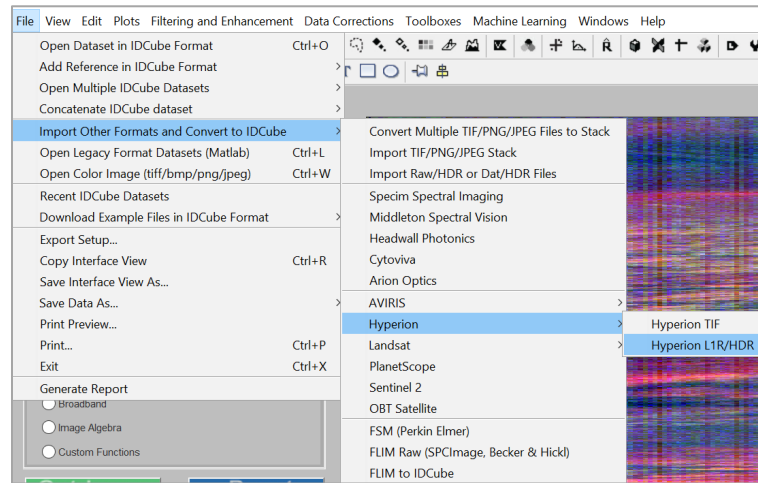


- In the Data Range (below) specify the Date, Cloud Cover, and other options.
- In the Data Sets tab (on the top), go to EO-1 and select sat dropdown menu which contains EO-1 Hyperion.

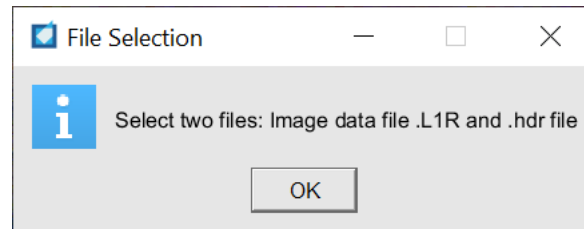


When the download is complete, unzip the file.

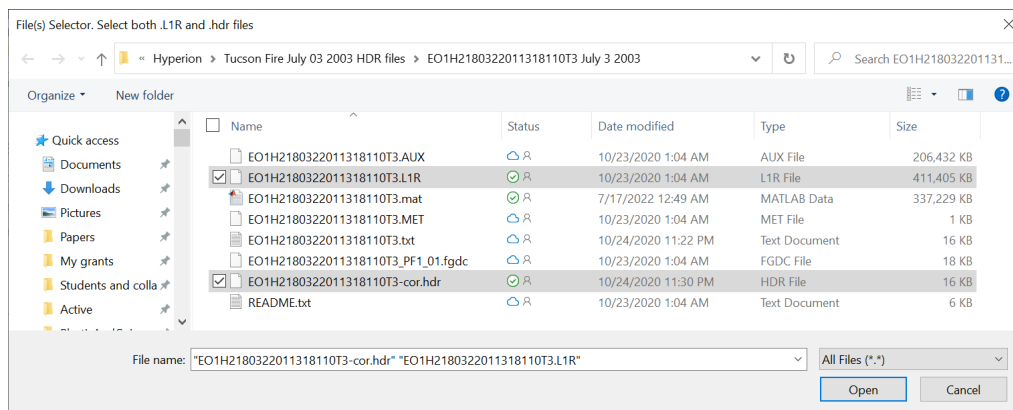
Step 2. To import the file to IDCube format select **File** → **Import Other Formats and Convert to IDCube** → **Hyperion (L1R/hdr)**.



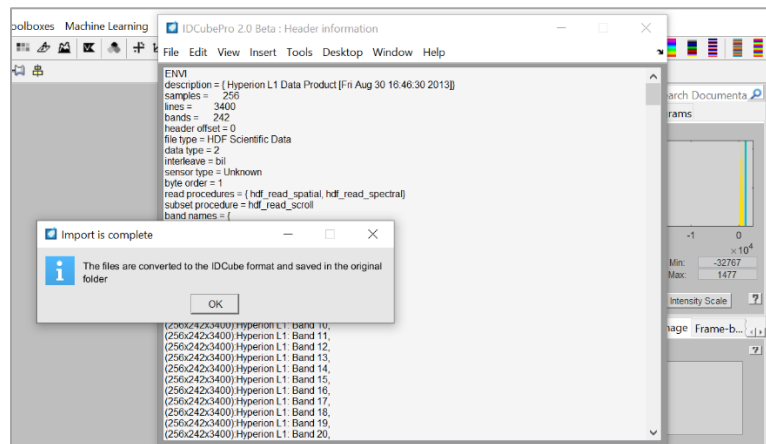
A pop-up message will ask to select two files with *.L1R* (datafile) and *.hdr* (metadata) extensions.



Click **OK** and select two files. The Image data file is usually the largest file and the header file has a *.hdr* extension.



Select the files and click **Open**. The conversion will start immediately. After the conversion is completed, the header file will be opened automatically. The new imaging file in the IDCube format (with a *.mat* extension) will be generated and saved with the same name as the *L1R* file.



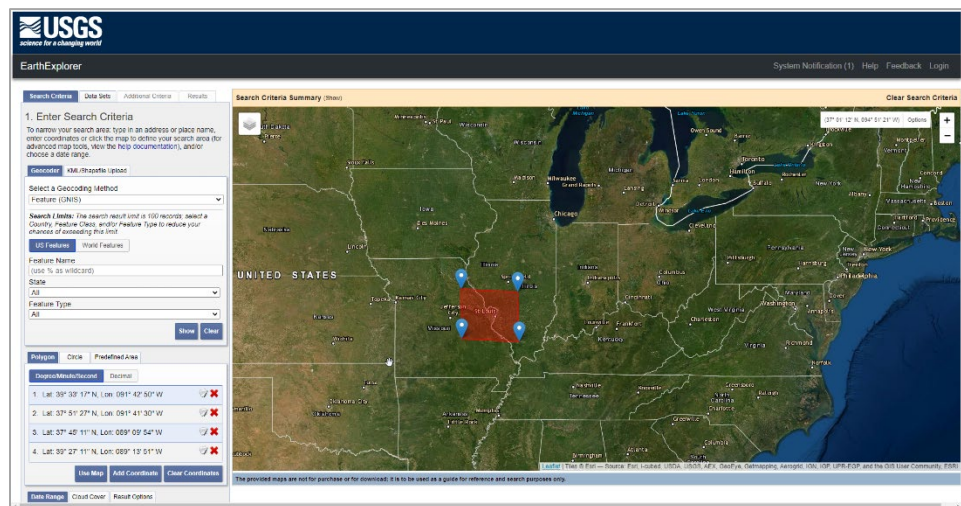
Landsat 9

Features: IDCubePro® allows for the conversion of different file formats to IDCube files. This manual will outline the steps to download and convert Landsat 9 data from the USGS website to IDCube format files.

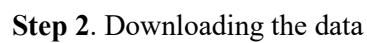
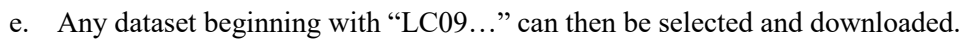
Step 1: Selecting the area and Landsat 9

Landsat 9 data can be obtained by visiting <https://earthexplorer.usgs.gov/>. You will have to log in to the website in order to download the data.

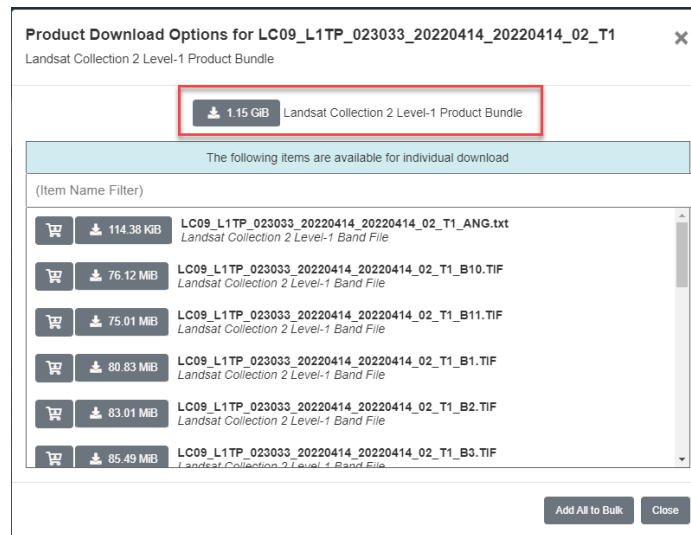
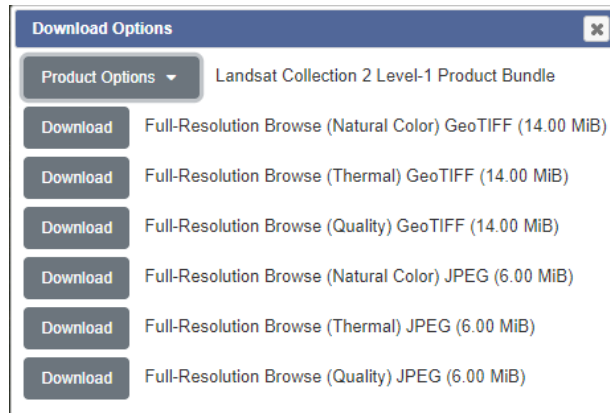
Move to the location of interest and select the area by, for example, clicking on the map



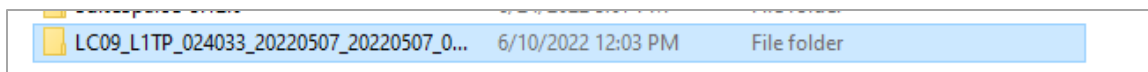
- c. In the Data Range (below) specify the Date, Cloud Cover, and other options.
- d. In the Data Sets tab (on the top), find a Landsat dropdown menu that contains “Landsat Collection 2 Level 1” data. In this dropdown menu, the “Landsat 8-9” data can be selected.



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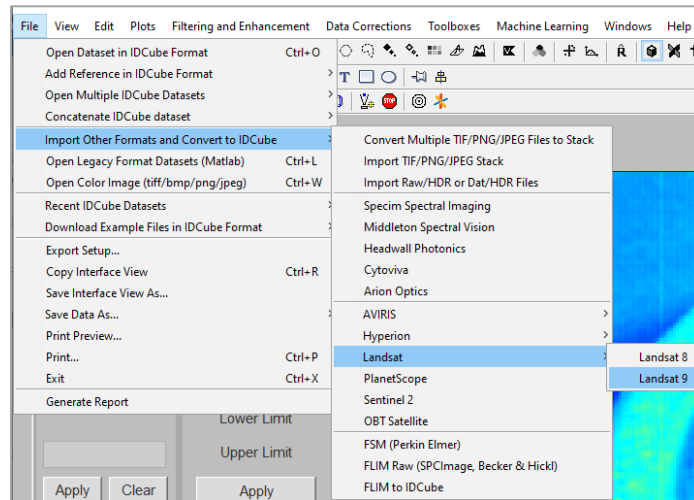


Once downloaded the dataset will appear as a zip file. This file can be unzipped using any software. We use 7-Zip software to extract the data. The resulting data file will be a folder.

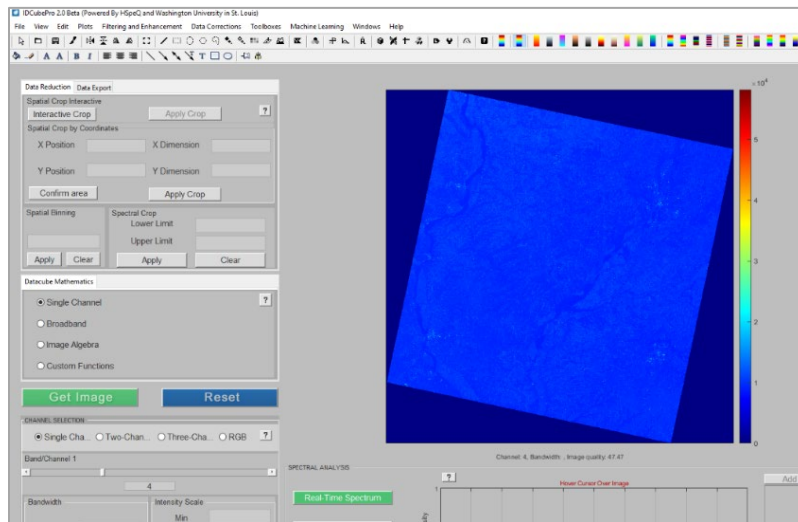


Step 3. Converting the data from the Landsat to IDCube format.

The conversion function in IDCube can be accessed by navigating to the **File** menu → **Import Other Formats and Convert to IDCube** → **Landsat** → **Landsat 9**.



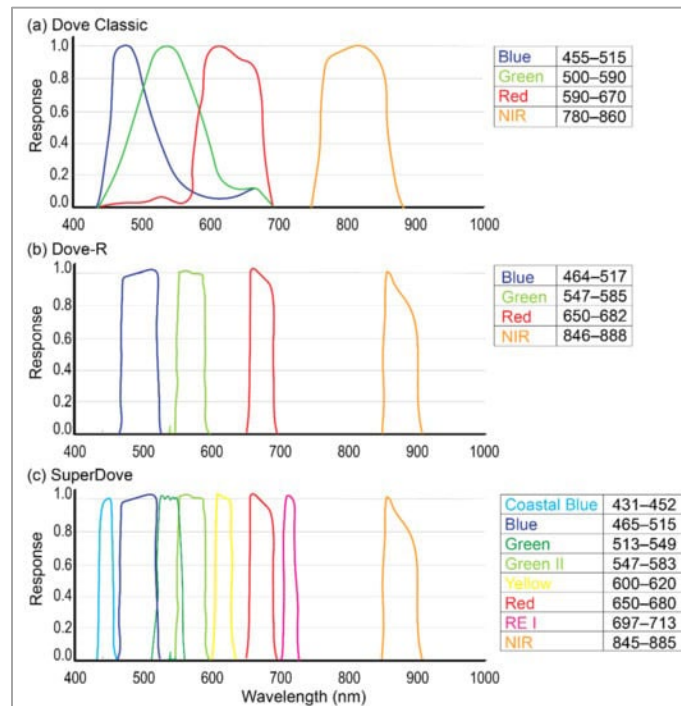
The desired Landsat 9 data folder can then be selected for conversion.



The converted file will be saved in the original folder path and the file will automatically be opened in IDCube.

PlanetScope Satellites

Planet launched their first Dove microsatellites in 2015 with multiple launches in subsequent years. As of 2022, over 240 PlanetScope microsats were orbiting the planet, providing daily imagery of most Earth's landmass at 3-meter resolution with 4 multispectral bands (i.e. blue, green, red and near-infrared [NIR]). SuperDoves launched since 2019 feature 3-m imagery with 8 multispectral bands, adding coastal blue and red edge data.



Spectral responses for PlanetScope: (a) Dove Classic ‘PS2’, (b) Dove-R ‘PS2.SD’, and (c) SuperDove ‘PSB.SD’ sensors. (see ref)

Ref:

A. E. Frazier and B. L. Hemingway. A Technical Review of Planet Smallsat Data: Practical Considerations for Processing and Using PlanetScope Imagery, *Remote Sens.* 2021, 13(19), 3930; <https://doi.org/10.3390/rs13193930>

Sentinel-2

Sentinel-2 is an Earth observation mission from the Copernicus Programme that systematically acquires optical imagery at a high spatial resolution over land and coastal waters. The mission is currently a constellation with two satellites, Sentinel-2A (launched in 2015) and Sentinel-2B (launched in 2017); a third satellite, Sentinel-2C, is currently undergoing testing in preparation for launch in 2024. Level-2A data is the most ideal for research activities as it allows further analysis without applying additional atmospheric corrections. Sentinel-2 collects multi-spectral data with 13 bands in the visible (B02, B03, B04), near-infrared (B05, B06, B08, B08A), and short-wave infrared parts (B09, B10, B11, B12) of the spectrum. Sentinel 2 provides images with three types of spatial resolution: 10 m, 20 m, and 60 m as shown in the Table:

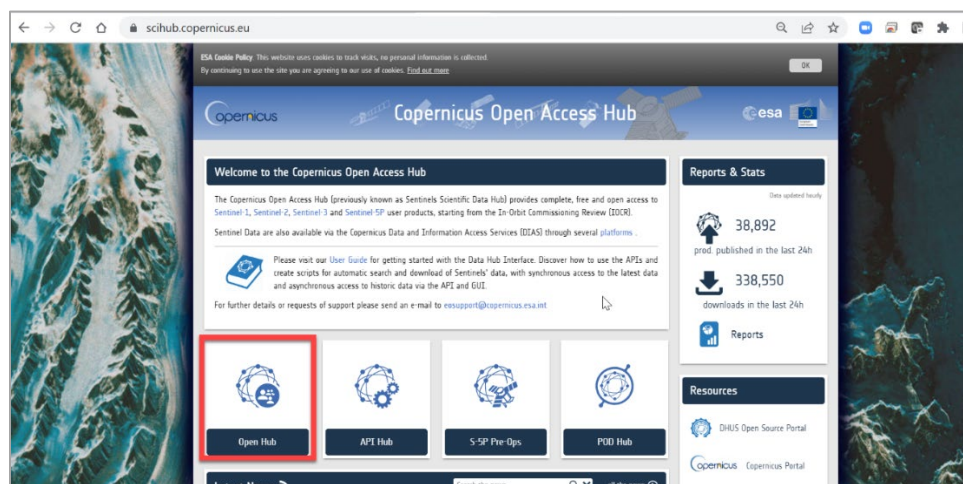
Table: Sentinel 2 Bands

| Band name | Resolution (m) | Central wavelength (nm) | Bandwidth (nm) | Purpose |
|-----------|----------------|-------------------------|----------------|-----------------------------------|
| B01 | 60 | 443 | 20 | Aerosol detection |
| B02 | 10 | 490 | 65 | Blue |
| B03 | 10 | 560 | 35 | Green |
| B04 | 10 | 665 | 30 | Red |
| B05 | 20 | 705 | 15 | Vegetation classification |
| B06 | 20 | 740 | 15 | Vegetation classification |
| B07 | 20 | 783 | 20 | Vegetation classification |
| B08 | 10 | 842 | 115 | Near-infrared |
| B08A | 20 | 865 | 20 | Vegetation classification |
| B09 | 60 | 945 | 20 | Water vapor |
| B10 | 60 | 1375 | 30 | Cirrus |
| B11 | 20 | 1610 | 90 | Snow / ice / cloud discrimination |
| B12 | 20 | 2190 | 180 | Snow / ice / cloud discrimination |
| AOT | 20 | | | Aerosol Optical Thickness map |
| SCL | 20 | | | Scene classification layer |
| TCI | 10 | B02+B03+B04 | | True color image |
| WVP | 20 | | | Scene-average Water Vapor map |

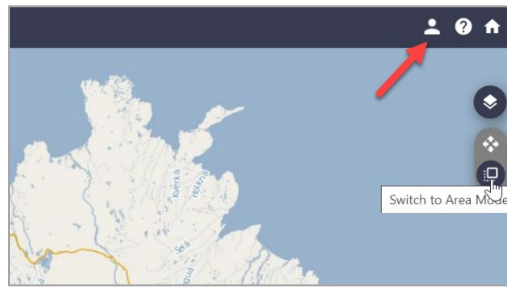
Step 1. Download data.

The data can be downloaded from several resources such as Copernicus Open Access Hub (<https://scihub.copernicus.eu/dhus/#/home>) and Earth Explore (<https://earthexplorer.usgs.gov/>).

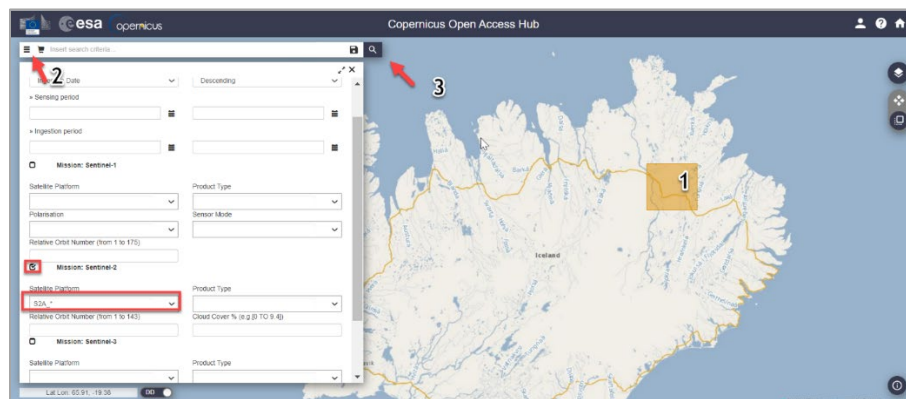
A brief guidance from the Copernicus Open Access Hub is shown here.



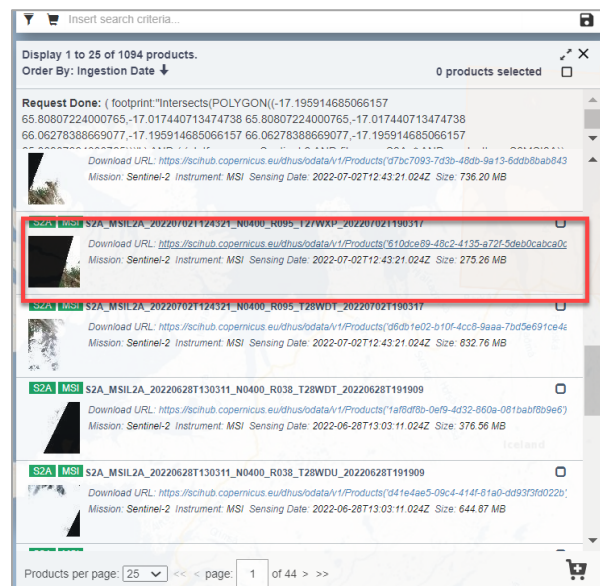
Press the **Open Hub** panel and put your login information (or register if you are a new user). After that switch the Navigation Mode to Area Mode.



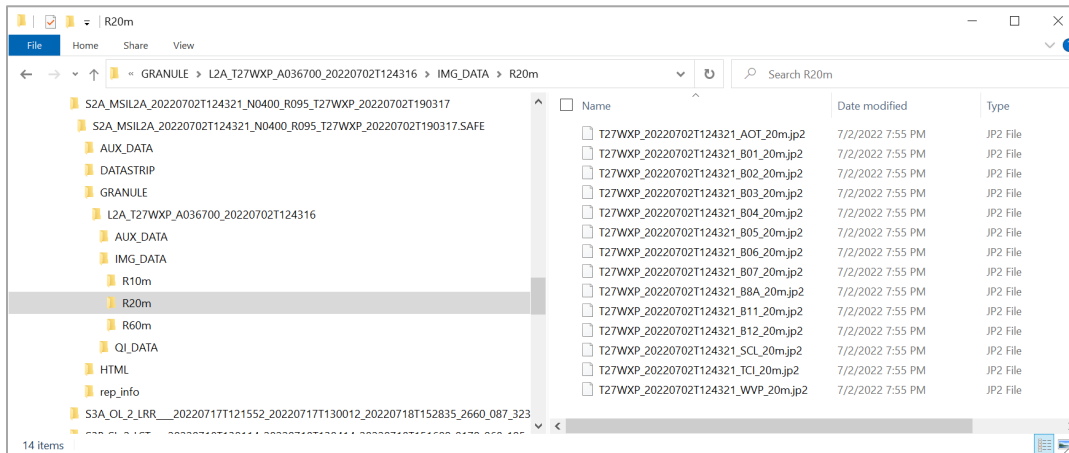
Then, 1) draw the region of interest (which will turn yellow). 2) Press the three lines on the Search Criteria and add criteria to narrow down the search. We suggest specifying Sentinel 2 as a mission platform. 3) Click Search to start the search process.



The search has identified 1045 datasets. Select the appropriate dataset and download it.

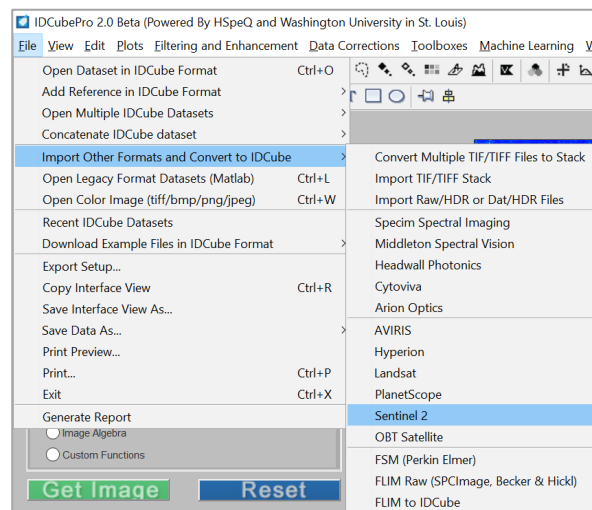


Unzip the file. Sentinel 2 dataset has the structure as shown on the left panel. Navigate to the IMG_DATA folder. In some cases, the IMG_DATA folder has subfolders, such as R10, R20, and R60. R20 and R60 are supported by the IDCubePro®. If any of the subfolders are selected (i.e., R20) you can see all bands that are available for processing. Refer to the meaning of each band in the Table of Sentinel 2 bands above.

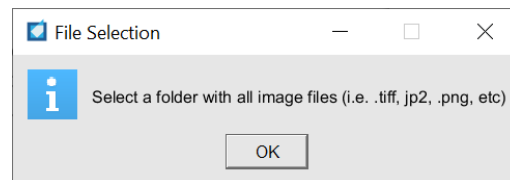


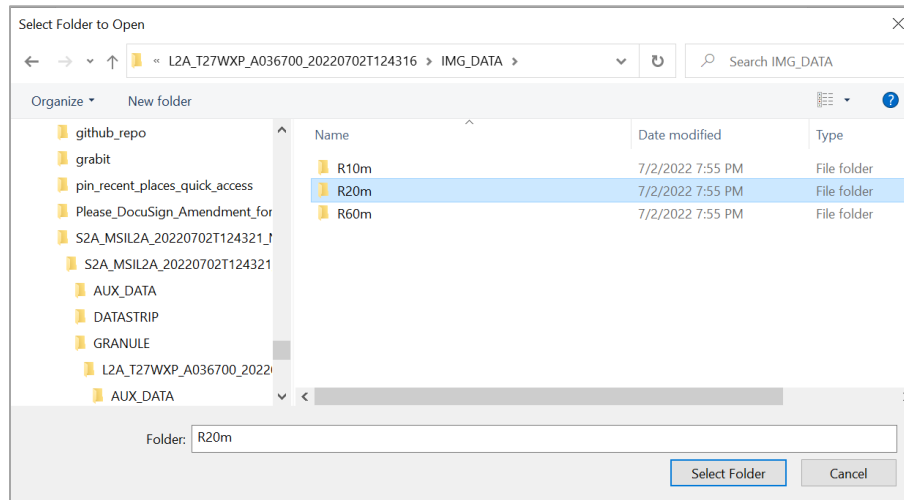
Step 2. Converting data into the IDCube format.

Select Import Other Formats and Convert to IDCube → Sentinel 2.

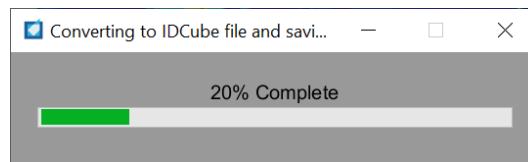


You will be prompted to select the folder with the data that will be imported into the IDCube format.



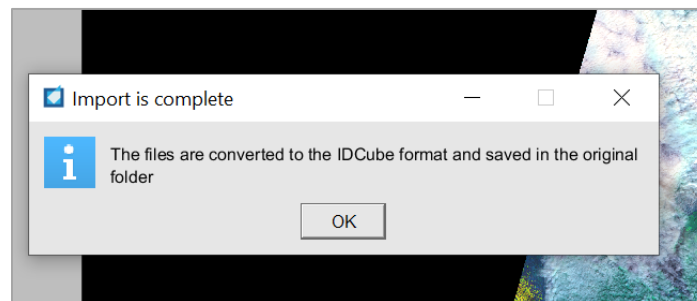


After selecting the IMG_DATA folder, a waitbar will appear to show the conversion progress.



The converted file will be saved in the original folder/file location.

The converted file will automatically be opened and visualized in the IMAGE DISPLAY panel. In this example, the data in a folder containing Sentinel 2 images were converted to a single IDCube file, saved in the same directory, and opened in the IDCube format.

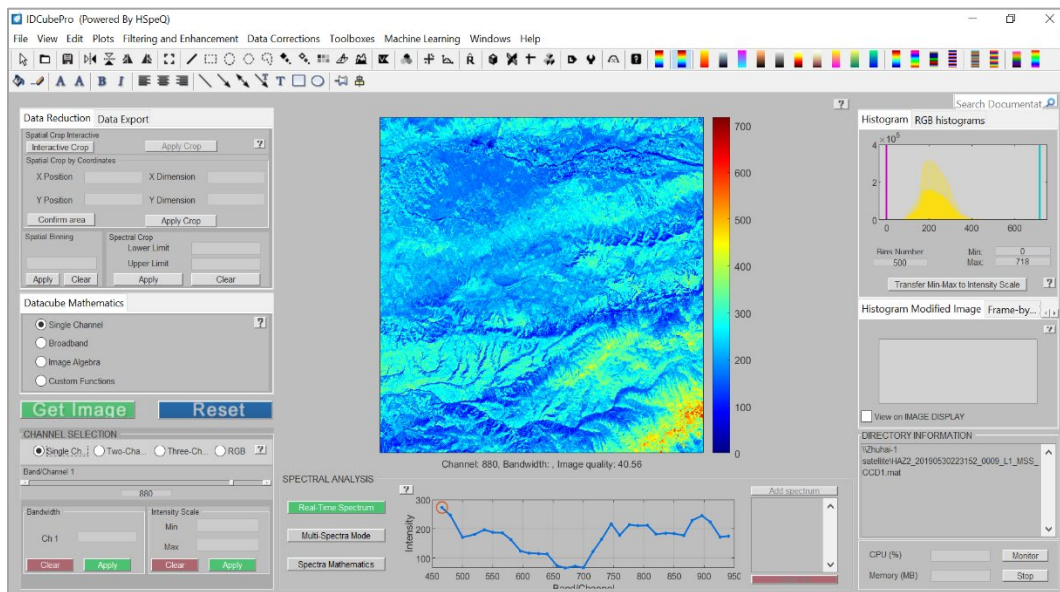


Zhuhai-1

The Zhuhai-1 hyperspectral satellite is a commercial remote satellite constellation that was launched first in 2018 and is currently operated by Zhuhai Orbita Aerospace Science and Technology Co., Ltd. On 2022, there were 10 hyperspectral satellites. These hyperspectral satellites can observe the Earth's surface every 2.5 days. The satellites images area are 50 x 50 km, with the spatial resolution 10 m. The sensor has 32 bands with the spectral resolution of 6 nm (FWHM) shown in the table, generating images 5056 x 5056. Additional information is available from <https://www.obtdata.com/en/zhuhai1.html>. The data are stored as individual *tiff* and *jpg* files with the *hdr* file.

Table: Zhuhai-1 Bands

| Band | Wavelength (nm) | Resolution (m) | Band | Wavelength (nm) | Resolution (m) | Band | Wavelength (nm) | Resolution (m) |
|------|-----------------|----------------|------|-----------------|----------------|------|-----------------|----------------|
| 1 | 440–446 | 10 | 12 | 639–641 | 10 | 22 | 779–781 | 10 |
| 2 | 462–469 | 10 | 13 | 664–666 | 10 | 23 | 805–807 | 10 |
| 3 | 486–494 | 10 | 14 | 669–671 | 10 | 24 | 819–821 | 10 |
| 4 | 496–504 | 10 | 15 | 685–687 | 10 | 25 | 832–834 | 10 |
| 5 | 505–514 | 10 | 16 | 699–701 | 10 | 26 | 849–851 | 10 |
| 6 | 526–535 | 10 | 12 | 639–641 | 10 | 27 | 863–866 | 10 |
| 7 | 545–555 | 10 | 17 | 708–710 | 10 | 28 | 878–881 | 10 |
| 8 | 554–565 | 10 | 18 | 729–731 | 10 | 29 | 894–897 | 10 |
| 9 | 574–585 | 10 | 19 | 745–747 | 10 | 30 | 908–912 | 10 |
| 10 | 590–602 | 10 | 20 | 759–761 | 10 | 31 | 923–930 | 10 |
| 11 | 619–621 | 10 | 21 | 775–777 | 10 | 32 | 937–944 | 10 |



References:

X. Feng, Z. Shao, X. Huang, L. He, X. Lv and Q. Zhuang, "Integrating Zhuhai-1 Hyperspectral Imagery With Sentinel-2 Multispectral Imagery to Improve High-Resolution Impervious Surface Area Mapping," in *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing*, vol. 15, pp. 2410-2424, 2022, doi: 10.1109/JSTARS.2022.3157755.

Bruker (Lumos)

Lumos microscope generates imaging files that can be saved in a *.mat* format. This conversion also generates an *.hdr* file that contains the information regarding the dimension of the image. An example of this *.hdr* file is shown below and includes *samples* that corresponds to the number of pixels in the X – axis, *lines* that corresponds to the number of pixels in the Y – axis, and *bands* that correspond to the number of spectral bands (Z – axis). (NOTE: the actual number of bands is $N = \text{bands} - 1$).

To start the conversion, select **File → Import Other Formats... → Bruker (Lumos)** and open both files.

| Name | Date modified | Type | Size | Folder |
|-------------------------------|-------------------|-------------|------------|--------|
| Lumos Opus file.0 | 9/30/2022 1:59 PM | HDR File | 1 KB | From V |
| Lumos Opus file matlab export | 9/30/2022 1:56 PM | MATLAB Data | 380,543 KB | From V |

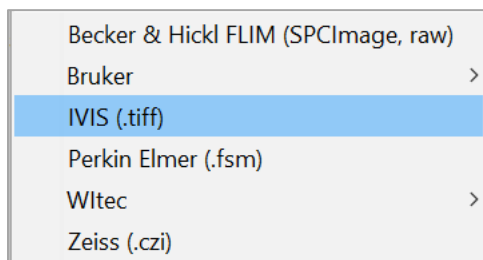
IVIS (.tiff)

IVIS (Perkin Elmer) small animal imaging systems such as IVIS SPECTRUM allow a user to collect the data at different combination of excitation/emission channels. The resulting data are combined in a single folder with multiple subfolders with each folder having several files:

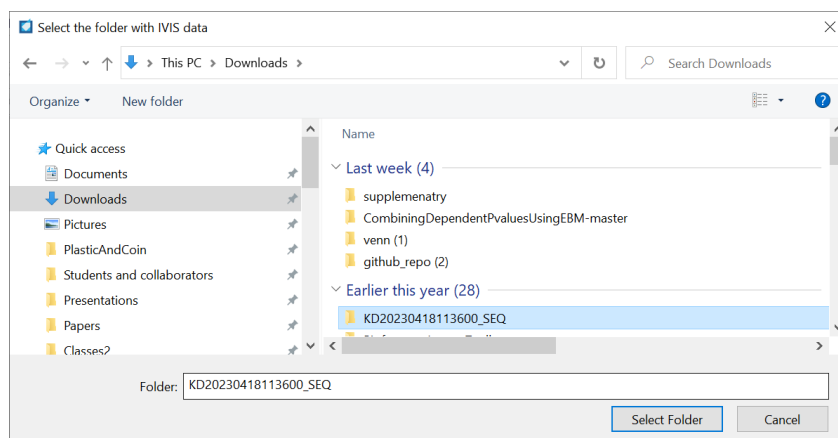
| Name | Date | Type | Size | Tags |
|--------------------------|--------------------|---------------|----------|------|
| extracted_files | 5/19/2023 8:16 PM | File folder | | |
| AnalyzedClickInfo.txt | 4/18/2023 11:49 AM | Text Document | 4 KB | |
| ClickInfo.txt | 4/18/2023 11:49 AM | Text Document | 27 KB | |
| fluorescentreference.tif | 4/18/2023 11:49 AM | TIF File | 1,803 KB | |
| luminescent.TIF | 4/18/2023 11:49 AM | TIF File | 113 KB | |
| photograph.TIF | 4/18/2023 11:49 AM | TIF File | 451 KB | |
| readbiasonly.TIF | 4/18/2023 11:49 AM | TIF File | 113 KB | |

IDCube extracts *Luminescent.tif* images and combine them in a stack. IDCube does not extract the metainformation that is located in the *.txt* file.

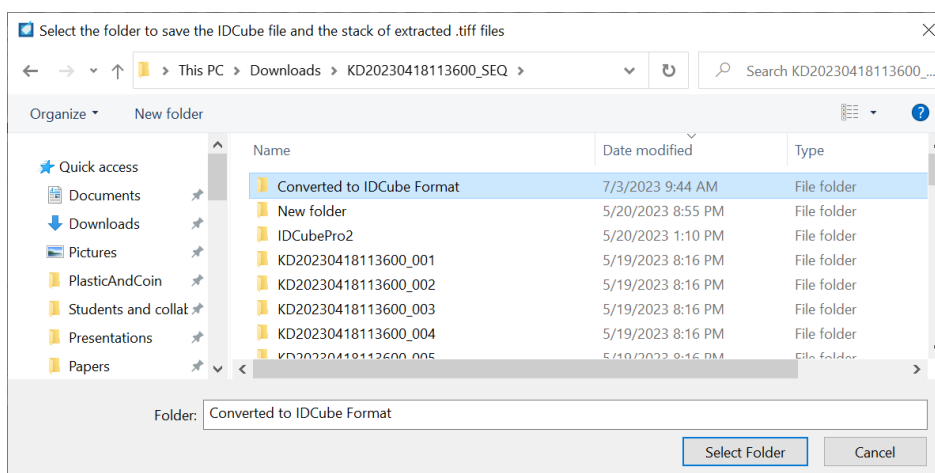
Step 1. Select **File → Import Other Formats... → IVIS (.tiff)**



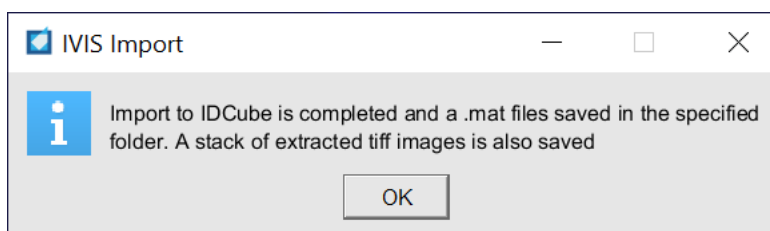
Step 2. In the pop-up menu select the location of the folder.



Step 3. Select or create a folder to save the IDCube file with the extracted information.



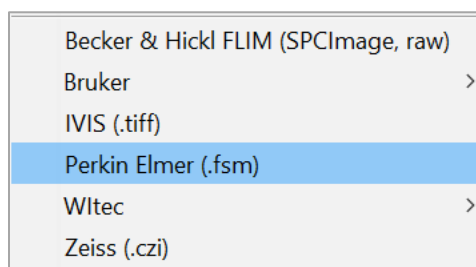
A messagebox will notify the user that the conversion to the IDCube format is completed and additionally a new stack of tiff files is generated and saved in the same directory.



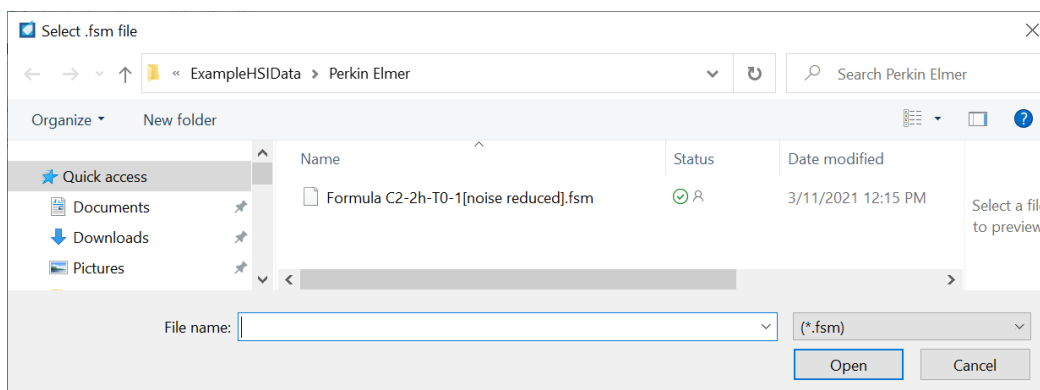
Perkin Elmer (.fsm)

Perkin Elmer FTIR microscopes and imaging systems collect spectral imaging data in the .fsm format. IDCube extracts the image file and converts into a single file. IDCube also extract the limited amount meta information.

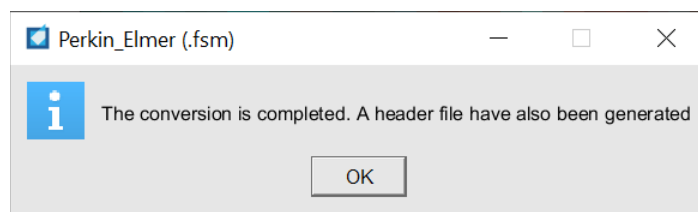
Step 1. To start the conversion, select **File** → **Import Other Formats...** → **Perkin Elmer (.fsm)** and open an .spc file.



Step 2: Select an *.fsm* file from the dialogue window.



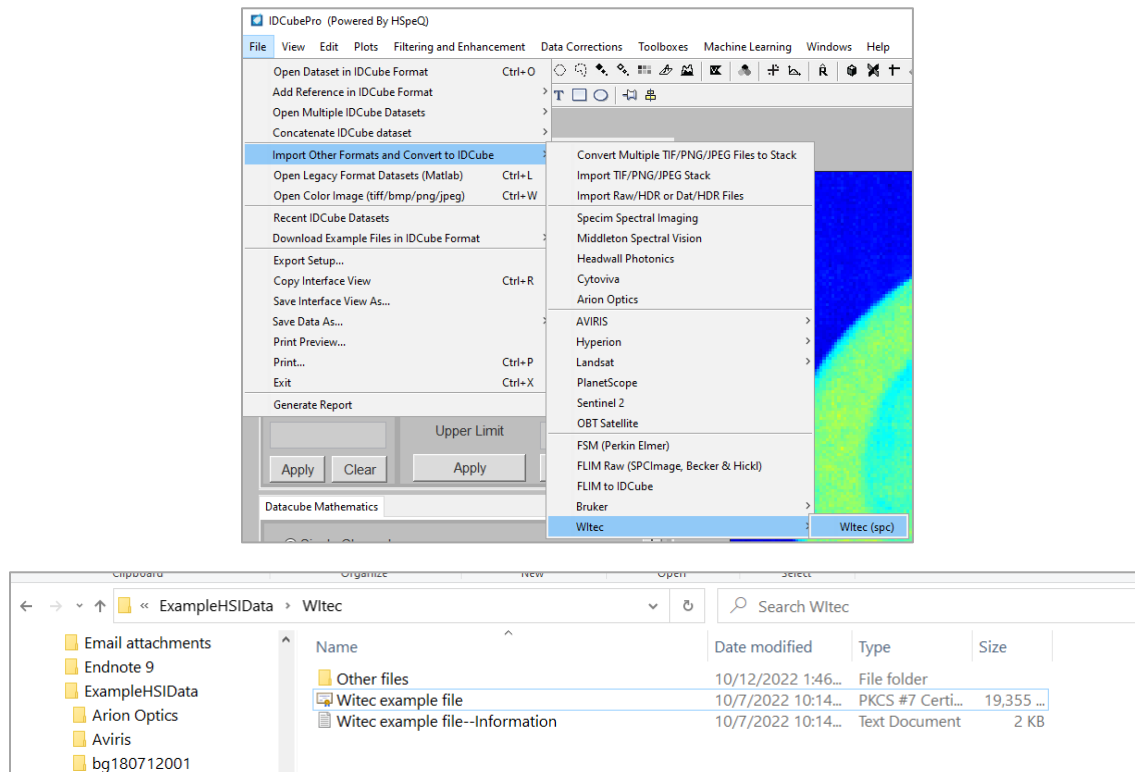
A popup message box will indicate when the conversion is complete. The conversion also generates a limited header file as a text file with the same filename as the original one. You can view the header file using **View → View Header information**.



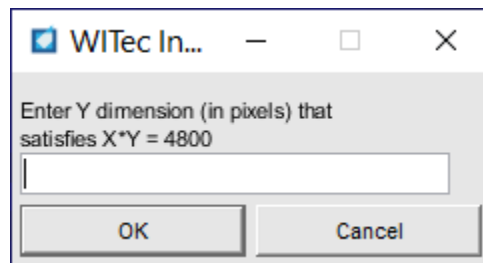
Reference: Based in part on Stephen Westlake, Seer Green, PerkinElmer Life and Analytical Sciences Copyright (C) 2007.

Witec (.spc)

Witec microscopes generates imaging files that can be saved in an *.spc* format. The Information file (*.txt*) is also stored. To start the conversion, select **File → Import Other Formats... → Witec → Witec (.spc)** and open an *.spc* file.



In the popup dialog window, **Witec Input**, enter the **Y dimension** to satisfy the condition specified in the window. Here, IDCube automatically recognized the total number of pixels (=4800).



To identify the **Y dimension**, open the saved text file with Notepad (only a portion of the text is shown below). **Point per Line** corresponds to the width (**X dimension**), **Lines per Image** corresponds to the height (**Y dimension**).

General:

System ID: 500-1200-994

Start Time: 4:36:29 PM

Start Date: Wednesday, July 6, 2022

Duration: 19h 2m 42s

User Name: Witec

Sample Name: Ouai moisture 24 hours

Configuration: Raman CCD1

Large Scale Image Scan (Depth):

Points per Line: 80 X - axis

Lines per Image: 60 Y - axis

Scan Width [μ m]: 80.000

Scan Depth [μ m]: 60.000

Scan Origin X [μ m]: 0.000

Scan Origin Y [μ m]: 0.000

Scan Origin Z [μ m]: -30.000

Gamma [$^{\circ}$]: 0.000

Scan Speed [s/Line]: 1120.000

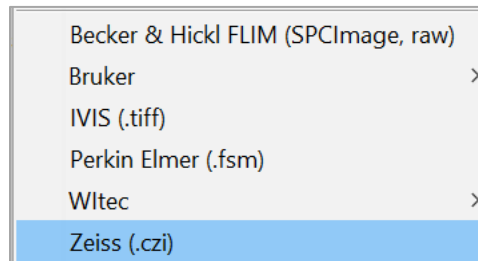
Integration Time [s]: 14

You can save the dataset as a new file in the IDCube format by clicking **Save Data As...** → **Save in IDCube format(.m)** or **CTRL+S**.

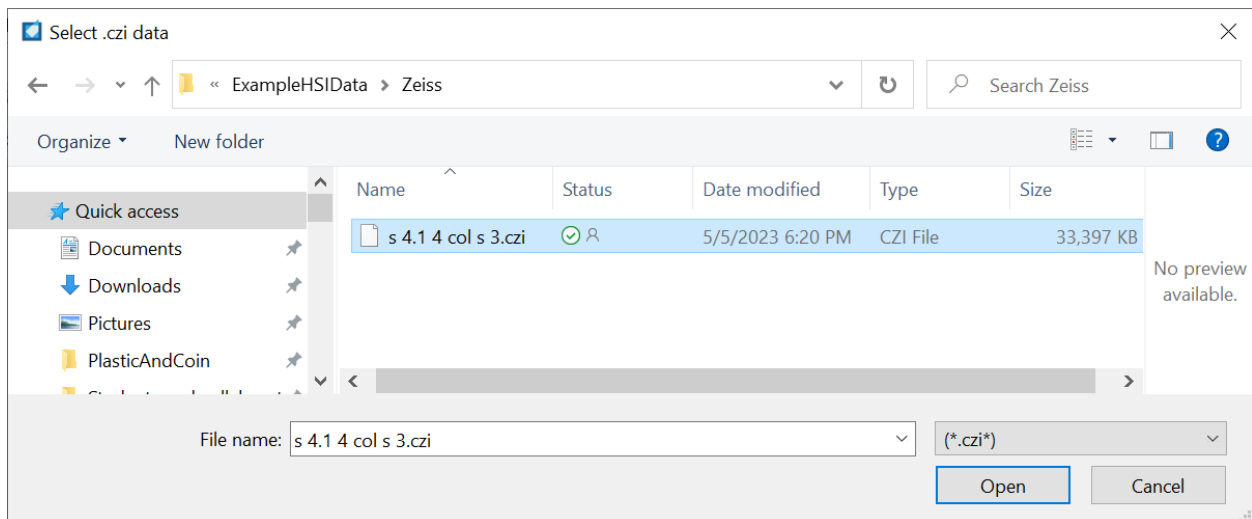
Zeiss (.czi)

Zeiss microscopes generates imaging files saved in an .czi format. Perform the following steps

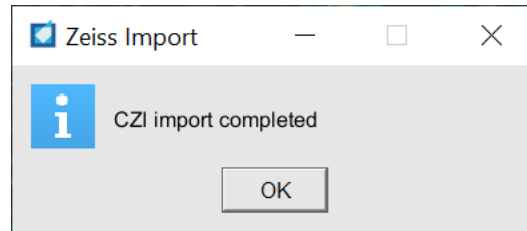
Step 1. To start the conversion, select **File** → **Import Other Formats...** → **Zeiss (.czi)**



Step 2. Select a .czi file from a dialogue window.



A popup message box will indicate when the conversion is complete. The conversion also generates a limited header file as a text file with the same filename as the original one. You can view the header file using **View → View Header information**.



Open Color Image

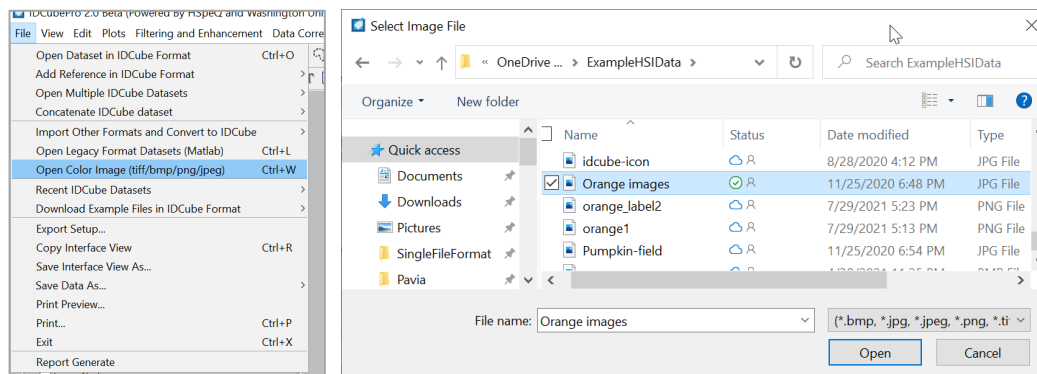
NOTE: Opens a color image in *tiff*, *png*, or *jpeg* format.

Features:

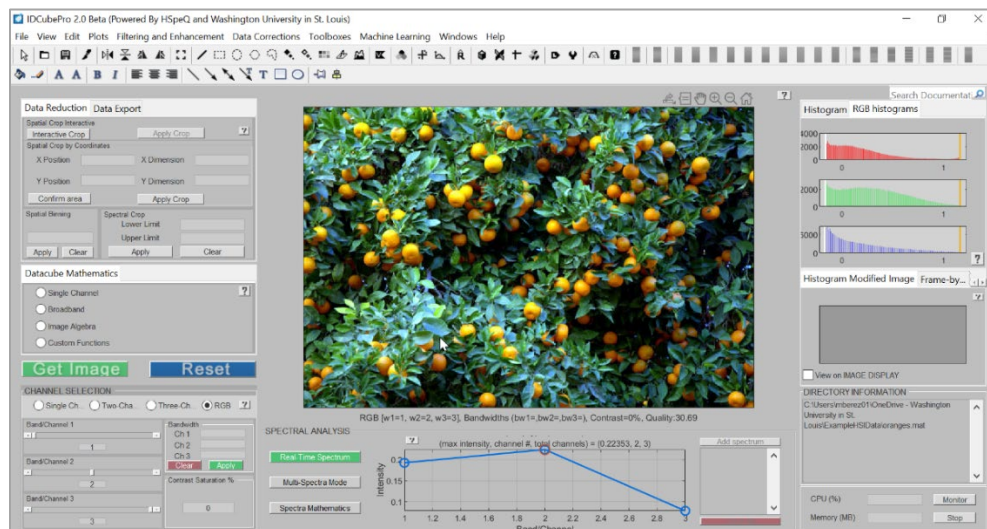
Enables the users to process any color image as a hyperspectral imaging dataset.

Steps:

1. Select **File → Open Color Image** and open the file.



2. Process the file with any of the functions available in IDCube.



The number of channels is equal to 3. Red color corresponds to channel 1, green color corresponds to channel 2, and blue color corresponds to channel 3.

Convert individual *tif/tiff*, *png*, and *jpeg* images into a stack

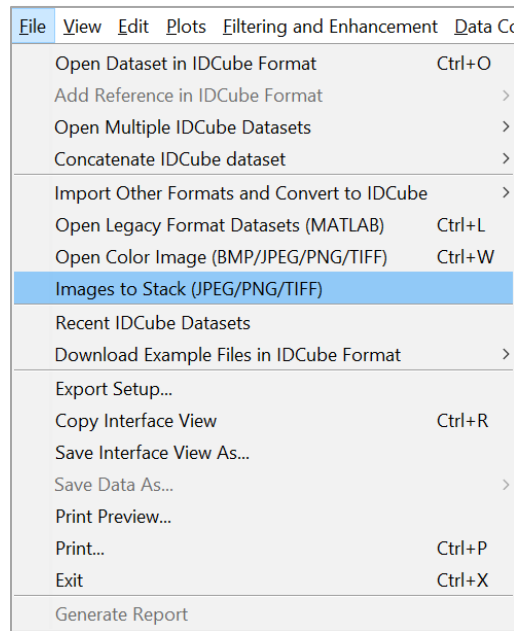
NOTE: IDCube directly imports only stacks. Importing individual files requires converting individual images into a stack and then importing the formed stack.

Features:

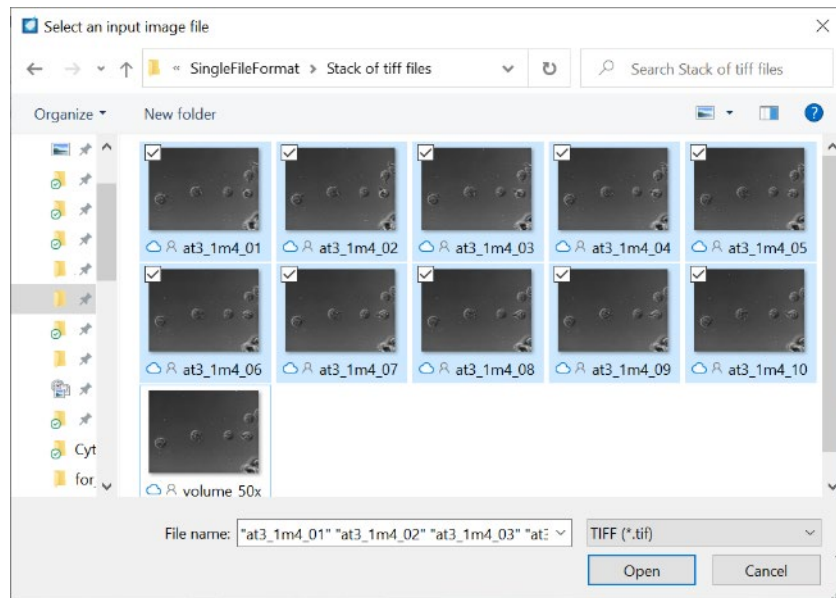
IDCubePro® enables the user to convert multiple individual *tiff*, *png*, and *jpeg* files into a stack (the user can select the type of a stack file: *tiff*, *png*, or *jpeg*) and then import a stack file to IDCubePro®.

The following example *Cells_tiffs* dataset is used as an example: The file presents a compilation of 10 tiff files.

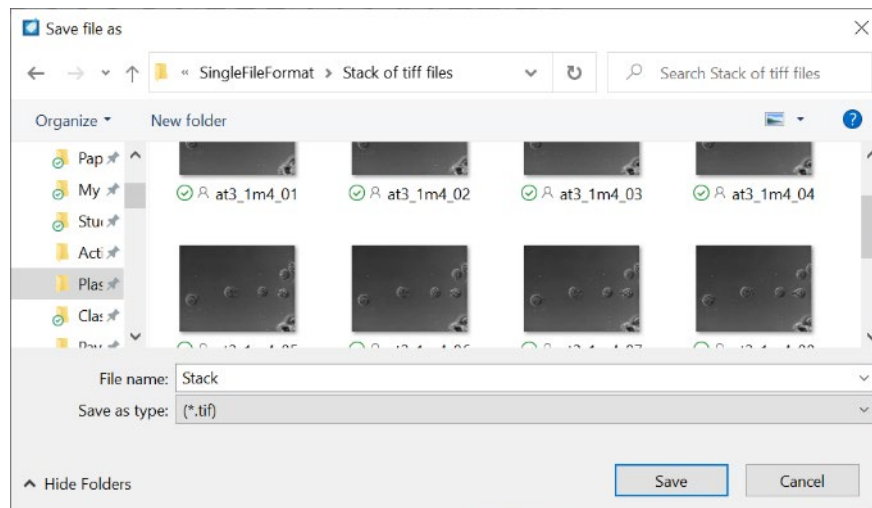
1. Click **File** → **Import other formats and Convert to IDCube** → **Convert Multiple JPEG/PNG/TIF/ Files to Stack**.



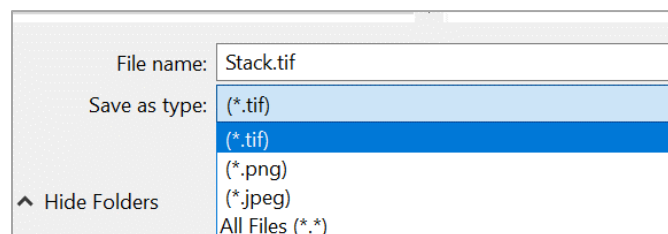
2. From the opened directory navigate to the folder and select individual *tiff* files that you would like to convert to a stack.



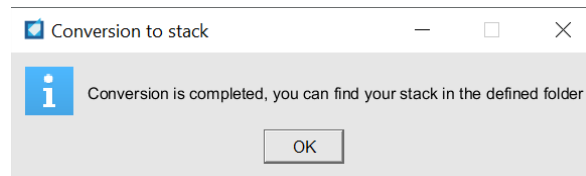
3. Press **Open**. A new window will be opened asking where to save the stack file. The default name is 'Stack' and the default extension is *.tif*.



You can rename the file and select a different type of file from the dropdown menu.



Click **Save**. The completion of the file conversion will be confirmed.



Press **OK**. The stack file will be ready for import into IDCubePro® as shown in the next chapter **Import JPEG/ PNG/ TIF/ Stack**.

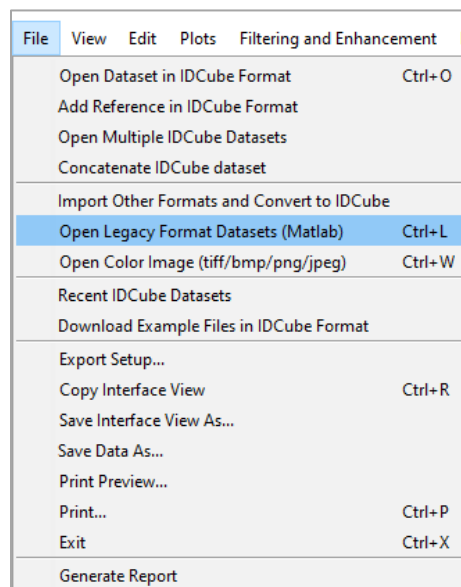
Open Legacy Format

NOTE: This function is only available for data stored in a folder with two separate matlab files: **Image.m** and **wavelength.m**.

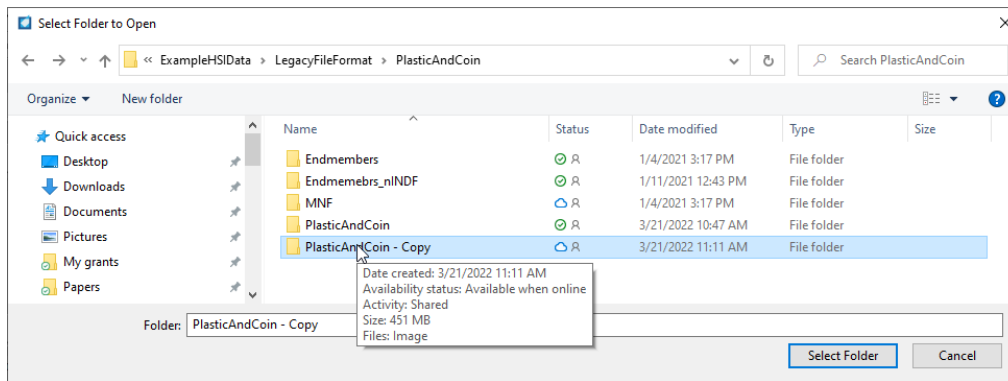
Features: opens MATLAB datafiles with or without header files. *Image.m* file has all the data, and *wavelength.m* files have header information.

Steps:

1. Click **File** → **Open Legacy Format Datasets (Matlab)**, or click **Ctrl+L**.



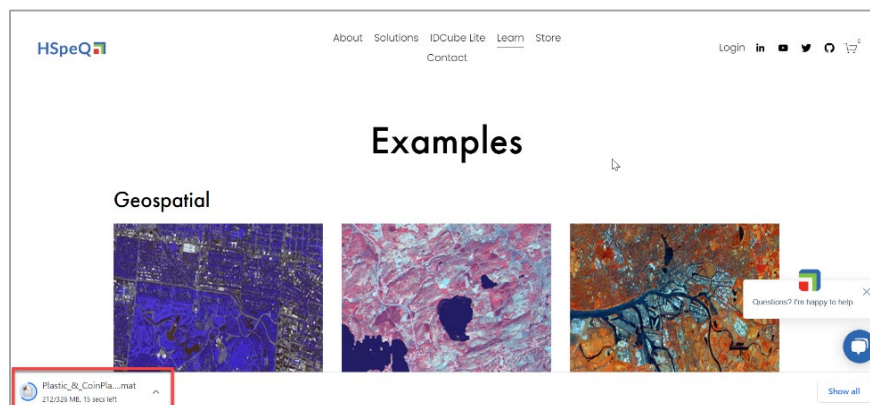
2. Select a folder with your data. The folder should have one file **Image** (format N x M x L) or two files with the names **Image** (format N x M x L) and **wavelength** (a linear vector that defines the wavelengths in L). Files with other names will be ignored.
3. Click **Open** to visualize the data. **NOTE:** if the **wavelength** file is absent the channels for datasets will be defined as 1,2,3 etc.



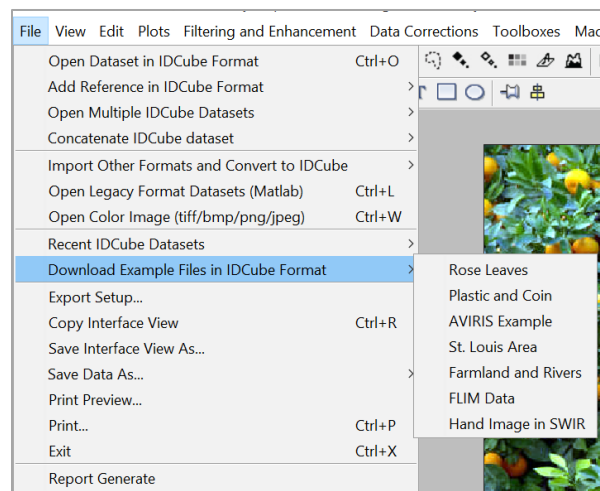
Download Example Files

IDCubePro® enables the user to download files directly from the IDCube files depository stored in a cloud location. The file will be downloaded as a ready-to-use file in the IDCubePro® format (.mat or .m extension). Additional datasets can be also opened from our website <https://www.idcubes.com/examples>.

You can see in the left corner that the file will start downloading after you select the example dataset.



If the file is too large it might be downloaded as a zip file. The files can also be downloaded from the file menu. Go to **File** → **Download example files in IDCube format**.



Selects the example file to download. Currently available options are:

- Rose Leaves (hyperspectral)
- Plastic and Coin (hyperspectral)
- AVIRIS data (hyperspectral)
- St. Louis area (multispectral)
- Farmland and rivers (multispectral)
- FLIM (fluorescence lifetime imaging) data
- Hand image in SWIR (hyperspectral)

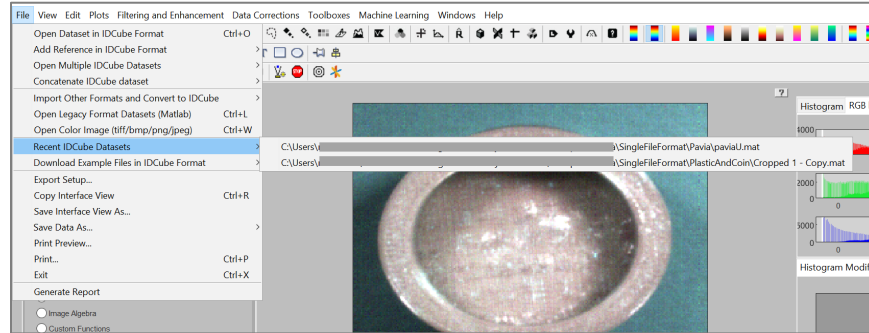
The list of files might be updated. You will be redirected to a web browser. IDCube file format will download automatically.

References:

For more information on the example files like size and instrument, visit our website at <https://www.idcubes.com/examples>

Recent IDCube Datasets

The function allows the user to reopen recently opened files. The function shows files opened during the current session of the software



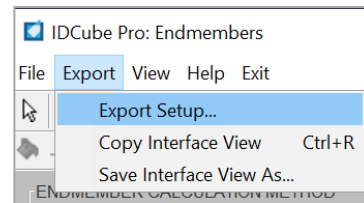
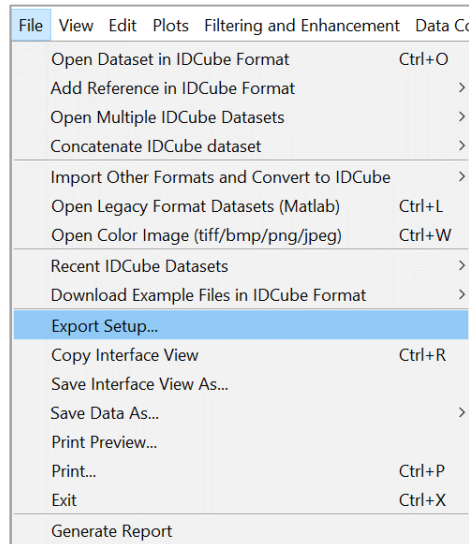
Export Setup

NOTE: Can be used to export the panel views without performing screenshots. Available for the Main Interface and all toolboxes.

Features: Customizes figures and interfaces before saving.

The example below shows how to use the EXPORT SETUP window to customize a figure before saving. It shows how to change the figure size, background color, font size, and line width. It also shows how to save the settings and apply them to other figures and toolboxes before saving them.

Set the figure size by clicking **File** → **Export Setup**. In the toolboxes, this function is located in the **Export** → **Export Setup**.



Set Figure Size

Specify the desired dimensions in the **Width** and **Height** fields, for example, 5-by-4 inches. The dimensions include the entire interface window except for the frame, title bar, menu bar, and toolbars. If the specified width and height are too large, then the figure might not reach the specified size.

To make the axes fill the figure, select **Expand axes to fill the figure**.

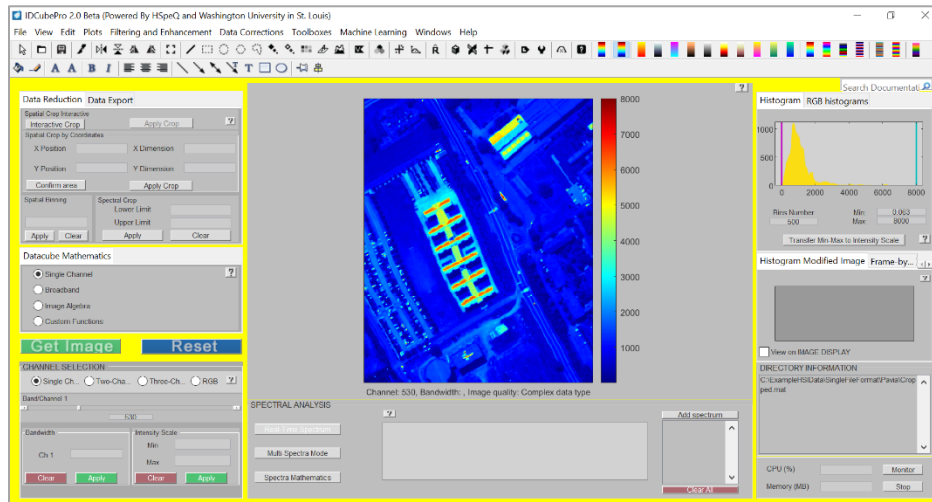
The screenshot shows the 'EXPORT SETUP' dialog box with the 'Size' property selected in the 'Properties' list. The 'Width' is set to 5 and 'Height' is set to 4, both with units of 'inches'. There is an unchecked checkbox for 'Expand axes to fill figure'. On the right side, there are buttons for 'Apply to Figure', 'Restore Figure', 'Export...', 'OK', 'Cancel', and 'Help'. At the bottom, there is an 'Export Styles' section with fields for 'Load settings for:' (default), 'Save as style named:' (default), and 'Delete a style:', each with a corresponding button (Load, Save, Delete).

Click **Apply to Figure**. Applying the settings changes the appearance of the Interface figure on the screen. All settings from the EXPORT SETUP dialog are applied to the figure. Thus, more than just the figure size can change. For example, by default, IDCubePro® converts the background color of the saved figure to white.

Set Figure Background Color

Set the figure background color by clicking the **Rendering** property in the EXPORT SETUP window. In the **Custom color** field, specify either a color name from the table or an RGB triplet. For example, set the background color to yellow by typing 'y' in the custom color field.

The screenshot shows the 'EXPORT SETUP' dialog box with the 'Rendering' property selected in the 'Properties' list. The 'Colorspace' is set to 'RGB color'. The 'Custom color' checkbox is checked, and the 'Custom color' field contains 'w'. The 'Custom renderer' checkbox is unchecked, and the 'Custom renderer' dropdown is set to 'painters (vector format)'. The 'Resolution (dpi)' is set to 'auto'. There are three checked checkboxes: 'Keep axis limits' and 'Show uicontrols'. On the right side, there are buttons for 'Apply to Figure', 'Restore Figure', 'Export...', 'OK', 'Cancel', and 'Help'. At the bottom, there is an 'Export Styles' section with fields for 'Load settings for:' (default), 'Save as style named:' (default), and 'Delete a style:', each with a corresponding button (Load, Save, Delete).

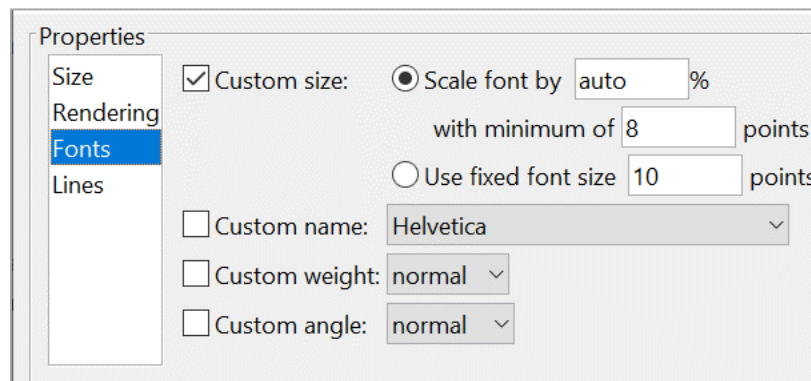


An RGB triplet is a three-element row vector whose elements specify the intensities of the red, green, and blue components of the color. The intensities must be in the range $[0,1]$, for example, $[0.4 \ 0.6 \ 0.7]$. This table lists some common RGB triplets that have corresponding color names. To specify the default gray background color, uncheck the **Custom Color** checkbox.

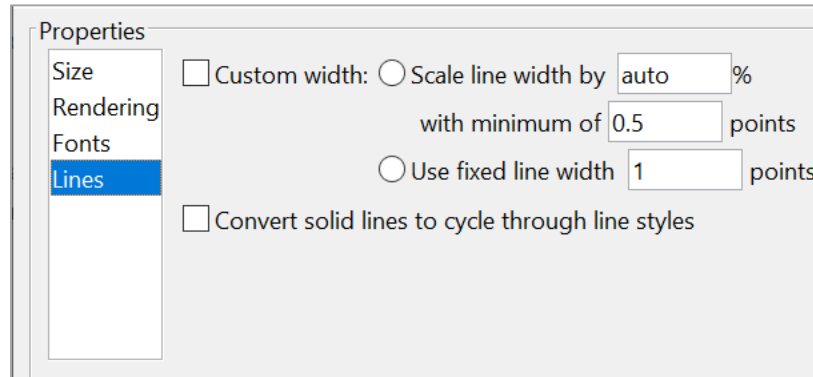
| Long Name | Short Name | Corresponding RGB Triplet |
|-----------|------------|---------------------------|
| white | w | $[1 \ 1 \ 1]$ |
| yellow | y | $[1 \ 1 \ 0]$ |
| magenta | m | $[1 \ 0 \ 1]$ |
| red | r | $[1 \ 0 \ 0]$ |
| cyan | c | $[0 \ 1 \ 1]$ |
| green | g | $[0 \ 1 \ 0]$ |
| blue | b | $[0 \ 0 \ 1]$ |
| black | k | $[0 \ 0 \ 0]$ |

Set Figure Font Size and Line Width

Change the font by clicking the **Fonts** property. Specify a fixed font size and select a font name, font-weight, and font angle. For example, use the default font. The tick mark locations might change to accommodate the new font size.



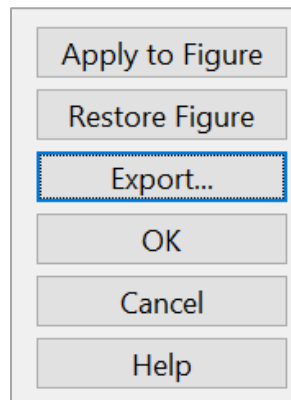
Change the line width by clicking the **Lines** property. Specify a fixed line width, for example, 2 points.



Click **Apply to Figure** on the right side of the **Export Setup** dialog.

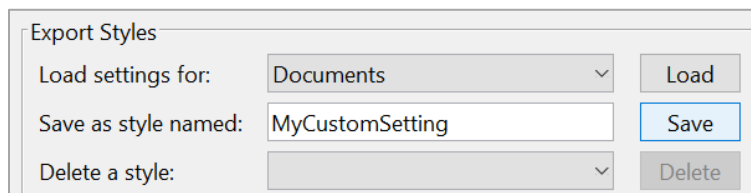
Save Figure to File

Save the figure to a file by first clicking **Export**, and then specify a file name, location, and desired format. For more information about file formats, see the following chapter **Save Interface Image As...**



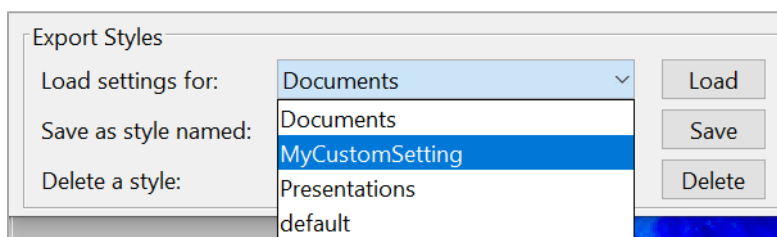
Save Figure Settings for Future Use

Save your settings to use for other figures (i.e., toolboxes) by creating an export style. In the **Export Styles** section, type a style name, for example, MyCustomSettings. Then, click **Save**.



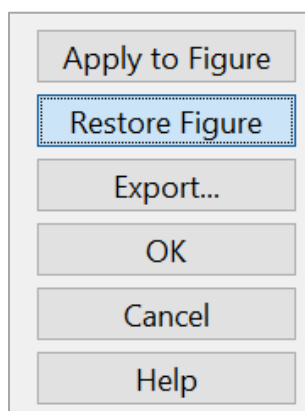
Apply Settings to Another Figure

Apply your settings to another figure by opening the **Export Setup** box from its figure menu. In the **EXPORT STYLES** section, select the style name and click **Load**. Next, click **Apply to Figure** on the right side of the Export Setup dialog. MATLAB applies the saved style settings to the figure.



Restore Figure to Original Settings

Restore the figure on the screen to the original settings by clicking **Restore Figure**.



Copy Interface View

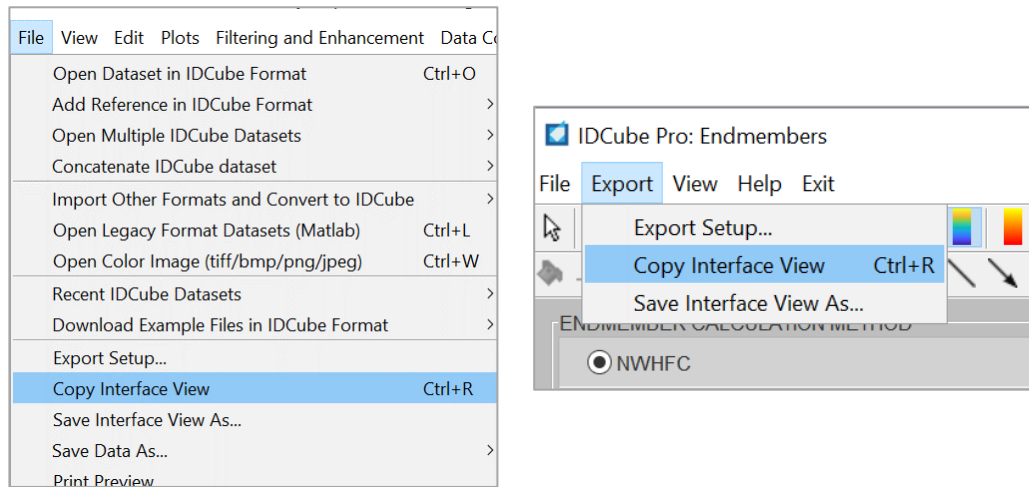
NOTE: Can be used with the Main Interface, all toolboxes, and many pop-ups. In the toolboxes, this function is in the **Export** tab.

Feature: Enables the user to copy the entire interface of the selected frame or window.

Steps:

1. Open a file.

Select **File** → **Copy Interface View** (or **Ctrl+R**). In the toolboxes, this function is located in the **Export** → **Copy Interface View** (or **Ctrl+R**).



2. Open Word, PowerPoint, or any other software and paste (i.e. by clicking **Ctrl+V**).

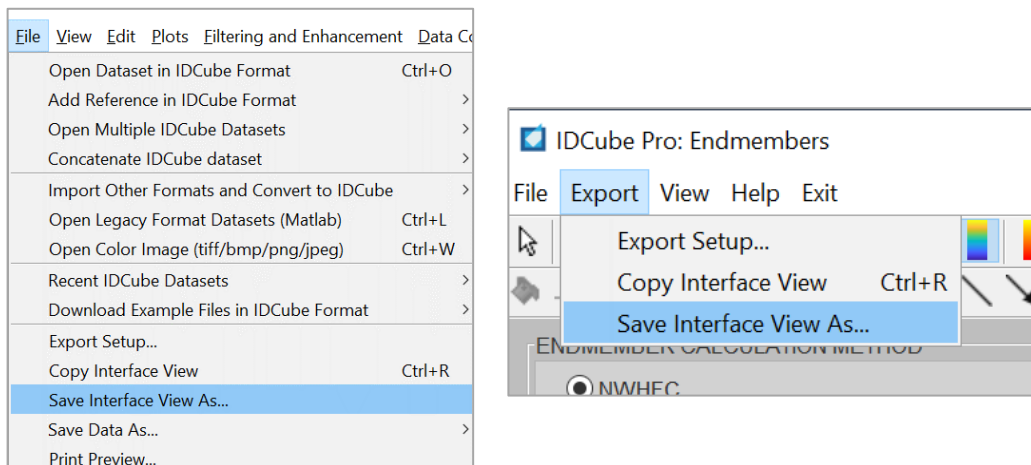
Save Interface View As...

NOTE: Common for the **Main Interface**, all toolboxes, and many pop-ups.

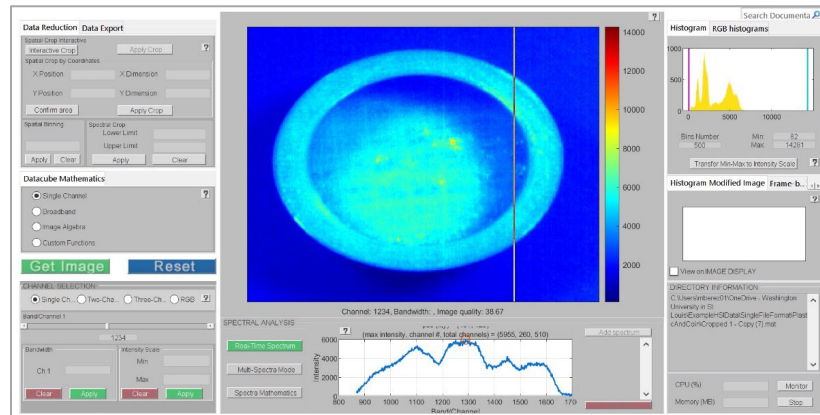
Feature: Enables the user to save the entire image of the IDCubePro® **Main interface** and toolboxes.

Steps:

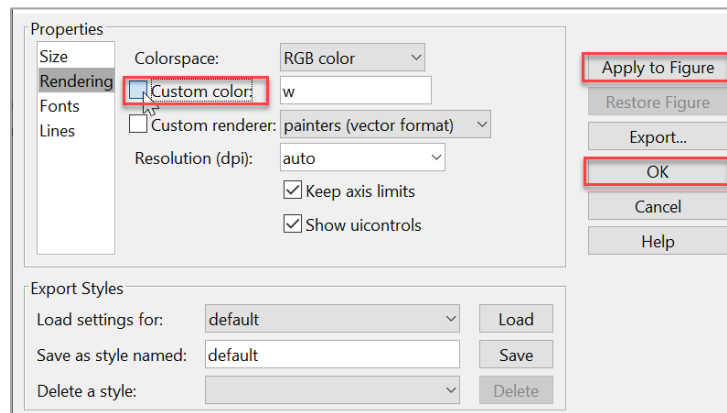
1. Open a file.
2. Select **File** → **Save Interface View As...** In the toolboxes, this function is located in the **Export** → **Save Interface View As...**



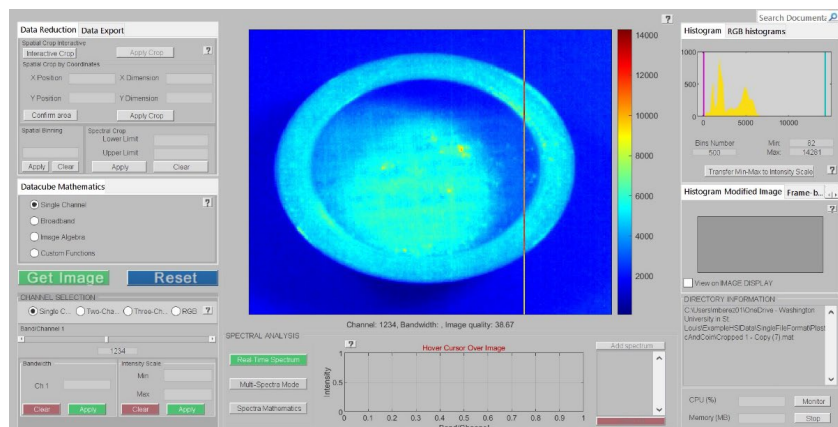
3. You will be asked to name the file and select the folder. By default, the folder will be the same as where the original file is located.



NOTE: The saved image might look different from the actual image. For example, you might see white fields around the panels. To remove this white background use **Export Setup**, select **Rendering** and uncheck the custom color (w stands for white).



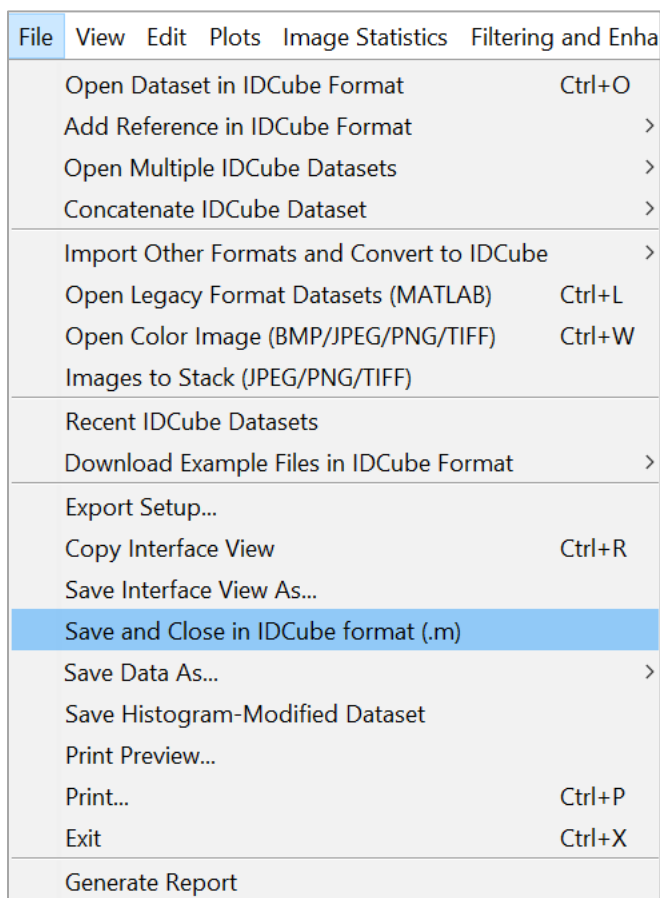
Click **Apply to Figure** and **OK** to close the **Export Setup** dialogue window. The white background will be replaced with the original gray.



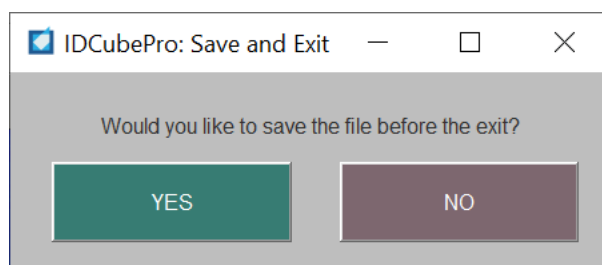
Save and Close in IDCube Format

Features: This function is used to prompt users whether they want to save the image before returning to the original view without exiting the application. The same function is available from the toolbar by

clicking the corresponding icon .

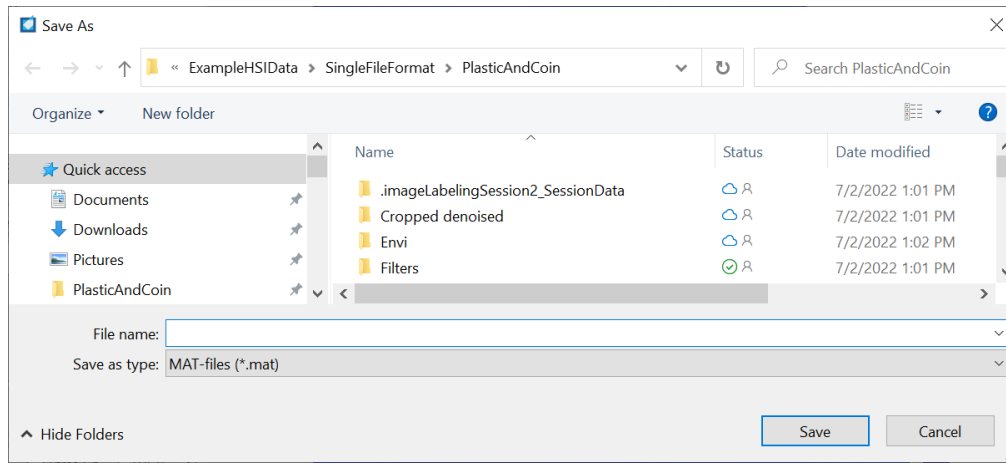


Call this feature by selecting **File** → **Save and Close in IDCube format (.m)** and choose a format. Once called, the function will open a new figure window, asking the user if they would like to save the file before exiting the application.

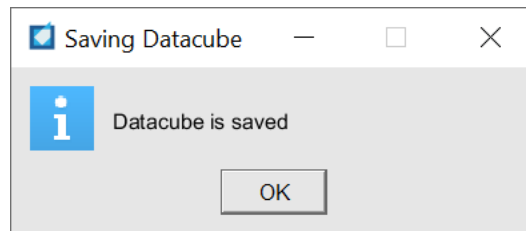


In the figure, there are two buttons: "YES" and "NO". The user should click on one of these buttons to proceed.

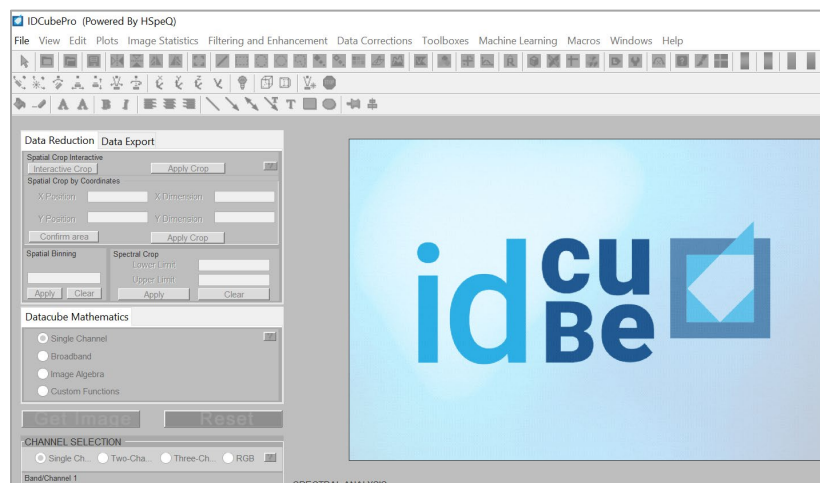
If the user clicks **"YES"**, the new datacube file will be saved in the IDCube format (.mat file) in the default directory and asks for the file name.



A waitbar will appear, displaying the progress of the saving operation. When the data has been saved, a message box appears informing the user that the data cube has been saved.



The function will then close the figure window and return to the original screen.



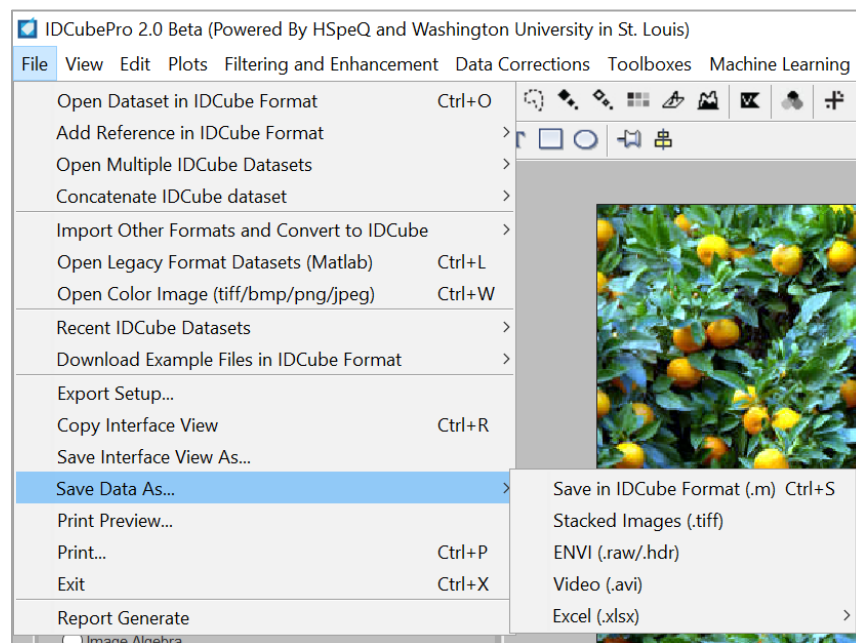
If the user clicks **"NO"**, instead of saving the data, it simply closes the window and displays a message box saying that the data cube has not been saved.

Save Data As...

Features: Enables the user to save and export the processed dataset into several formats including *tiff*, *raw/hdr*, *avi*, and *.xlsx* which are commonly used by a variety of data and image analyses.

Load the image file and select **File** → **Save Data As...** and choose a format. Available options are:

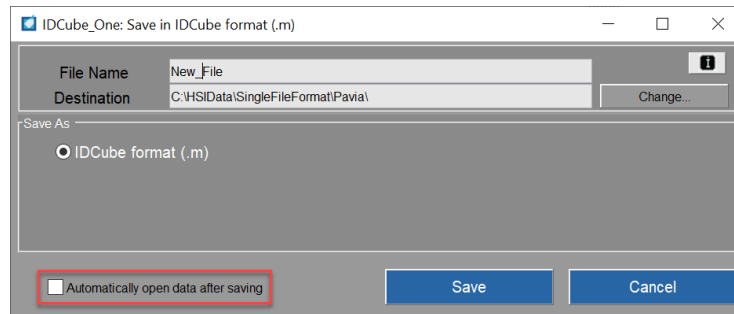
- Saving in the IDCube format
- Saving as a tiff stack of frames in a *tif/tiff* format
- Saving in an ENVI (*raw/hdr*) format
- Saving datacube into a video (*avi*) format
- Saving the entire datacube in an Excel (*xlsx*) format
- Saving the current frame in an Excel (4) format



Save in IDCube format (.m)

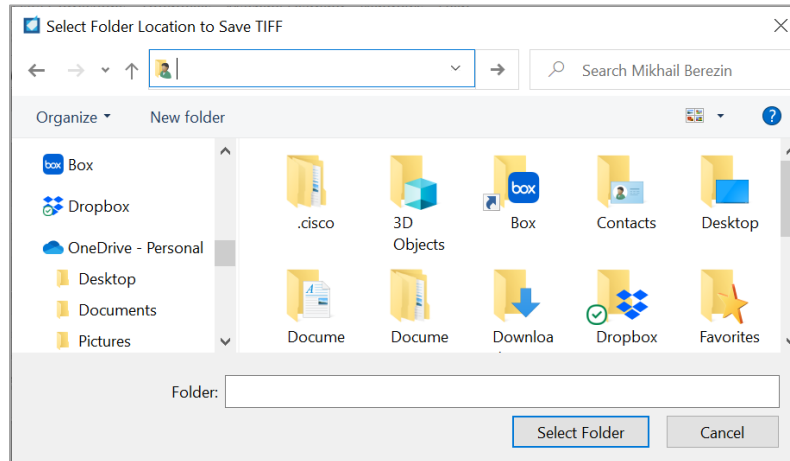
You can use this function to save the changes in the IDCube format. A pop-up window will ask for the name of the new file and the folder. By default, IDCubePro® uses the original folder for saving.

You can opt for automatic opening of the saved file by checking the **Automatically open data after saving** box.

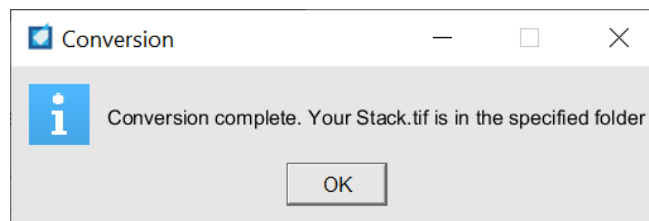


Save as a stack of frames in tif/tiff format

This option allows the user to save the entire dataset into a tiff stack of frame-by-frame tiffs. You will be asked to select a folder.



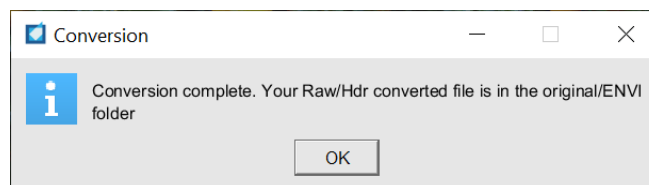
The stack of frames in a *tiff* format will be automatically saved in the selected directory.



Save in ENVI (raw/hdr) format

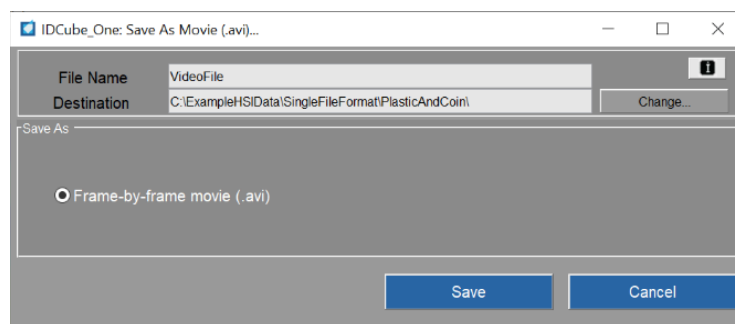
This option allows the user to save the entire dataset into one of the most common hyperspectral imaging formats used by ENVI Image Processing & Analysis Software and other companies.

Select **Raw/HDR** radio button and specify a folder from the pop-up window. Click **Convert**.

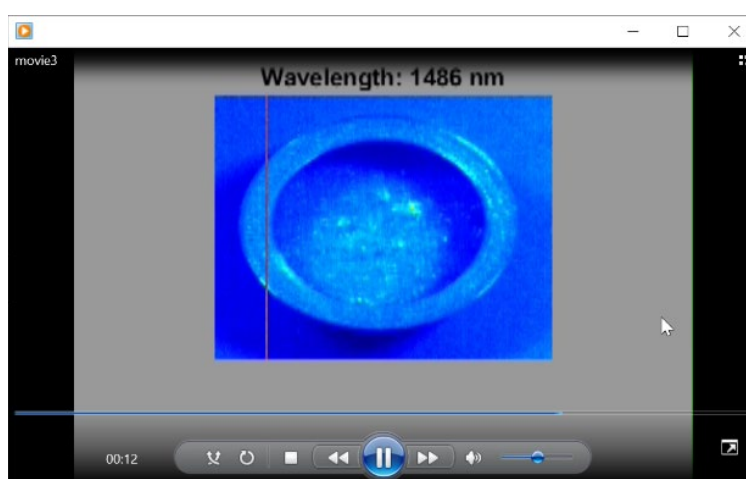


Save in a video (avi) format

You can use this function to generate a frame-by-frame movie. This function can also be combined with a **Single Channel** and **Two-Channel** option with selected equations. A new pop-up will ask for the name of the new file and the folder. By default, IDCube uses the original folder for saving.

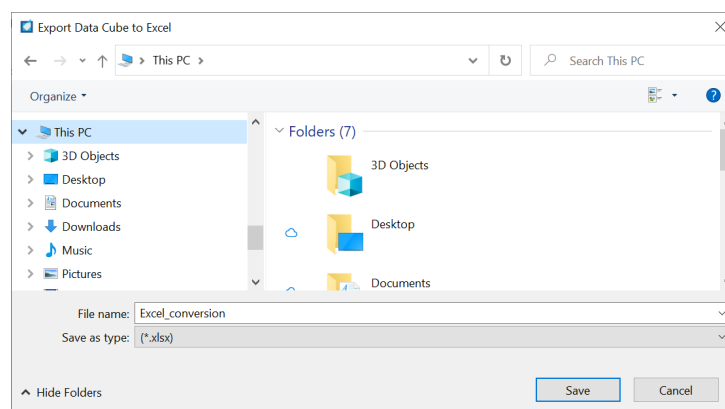


After the file is formed, it can be opened via a variety of programs that support the *avi* format.

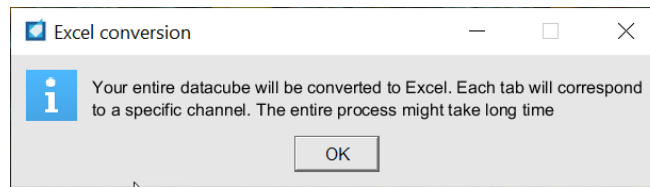


Convert the Entire Datacube into the Excel format

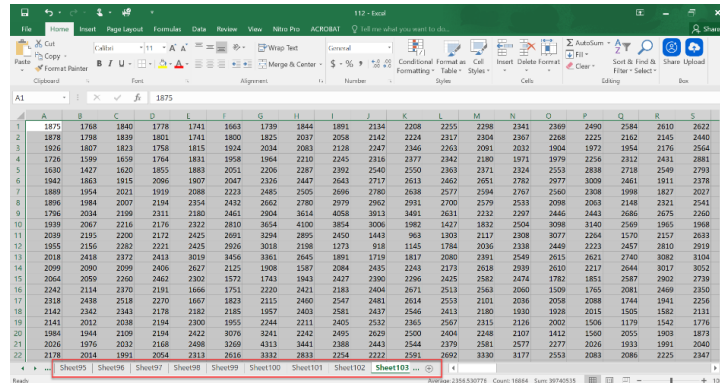
Click **Save As...** → **Excel** → **Entire Datacube** and put the name of the file. Click **Save**.



A pop-up message will warn that this operation might take time. A pop-up message box will inform when the conversion is complete.

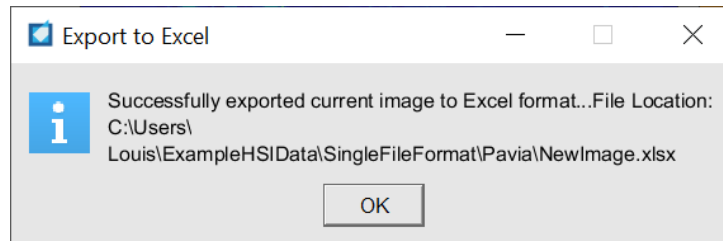


The number of tabs in the Excel spreadsheet is equivalent to the number of bands/channels. For example, if the file has 103 channels, there will be 103 tabs labeled 1-103. The assignment of the channels to wavelengths will be implemented in future versions of IDCube.

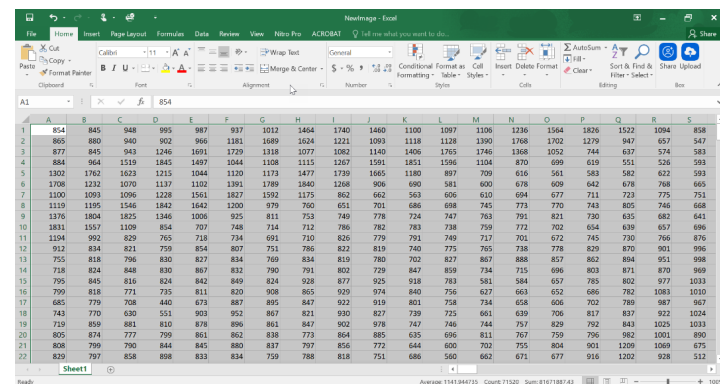


Save the Current Image into the Excel format

Click **Save As...** → **Excel** → **Current Image** and select the folder and the name of the file. Click **Save**. A pop-up message box will inform when the conversion is complete.



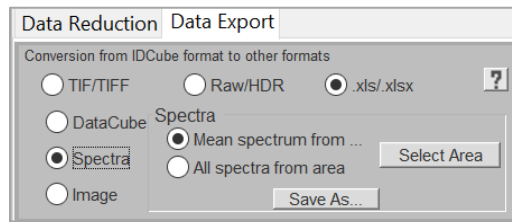
Open an Excel file. The rows and columns correspond to the spatial dimensions of the saved image.



Additional Information:

All saving functions, except the movie, can be also activated through the **Export Tab**.

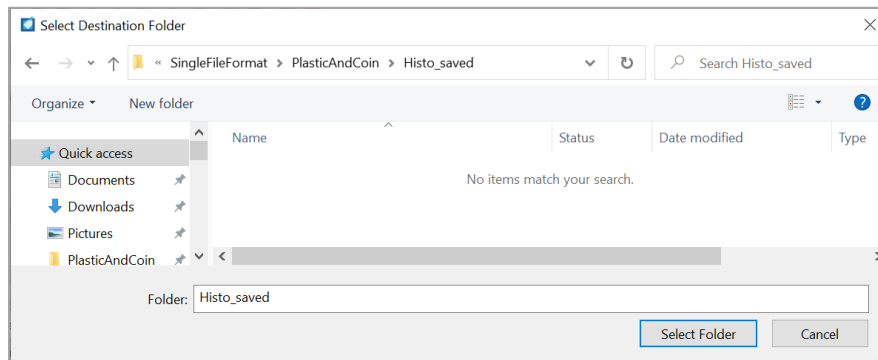
Additional saving functions (such as interactive **Mean spectrum from the area**, and **All Spectra from the area**) are available from the **Export Tab**.



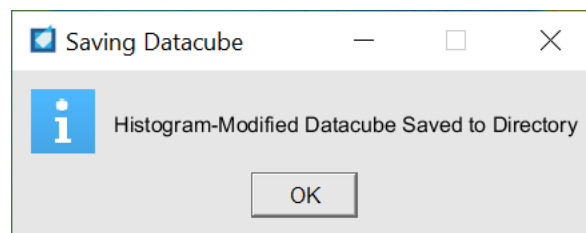
Save Histogram-Modified Dataset

Features: This function enables saving the entire dataset after adjusting monochromatic histogram in the HISTOGRAM panel. The intensity of pixels outside the boundaries defined by the HISTOGRAM panel will become equal to zero.

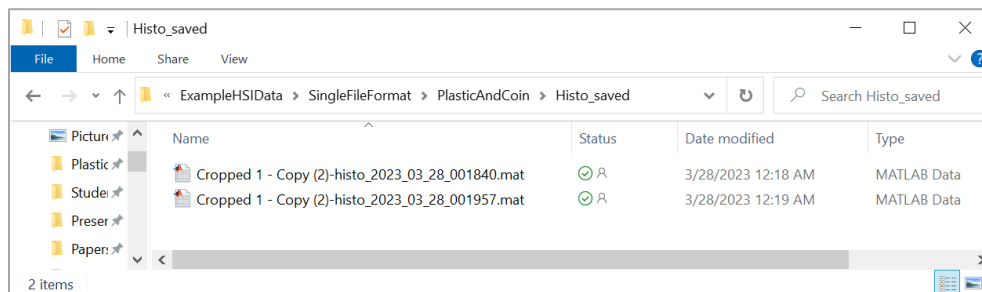
Steps: After adjustment the histogram select **File** → **Save Histogram-Modified Dataset** and select a destination folder. By default, the current folder will be opened. You can create a different folder. Press **Select Folder**.



A message box will pop-up to display a message indicating that the file is being saved.



The saved file will be named automatically. The original filename will be appended with a timestamp.



Print Preview and Print

NOTE: Plastic Bowl file is used as an example.

Features:

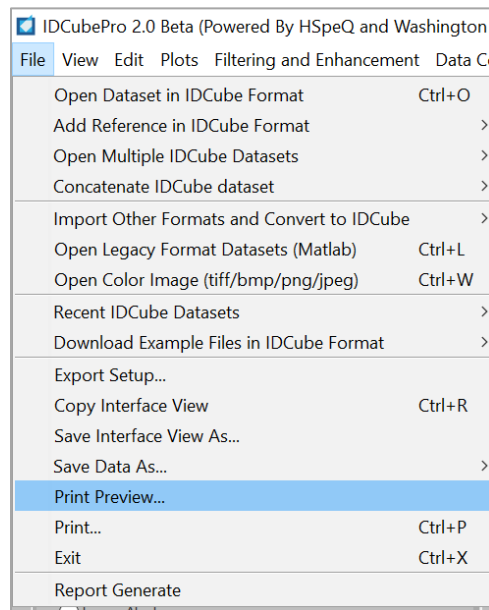
Enables the users to print a currently active figure window

Common for the Main Interface and all toolboxes

Steps:

We recommend adjusting the printing area by using Print Preview before printing.

1. Activate the window by clicking somewhere on the window. Select **File** → **Print Preview**

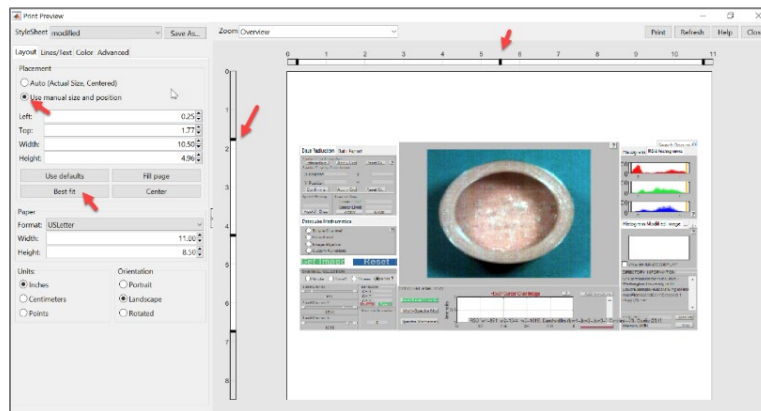


2. A **Print Preview** dialogue box will appear. This box controls the layout and appearance of figures before sending them to a printer or print file. A scaled version of the figure is displayed in the right-hand pane of the dialog box. Controls are grouped into four tabbed panels: LAYOUT, LINES/TEXT, COLOR, and ADVANCED.

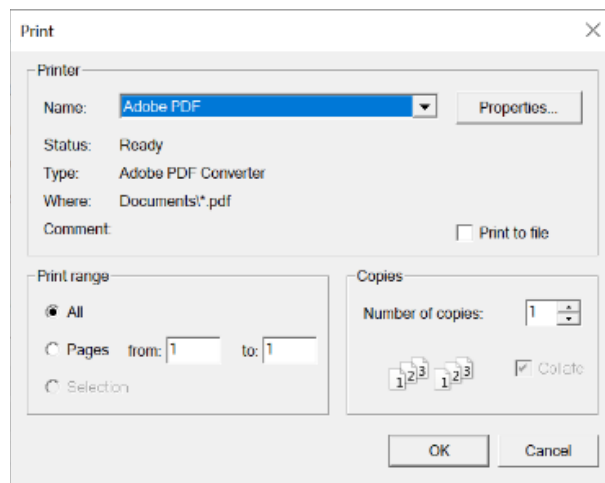
You can position and scale plots on the printed page using the rulers in the right-hand pane of the **Print Preview** dialog.

- Use the outer ruler handlebars (black boxes pointed by red arrows) to change margins. Moving them changes plot proportions.
- Use the center ruler handlebars to change the position of the plot on the page. Plot proportions do not change, but you can move portions of the plot.
- The buttons on that pane let you refresh the plot, close the dialog (preserving all current settings), print the page immediately, or obtain context-sensitive help.
- Use the **Zoom box** and scroll bars to view and position page elements more precisely.

Tip: To print the entire view of the window of interest (active window) select **Use manual size and position** the radio button and click **Best fit**.



3. Click **Print** and select printing preferences. (This function can be also activated from **File** → **Print** or **Ctrl+P**)



Layout

Use the LAYOUT tab, shown above, to control the paper format and placement of the plot on printed pages. The following table summarizes the Layout options:

| Group | Option | Description |
|-------------|--------------------------|---|
| Placement | Auto | Let IDCube decide the placement of the plot on the page. |
| | Use manual... | Specifies position parameters for a plot on the page. |
| | Top, Left, Width, Height | Standard position parameters in current units. |
| | Use defaults | Reverts to the default position. |
| | Fill page | Expands figure to fill printable area. |
| | Best fit | Expands figure to fill printable area, center the figure, and preserve the figure's aspect ratio. |
| Paper | Center | Centers plot on the printed page. |
| | Format | Allows U.S. and ISO® sheet size selector. |
| Units | Width, Height | Sets sheet size in current units. |
| | Inches | Uses inches as units for dimensions and positions. |
| | Centimeters | Uses centimeters as units for dimensions and positions. |
| Orientation | Points | Uses points as units for dimensions and positions. |
| | Portrait | Sets upright paper orientation. |
| | Landscape | Sets sideways paper orientation. |
| | Rotated | Currently the same as Landscape. |

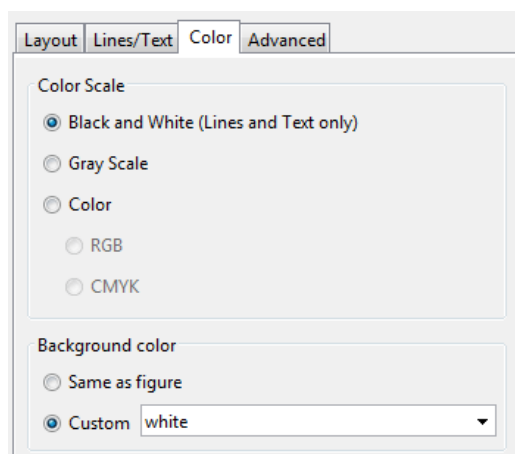
Lines/Text Tab

Use the LINES/TEXT tab, shown below, to control the line weights, font characteristics, and headers for printed pages. The following table summarizes the LINES/TEXT options:

| Group | Option | Description |
|--------|-------------|--|
| Lines | Line Width | Scales all lines by a percentage from 0 upward (100 being no change), print lines at a specified point size, or default line widths used on the plot. |
| | Min Width | Sets smallest line width (in points) to use when printing; defaults to 0.5 point. |
| Text | Font Name | Selects a system font for all text on the plot, or default to fonts currently used on the plot. |
| | Font Size | Scales all text by a percentage from 0 upward (100 being no change), print text at a specified point size, or default to this used on the plot. |
| | Font Weight | Selects Normal ... Bold font styling for all text from the drop-down menu or default to the font weights used on the plot. |
| | Font Angle | Selects Normal, Italic, or Oblique font styling for all text from the drop-down menu or default to the font angles used on the plot. |
| Header | Header Text | Allows typing the text to appear on the header at the upper left of printed pages, or leave it blank for no header. Header text only supports plain text characters. |
| | Date Style | Selects a date format to have today's date appear on each printed page, or none for no date. |

Color Selection Tab

Use the Color tab, shown below, to control how colors are printed for lines and backgrounds. The following table summarizes the Color options:



| Group | Option | Description |
|------------------|-----------------|---|
| Color Scale | Black and White | Select to print lines and text in black and white but use color for patches and other objects. |
| | Gray Scale | Convert colors to shades of gray on printed pages. |
| | Color | Print everything in color, matching colors on the plot; select RGB (default) or CMYK color model for printing. |
| Background Color | Same as figure | Print the figure's background color as it is. |
| | Custom | Select a color name or type a colorspec for the background; white (default) implies no background color, even on colored paper. |

Advanced Tab

Use the ADVANCED Tab, shown below, to control finer details of printing, such as limits and ticks, renderer, and resolution. The following table summarizes the ADVANCED options:

| Group | Option | Description |
|-----------------------|-------------------------------|---|
| Axes limits and ticks | Recomputes limits and ticks | Redraws x- and y-axes ticks and limits based on printed plot size (default). |
| | Keeps screen limits and ticks | Uses the x- and y-axes ticks and limits shown on the plot when printing the previewed figure. |
| Miscellaneous | Renderer | Selects a rendering algorithm for printing: painters, openGL, or auto (default). |
| | Resolution | Select resolution to print in dots per inch: 150, 300, 600, or auto (default), or type in any other positive value. |
| | Print UIControls | Not available in IDCube Pro. |

Alternatives: Use **File** → **Print Preview** on the figure window menu to access the Print Preview dialog box, described below. IDCube also offers additional controls such as Lines/Text, Color, and Advanced. Some functions and buttons might not be available for IDCubePro® users.

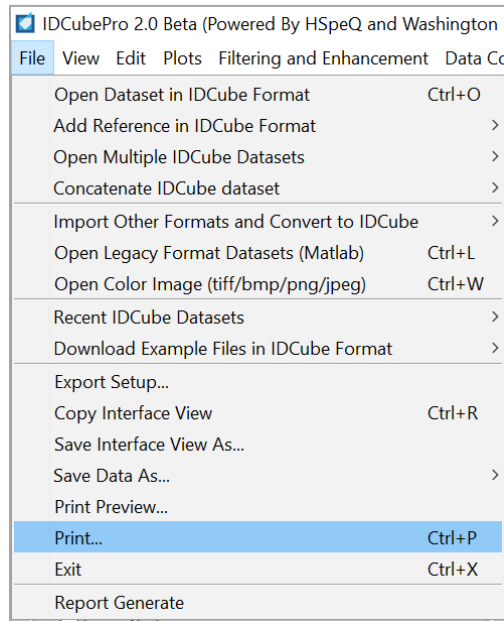
Print

NOTE: We highly recommend adjusting the printing parameters by using **Print Preview** first.

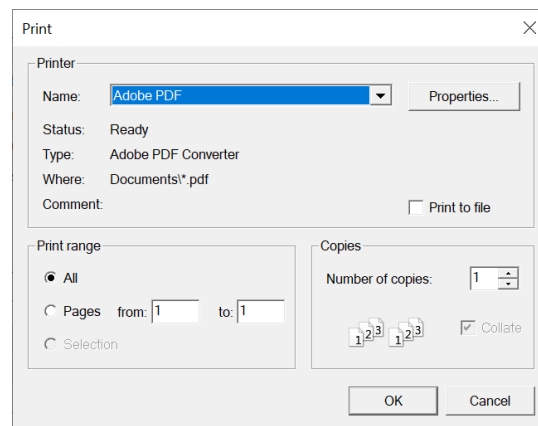
Features: Enables the users to print the currently active figure window. Common for the Main Interface and all toolboxes

Steps:

1. Select **File** → **Print** or press **Ctrl+P**



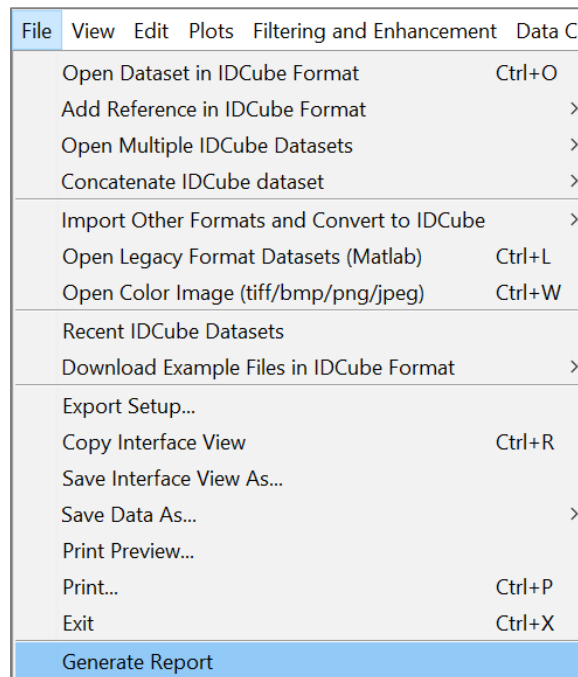
2. Select the printer and **press OK**



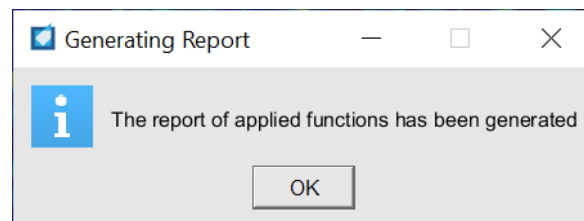
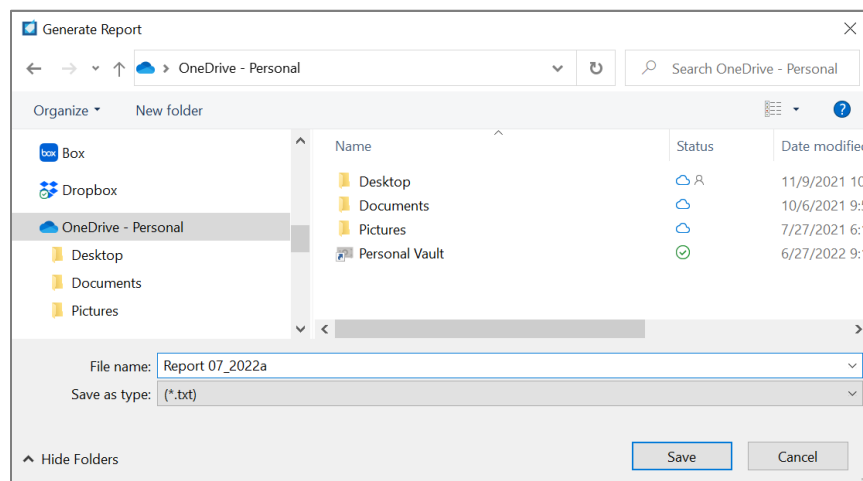
Generate Report

Feature: Reports are generated showing which functions were applied to the datacube. IDCubePro® stores many steps that were applied to the dataset.

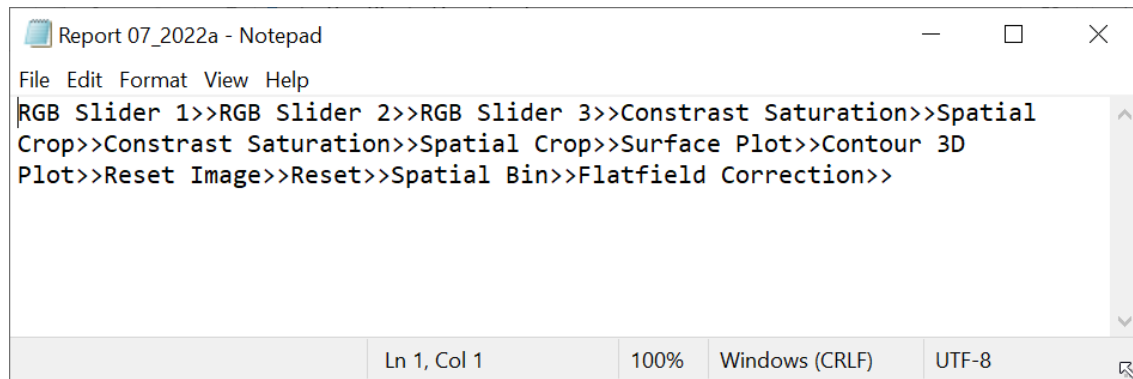
Select File → **Generate Report** to generate a list of functions that were applied to the dataset. This is usually done at the end of the image processing session.



Pressing **Generate Report** automatically activate a pop-up dialog window. Select the directory, enter the file name and click **Save**. The default directory is where the original dataset is located.



Open the saved file outside of IDCubePro®. The report lists all functions that were applied to the dataset.



7.2. Export Tab

NOTE: This tab is not available in the **Main Interface** window. The equivalent functions are located under the **File Tab**.

The functions implemented under the **Export Tab** enable changing the visualization of the interface, improving the visual appearance of the interface, and copying and saving the view of the interface. The functions also provide additional information regarding the dataset.

| Tabs | Function | Additional info |
|----------|------------------------------|--|
| View Tab | Export Setup | See description in File Tab – Export Setup section |
| | Copy Interface View (Ctrl+R) | See description in File Tab – Copy Interface View section |
| | Save Interface View As... | See description in File Tab – Save Interface View As... section |

7.3. View Tab

The functions implemented under the **View Tab** provide changes to the visual appearance of the entire IDCubePro® package with all connected toolboxes, add/remove toolbars, and improve the visual appearance of the image on the **Image Display**. The functions also provide additional information regarding the dataset.

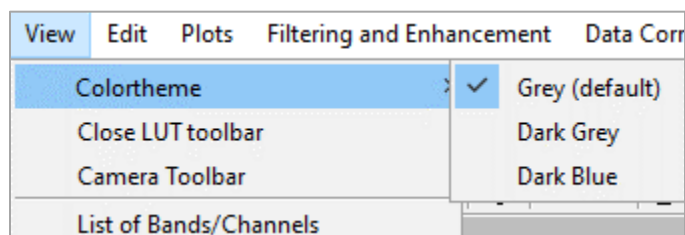
| View | Edit | Plots | Image Statistics | File |
|-------------------------|------|-------|------------------|--------|
| Colortheme | | | | > |
| Close LUT Toolbar | | | | |
| LUT Generator | | | | |
| Close Camera Toolbar | | | | |
| View All Frames | | | | |
| List of Bands/Channels | | | | |
| Image Scale | | | | Ctrl+G |
| Expanded View | | | | Ctrl+N |
| View Header Information | | | | |
| View Image Information | | | | Ctrl+I |
| View Image HeatMap | | | | |
| Edit Plot | | | | Ctrl+E |
| Turn Instructions Off | | | | |

| Tabs | Function | Additional info |
|----------|---|--|
| View Tab | Changing the Colortheme of The Software | Additional menu |
| | Close/Open Color LUT toolbar | Toggles the appearance of the colortheme |
| | Camera Toolbar | Enables Camera toolbar |
| | LUT Generator | Opens an interactive LUT generator |
| | View All Frames | Visualizes all frames in a 2D format |
| | List of Bands/Channels | A pop-up window shows all bands in the dataset |
| | Image Scale | Adds scale to the image |
| | Expanded View | Expands the image in X-dimension |
| | View Header Information | Pop-up window open the header information |
| | View Image Information | Pop-up window shows the current image information |
| | View Image HeatMap | Visualizes the image with in a HeatMap view (opens as a separate window) |
| | Edit Plot | Interactive changes in the layout |
| | Turn Instructions Off (toggle) | Prevents pop-up notification and suggestions |

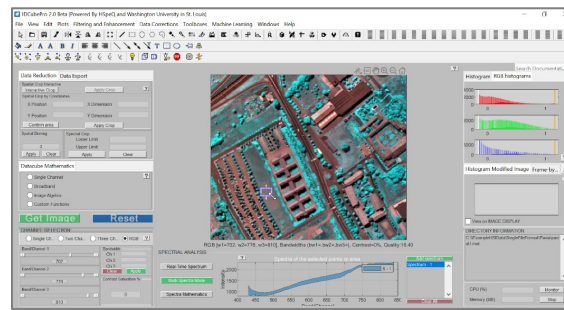
Changing the Colortheme of the Interface

Features: Enables the users to change the color of the interface work in three different colorthemes.

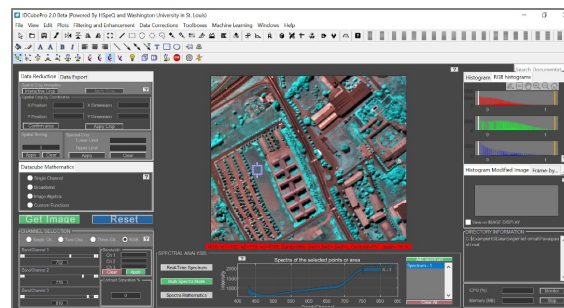
Select **View** → **Colortheme** and select one of the following options: Gray (default), Dark Grey, Dark Blue. All toolboxes will also follow the selection and will have the selected colortheme.



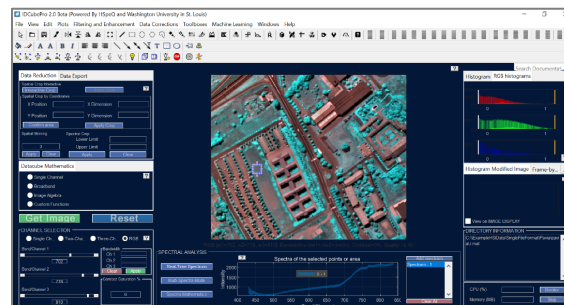
Gray (default):



Dark Gray:



Dark Blue:



LUT generator

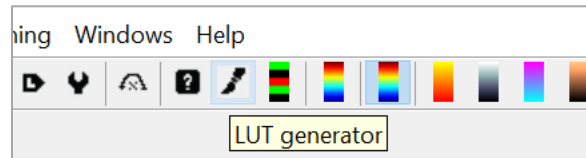
NOTE: Plastic and Coin dataset (cropped) is used as an example.

Features: The LUT generator GUI allows you to create and customize a color Lookup Table (LUT) using a graphical user interface.

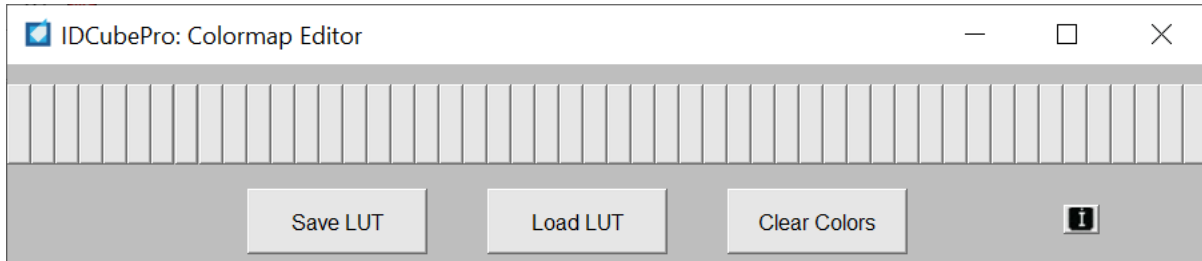
The LUT generator GUI provides an intuitive interface for creating and customizing a color Lookup Table. By following the steps outlined in this manual, you can select colors, create gradients, save and load LUTs, and clear the color selections. Experiment with different color combinations and gradients to generate the desired LUT for your application.

Steps to Use the LUT Generator GUI:

Step 1: Launch the GUI



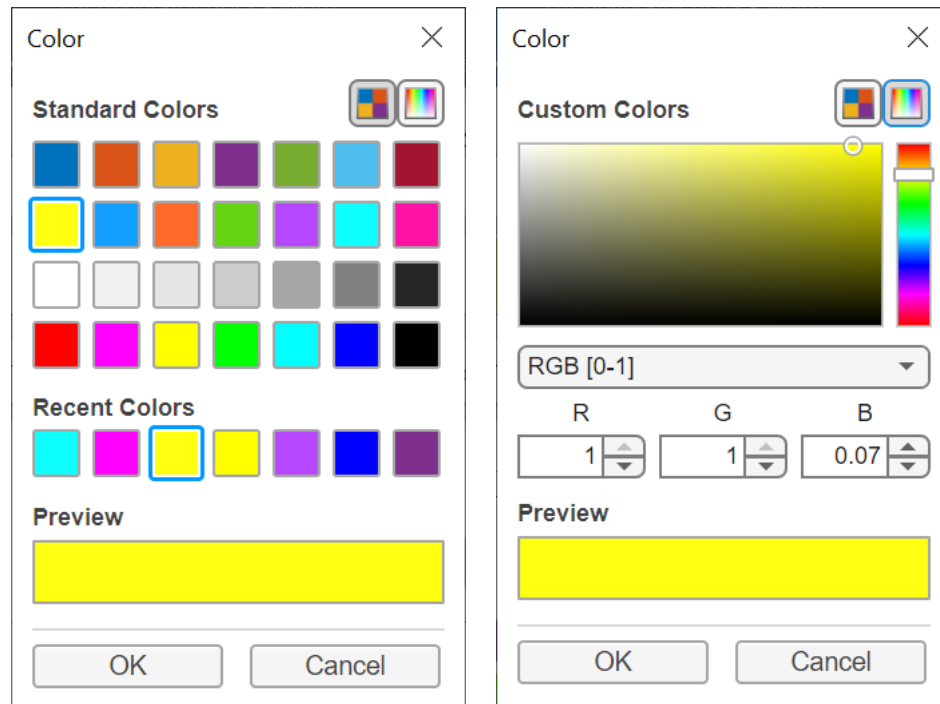
To launch the LUT generator GUI, press the brush icon or select **View** → **Colormap Editor**. The GUI window titled "IDCubePro: Colormap Editor" will appear.



Step 2: Select Colors

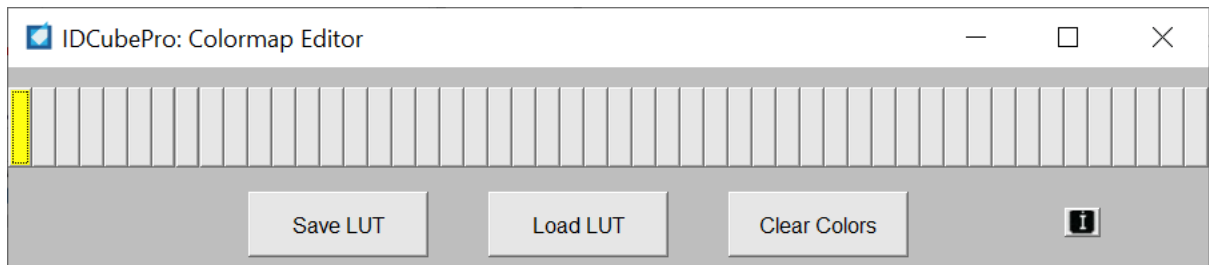
The GUI window displays 50 color strips as push buttons. Each button represents a color in the LUT. Follow these steps to select and customize colors:

1. Click on a color strip button, for example the first box on the left to open the **Color Picker** dialog. (Color Picker allows many ways to select the color)



In the color picker dialog, choose your desired color and click "OK."

2. The selected color will be applied to the corresponding color strip button.

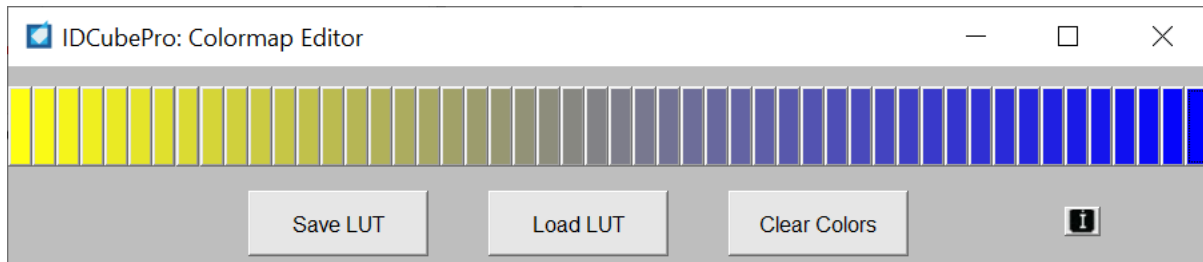


3. Repeat steps 1-3 to customize other color strips as needed manually.

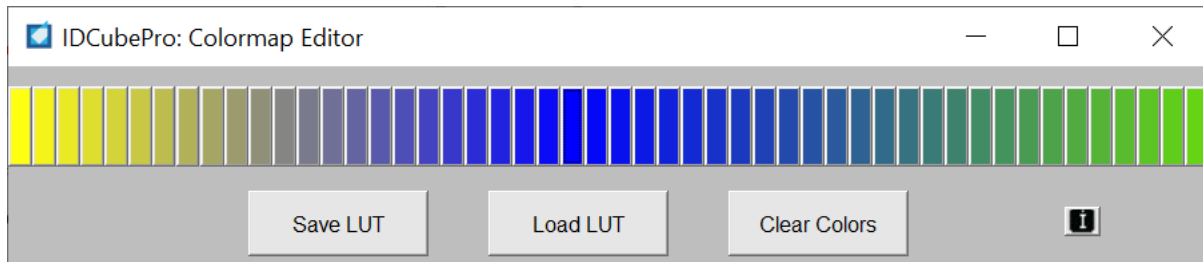
Step 3: Create Gradients

To create a gradient between two selected color strips:

1. Click on the first color strip button.
2. While holding the Shift key, click on the second color strip button.
3. The color strips between the selected strips will now form a gradient. The gradient is automatically calculated and displayed. In this example, the first button was assigned to yellow and the last button to blue colors.



4. You can generate more complex multicolor gradients by assigning colors to different buttons. In this example, the first button is yellow, the middle button is blue, and the last button is green.



Step 4: Save and Load LUT

You can save and load the created LUT using the provided buttons:

1. Click the "**Save LUT**" button to save the current LUT.
 - Choose a file name and location to save the LUT as a .mat file. In this example we save the multigradient LUT as New_Lut.mat
2. Click the "**Load LUT**" button to load a previously saved LUT.
 - Choose the saved .mat file to load the LUT into the GUI.

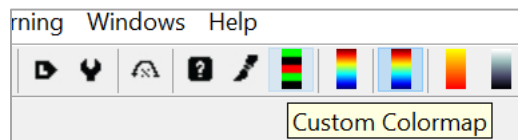
Step 5: Clear Colors

To clear all the colors and reset the LUT:

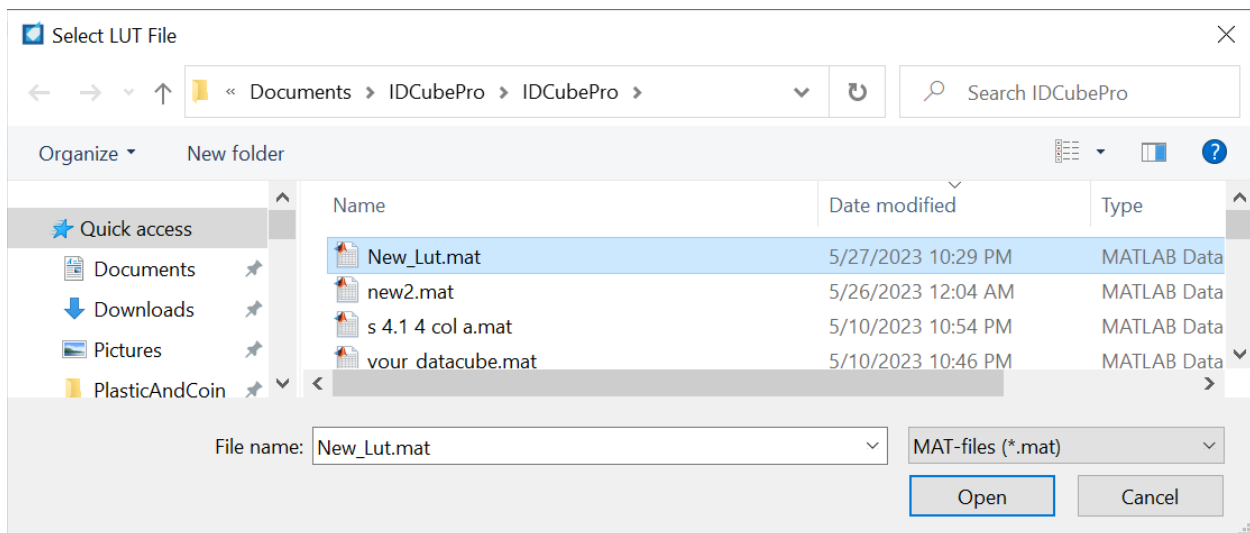
1. Click the "**Clear Colors**" button.
 - All color strips will be set to their default color.
 - The LUT will be reset to its initial state.

Step 6. Applying a new colormap

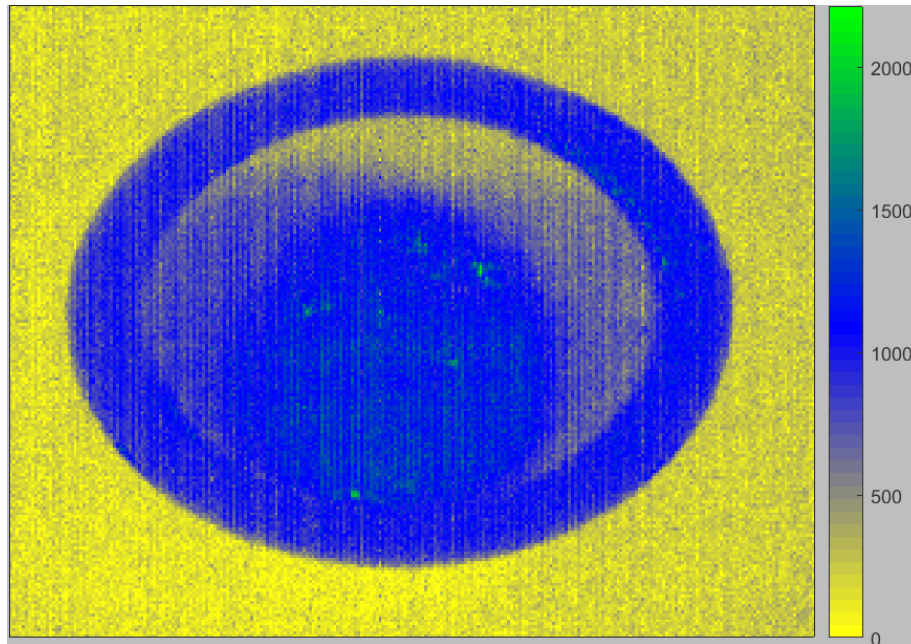
You can call the saved custom colormap by selecting **Custom Colormap** icon that at the start looks like the o .



That opens a dialogue where you can open a saved LUT. Select the file and click **OPEN**.



The new LUT will be automatically applied to the image.

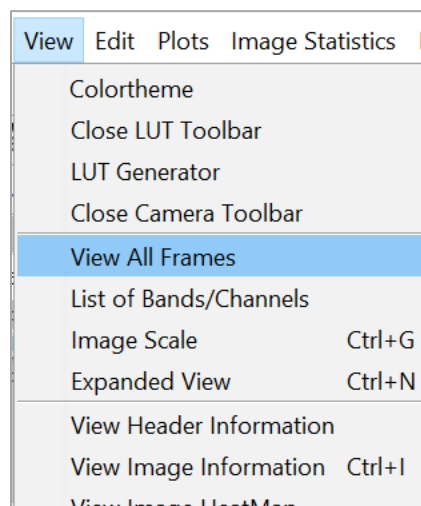


View All Frames

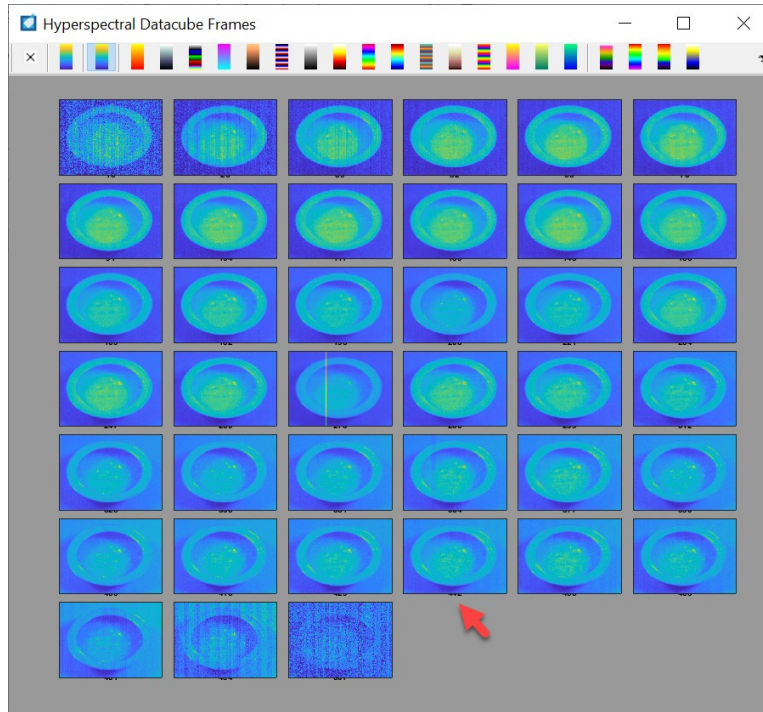
Features: The function is designed to visualize hyperspectral datacube images all at the same time as thumbnails.


The function processes a hyperspectral datacube, applies spatial (currently not implemented) and spectral binning (combining neighboring wavelength bands to reduce the number of frames), and visualizes all resulting images in a grid format. Each image corresponds to a different wavelength band of the data cube. Furthermore, the function provides an option to enlarge individual images upon clicking them.

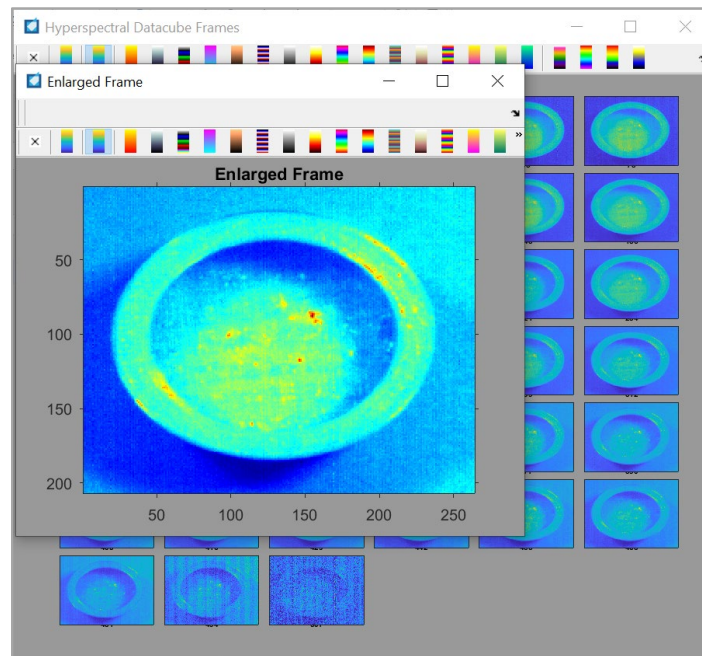
1. Select **View** → **Colortheme**. The function retrieves all necessary color data from the preset function.



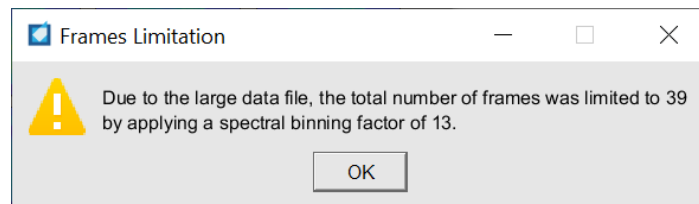
2. **Binning:** The function then performs spatial (not implemented) and spectral binning on the data cube to reduce its size. It ensures that the number of binned wavelengths doesn't exceed 40.
3. **Presenting frames:** A grid of subplots is created to display the images from the binned data cube. The number of rows and columns in the grid is determined based on the number of binned wavelengths.



4. **Interactivity:** Each image from the binned data cube is displayed on a subplot. Each subplot title is clickable (shown by a red arrow) and opens an enlarged version of the image when clicked. Enlarged image can be interactively processed through the **toolstrip bar** .



5. If the number of binned wavelengths is less than the original number of wavelengths in the data cube, a warning message is displayed to the user about the limitation of the number of frames. The user is also informed that they can click on the subplots to enlarge the images.



Notes:

- The function was designed to handle large hyperspectral data cubes. However, due to the size of such data cubes, the visualization might take some time.
- If the number of wavelengths in your datacube is very large (more than 40), the function will limit the number of displayed frames by binning the wavelengths. A warning message will inform you about this.

List of Bands/Channels

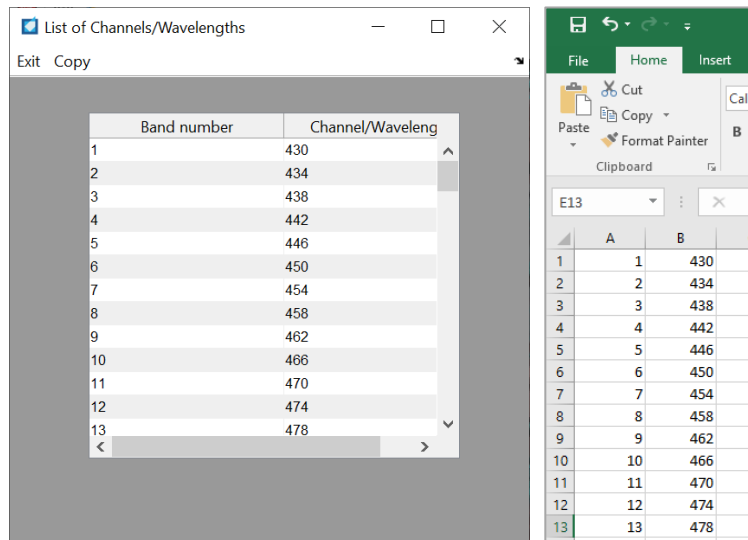
NOTE: PAVIA dataset is used as an example

Features: Enables viewing a list of bands and channels in the dataset.

IDCube uses the following notation: bands are assigned the order number (1, 2, 3, etc.), while the channels have units (i.e., wavelengths, 430, 434, 438, etc.) as illustrated in the screenshot below.

Steps:

1. Open a hyperspectral imaging file through the **Main interface: File → Open dataset in IDCube format.**
2. Click **View → List of bands/channels.**



3. **Copy** the list of the bands with the corresponding channels to Excel or another software.
 - a. By clicking on the Copy menu option.
 - b. By highlighting the desired data and right-clicking.
 - c. By highlighting the desired data and using **Ctrl+C**.

Image Scale

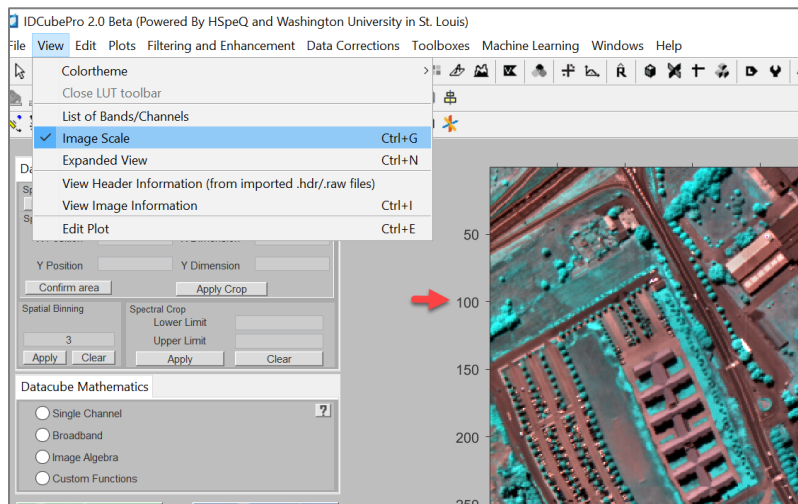
NOTE: The default image does not show a scale. The addition of the scale to the image is temporary.

Features: Enables the users to see the scale in pixels. The same effect can be achieved by using a hotkey: a spacebar on the keyboard.

Steps:

Select **View → Image Scale (Ctrl+G)** to visualize the scale. Move any of the sliders or engage any of the functions to remove the Image Scale.

Or click on the **Image Display** and press the spacebar to activate scale (See **Keyboard and Mouse Shortcuts**).



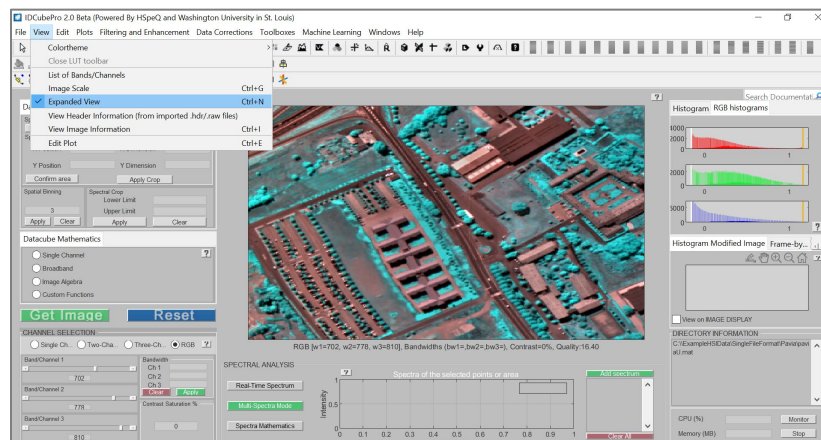
Expanded View

NOTE: Enables temporary expansion of the image over the entire IMAGE DISPLAY panel.

Features: Enables the users to automatically adjust the image to the entire view. The same effect can be achieved by using hot keys: **n** – expanded view, **e** – normal view (default) from the keyboard.

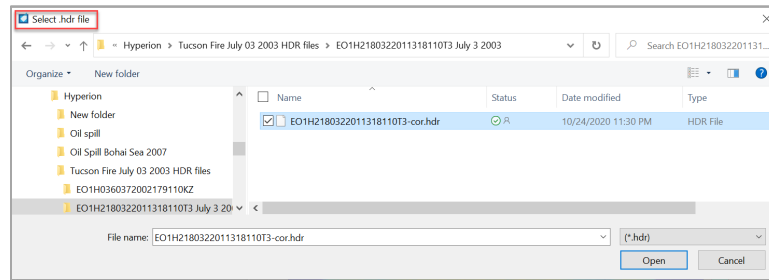
Steps:

1. Select **View** → **Expanded View** (Ctrl+N) to visualize the image over the entire IMAGE DISPLAY panel.



View Header Information

Features: Extracts header information from a limited number of formats. Currently, only *hdr* files from the ENVI format are fully supported.



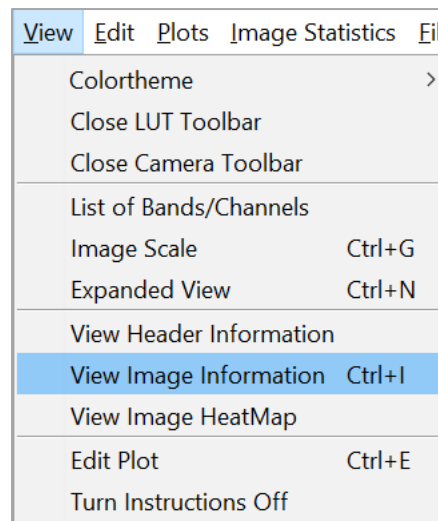
View Image Information

NOTE: IMAGE INFORMATION panel only shows the information of the visualized frame. The panel also pops up after changes to the spatial coordinates (i.e., cropping, binning).

Features: Enables the users to view basic information about the entire dataset.

Steps:

1. Open a file.
2. Select **View** → **Image Information** or use a hot key (**Ctrl+I**).



3. Visualize the information about the image. The IMAGE INFO panel includes the width (x-dimension) and height (Y-dimension) of the image, class of data (single, double), image type (intensity for monochromatic, and truecolor for RGB), the minimum and maximum intensity of the currently shown image, the number of bands (z-axes), and the size of the file calculated as

$$Size = [(columns \times rows \times bands) \times 8] / (1000^2), MB$$

| Image Info (IDCubePro (Powered By HSpeQ)) | |
|---|-----------|
| Attribute | Value |
| Width (columns) | 264 |
| Height (rows) | 207 |
| Class | double |
| Image type | intensity |
| Minimum intensity | 74 |
| Maximum intensity | 8635 |
| Number of bands | 510 |
| Datacube size, MB | 26.5794 |

| Image Info (IDCubePro (Powered By HSpeQ)) | |
|---|-----------|
| Attribute | Value |
| Width (columns) | 264 |
| Height (rows) | 207 |
| Class | double |
| Image type | truecolor |
| Number of bands | 510 |
| Datacube size, MB | 26.5794 |

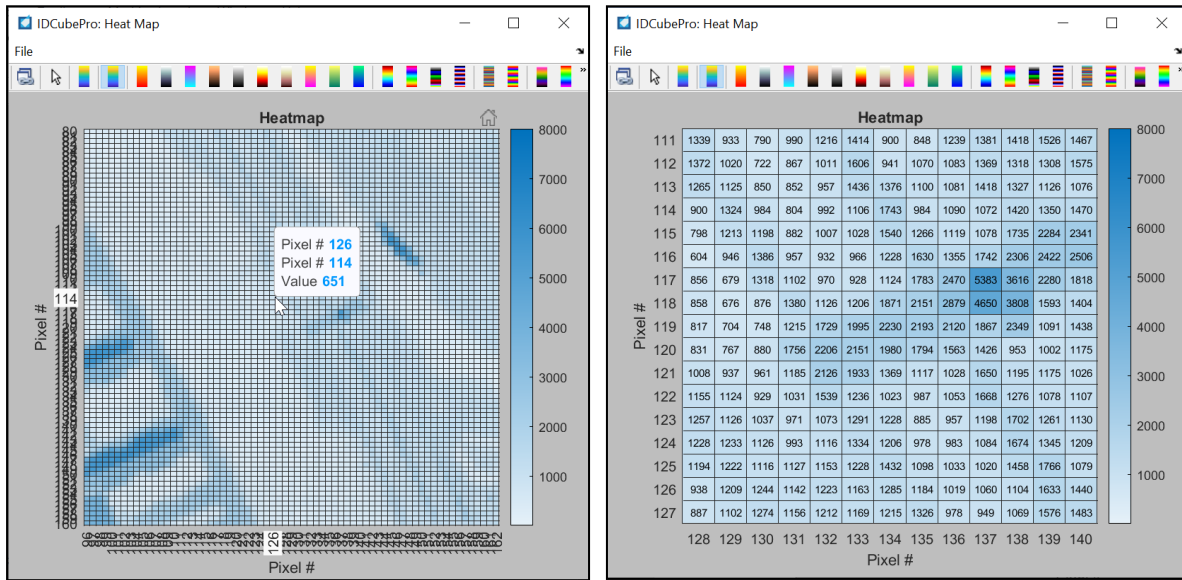
NOTE: The size of the file is determined based on MATLAB's conventions. This calculated size may differ from the actual displayed size. This discrepancy can occur due to the difference in storage units used, overhead from the file system, and the file compression methods used by the operating system. For instance, a file named 'Pavia' has an image size of 610x340x103 in the double class, which translates to 170897600 bytes or approximately 170.8976 MB. However, when you look at the size of this file in the File Explorer, it shows as only 48.990 MB.

View Image HeatMap

Features: This feature visualizes the image as a Heatmap that allows the user to visualize the values of individual pixels after the zoom.

| View | Edit | Plots | Image Statistics | File |
|-------------------------|------|-------|------------------|--------|
| Colortheme | | | | > |
| Close LUT Toolbar | | | | |
| Close Camera Toolbar | | | | |
| List of Bands/Channels | | | | |
| Image Scale | | | | Ctrl+G |
| Expanded View | | | | Ctrl+N |
| View Header Information | | | | |
| View Image Information | | | | Ctrl+I |
| View Image HeatMap | | | | |
| Edit Plot | | | | Ctrl+E |
| Turn Instructions Off | | | | |

A new window Heat Map will be activated. Zoom on the window to visualize values of individual pixels.



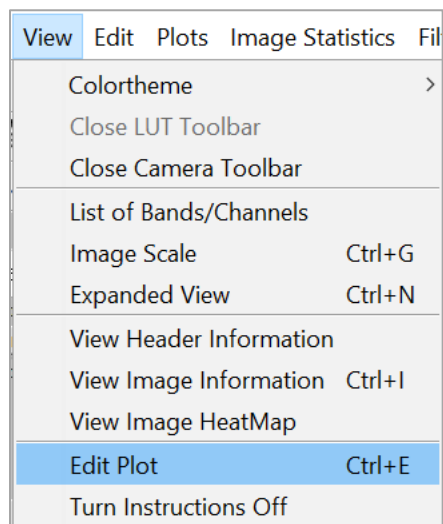
Tips


To interactively explore the data in your heatmap, use these options:


- *Zoom* — Use the scroll wheel of the mouse or the + and - keys to zoom.
- *Pan* — Click and drag the heatmap or use the arrow keys to pan across the rows or columns.
- *Data tips* — Hover over the heatmap to display a data tip.
- *Rearrange rows and columns* — Click and drag a row or column label to move it to a different position.
- *Sort values* — Click the icon that appears when you hover over the row or column label. Click once to sort the values in ascending order, twice to sort the values in descending order, and a third time to reset the order.

NOTE: The changes made with this feature will not affect your original data or the data used in the **Main** interface.

Edit Plot

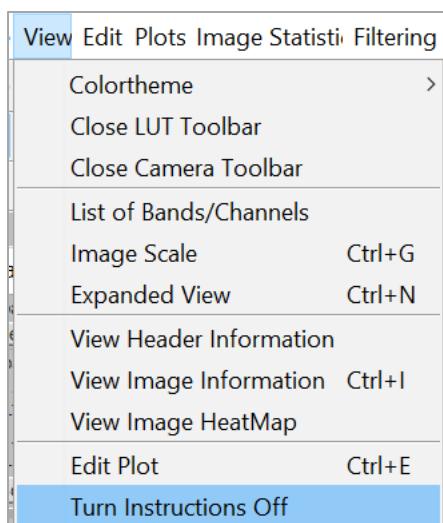


This action will activate the **Edit Plot** mode that can be also activated by pressing **Ctrl+E**. In this mode you can move most of the objects including buttons and frames. This function is equivalent to pressing the button . After activation the button will turn blue.

Exit the **Edit Plot** mode by clicking the button  located in the **Main Toolbar**. **NOTE:** the changes made in the **Edit Plot** mode can be undone using **Ctrl+Z**. See more about **Edit Plot** mode in the dedicated section.

Turn Instructions Off

Features: Many toolboxes provide brief instructions in the form of pop-up message boxes. This function enables the users to turn Instructions off.



7.4. Edit tab

Functions implemented in the **Edit Tab** allow you to modify your dataset. All changes are global, which means the changes are saved internally and replace the original dataset during the computation session. However, no changes are applied to the original data stored in your folder. Your original data will not be affected.


| Tabs | Function | Additional info |
|----------|---------------------------------|----------------------------|
| Edit tab | Rotate and Flip | Additional menu |
| | Spatial Crop | Additional menu |
| | Bin (spatial and spectral) | Additional menu |
| | Compression | |
| | Spectral Crop | Dialogue window |
| | Change Bands | Replaces with new bands |
| | Remove Bands | Pop-up window |
| | Remove Bad Pixels | Pop-up window |
| | Annotations (textboxes, arrows) | Additional menu |
| | Edit Plot Mode | Activates interactive plot |

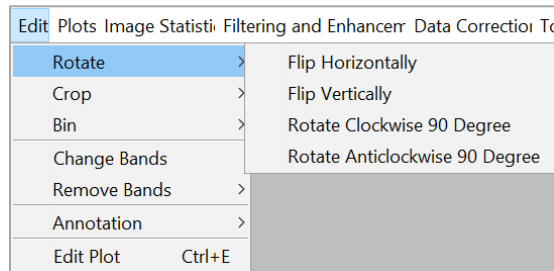
Rotate and Flip

NOTE: PAVIA dataset is used as an example.

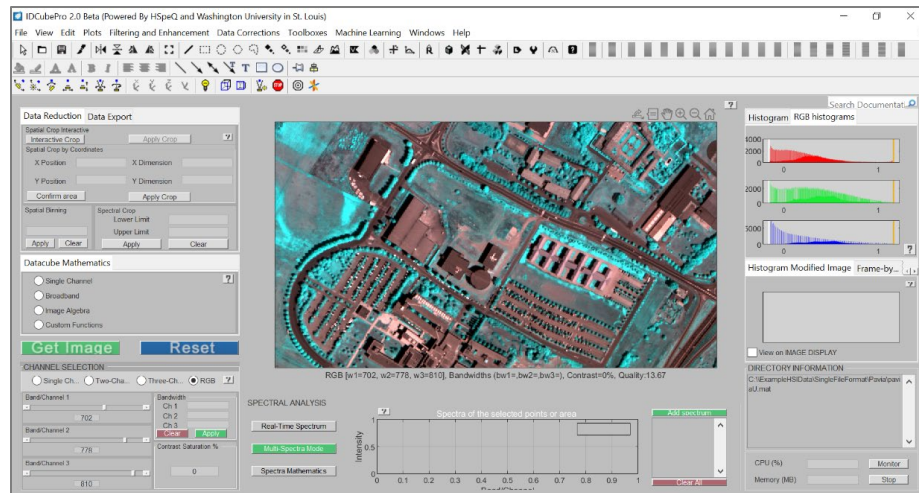
Features: Enables rotation of the entire dataset.

Steps:

1. Open a hyperspectral imaging file such as PAVIA through **File → Open Dataset in IDCube format**.
2. Click **Edit, Rotate** and select one of the rotation options or select the icons: 
 - a. Flip Horizontally
 - b. Flip Vertically
 - c. Rotate Clockwise 90 Degree
 - d. Rotate Anticlockwise 90 Degree.



Example: Rotate Clockwise 90 Degree:



Click **Reset** to return to the original view. **NOTE:** this will reset the entire image including a crop or filter.

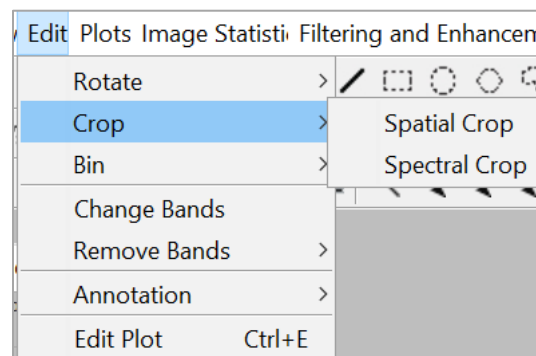
Spatial Crop


NOTE: PAVIA dataset is used as an example.

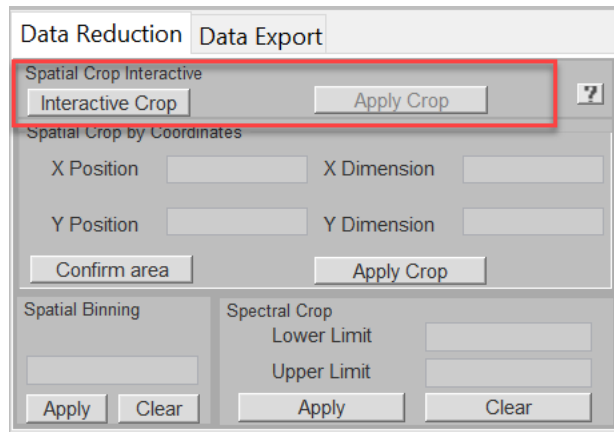
Features: Enables spatial cropping of the entire dataset.

Steps:

1. Open a hyperspectral imaging file through the **Main Interface**.
2. Click **Edit** → **Crop** and select one of the cropping options or select of the icons:

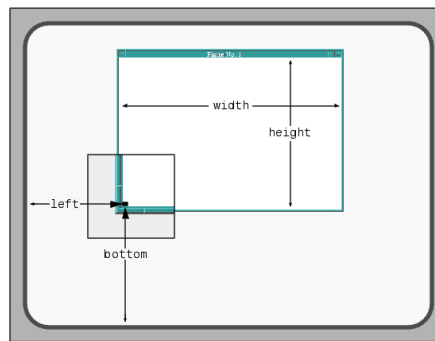


3. Click **Spatial crop** (also can be triggered by using an icon ).
4. Alternatively, click **Interactive crop** in the DATA REDUCTION panel.

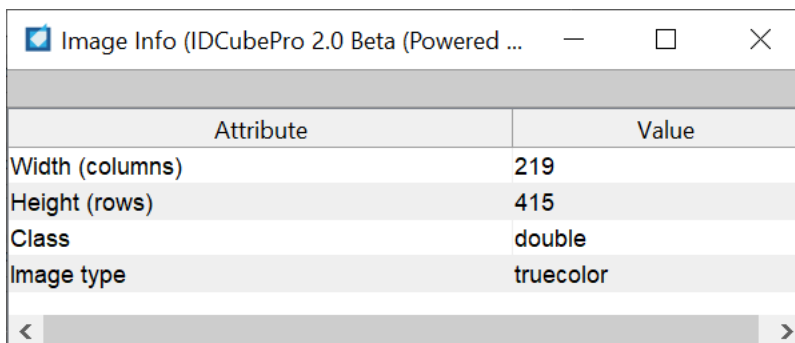


5. Move the boundaries of the active frame.

NOTE: Spatial crop activates an interactive rectangular (active frame) that enables the user to select the region of interest and crop the rest of the image. Move the boundaries of the active frame with the mouse. The coordinates of the frame in a format *[left bottom width height]* can be seen below the image. The meaning of the coordinates is shown below. The units are pixels. When the active frame size is adjusted, IDCube automatically updates the coordinates to the new values.



6. Click **Apply Crop**. The change will be applied globally and a new datacube will be stored in the internal memory. A new pop-up window with the information about the new dataset will appear in the left corner showing the dimension of the new frame, type of data, color, and maximum and minimum. In the case of the RGB, the maximum and minimum will not be shown.



| Attribute | Value |
|-----------------|-----------|
| Width (columns) | 219 |
| Height (rows) | 415 |
| Class | double |
| Image type | truecolor |

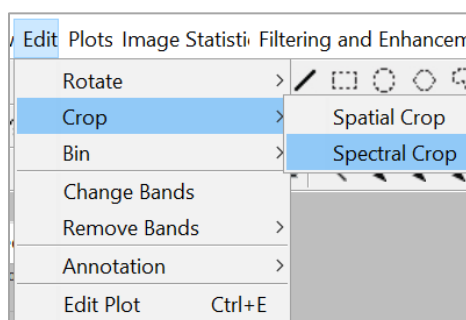
- Click **Reset** to return to the original view. **NOTE:** this will reset the entire image back to the original including any filters or histogram adjustments.
- The new dataset can be saved using a standard **Save** function.

Spectral Crop

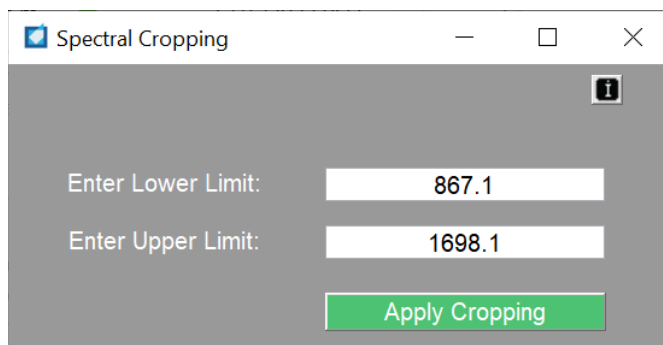
Features: Enables spectral (z-dimension) cropping of the entire dataset.

Steps:

- Open a hyperspectral imaging file through the **Main interface (File → Open)**.
- Click **Edit → Crop → Spectral Crop**.



A new window pops up. Enter the value for the lowest spectral limit and the upper spectral limit:

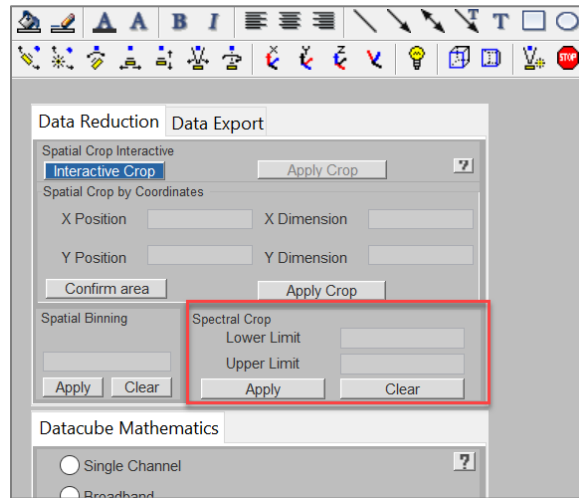


Enter Lower Limit: 867.1

Enter Upper Limit: 1698.1

Apply Cropping

Click **OK**. The new datacube will be spectrally cropped. The original data will not be affected. Alternatively, this can be done from the DATA REDUCTION panel on the **Main interface**:



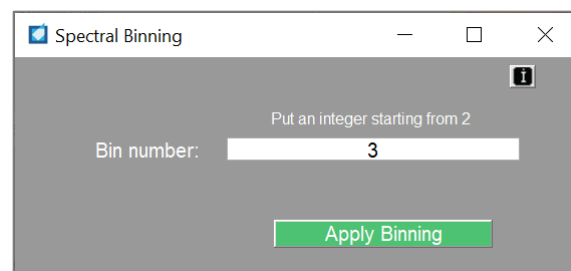
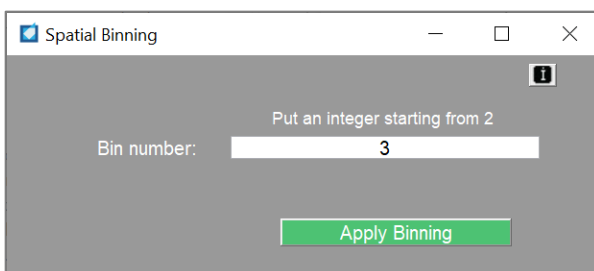
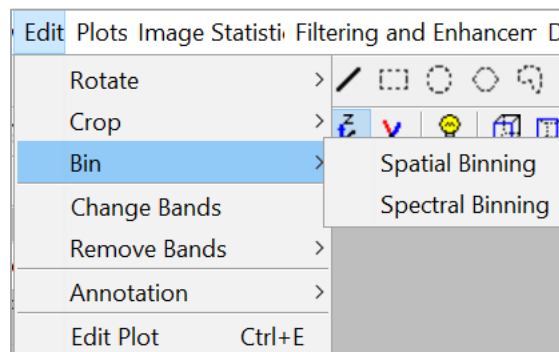
Bin (spatial and spectral)

NOTE: PAVIA dataset is used as an example.

Features: Performs spatial and spectral binnings of the entire dataset.

Steps:

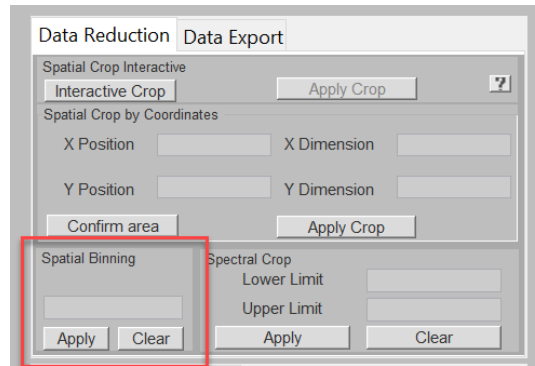
1. Open a hyperspectral imaging file through the **Main Interface**.
2. Click **Edit** → **Bin** and select one of the binning options:
 - a. **Spatial binning** – only perform binning in the spatial coordinate to decrease the number of pixels.
 - b. **Spectral binning** – only perform binning in the spectral coordinate to decrease the number of spectral bands.



3. Click **Reset** to return to the original view.

NOTE: **Reset** will reset all changes made including crop and filters.

4. The new dataset can be saved using the standard **Save** function. Alternatively, **Spatial Binning** can be done from the **Main Interface**.



Compression

There are several compression algorithms that can be used for hyperspectral imaging. Some commonly used ones:

Lossy compression algorithms: These algorithms compress the data by removing some of the less significant information. Popular lossy compression algorithms for hyperspectral imaging include Principal Component Analysis (PCA), Independent Component Analysis (ICA), and Wavelet Transform. These compression functions are implemented in the IDCubePro. Another popular compression function Discrete Cosine Transform (DCT) *will be implemented in future releases*

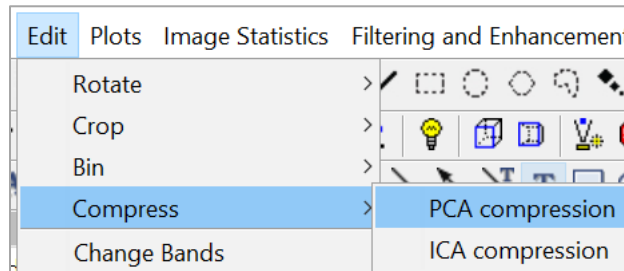
Lossless compression algorithms: These algorithms compress the data without any loss of information. Some popular lossless compression algorithms for hyperspectral imaging include Huffman coding, Arithmetic coding, and Run-length encoding. *These compression functions will be implemented in future releases.*

Hybrid compression algorithms: These algorithms combine both lossless and lossy compression techniques to achieve better compression ratios. One example of a hybrid algorithm is the Spectral-Spatial Hyperspectral Image Compression (SSHIC) algorithm *These compression functions will be implemented in future releases.*

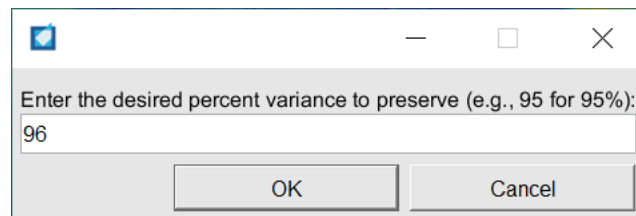
The choice of compression algorithm will depend on the specific requirements of the application, such as the desired compression ratio and the level of compression artifacts that can be tolerated.

PCA compression

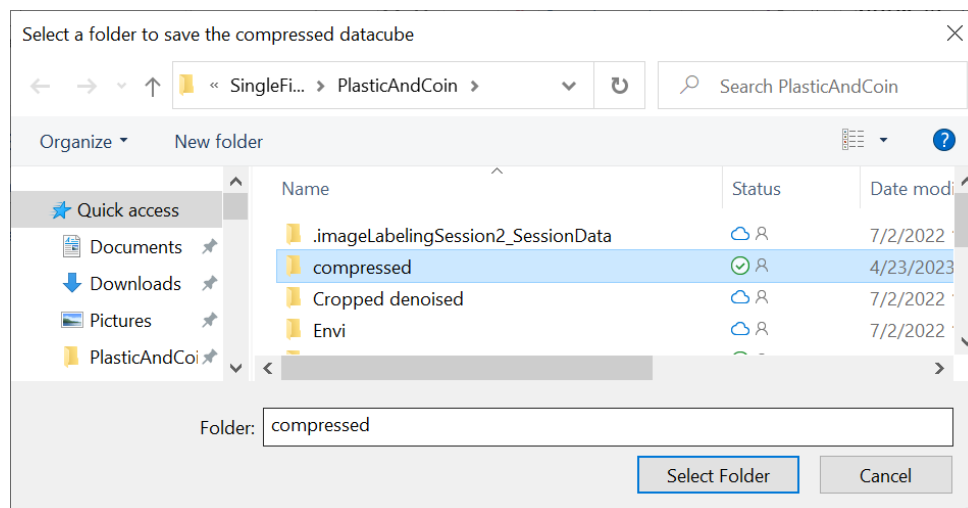
Step 1. Select a compression method: **Edit** → **Compress** → **PCA compression**



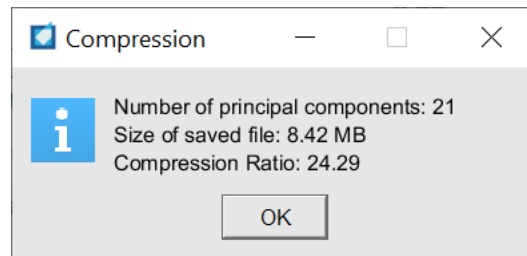
Step 2. Select the desired percent variance from a dialogue window. Higher number of variance will give more bands and low compression ratio. Significant level of information might be preserved. Lower number will have very few principal components.



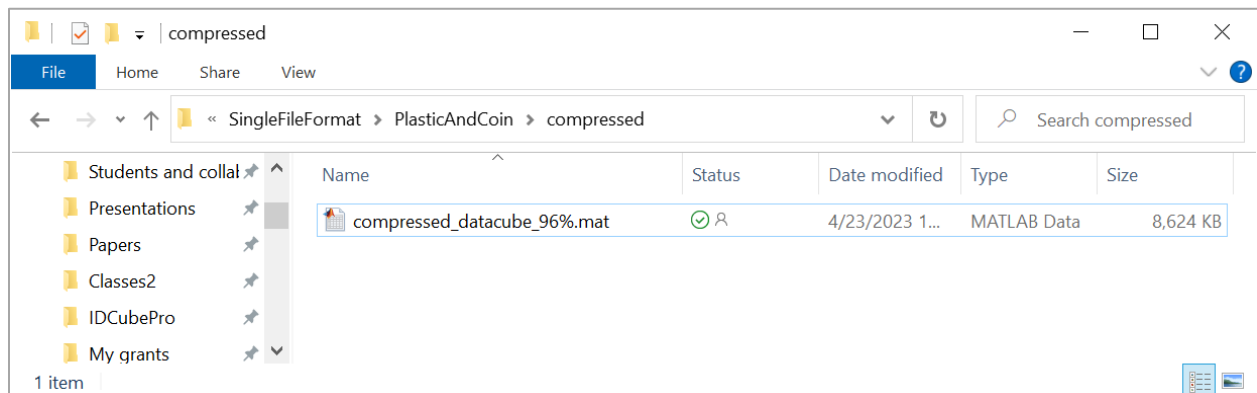
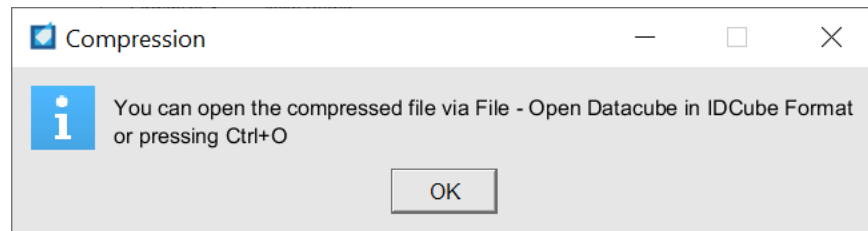
Step 3. Select a folder to save the compressed datafile. The file name will be generated automatically as *compressed datacube_96%.mat*, where the number indicated selected percent variance.



After completion, IDCube calculates the compression ratio by comparing the size of the original data and the size of the compressed data. This information, along with the number of independent components and the size of the saved file, is then displayed to the user.



The message box indicates that the new compressed datacube file can be opened in a usual way.



Additional Information

Principal Component Analysis (PCA) is a technique often used to reduce the dimensionality of large data sets, such as hyperspectral images, by transforming a large set of variables into a smaller one that still contains most of the information in the larger set.

Hyperspectral images contain hundreds to thousands of bands for each pixel in an image, which results in a huge amount of data. PCA can be used to compress this data by finding new variables, or principal components, that capture most of the variance in the original data set. To compress the hyperspectral data using PCA with a percent variance as a criteria the algorithm follows the following steps:

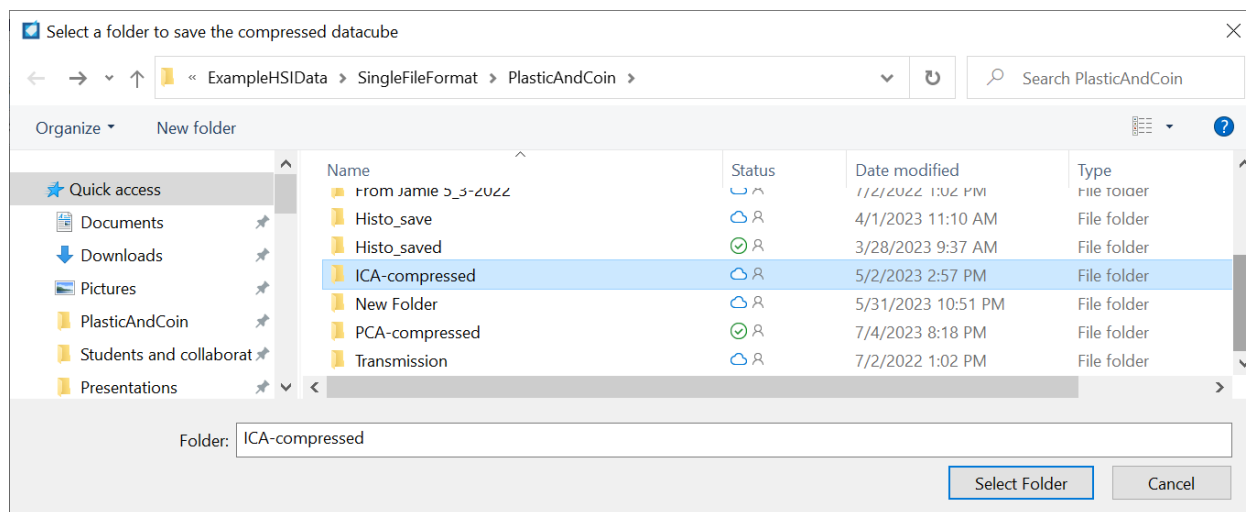
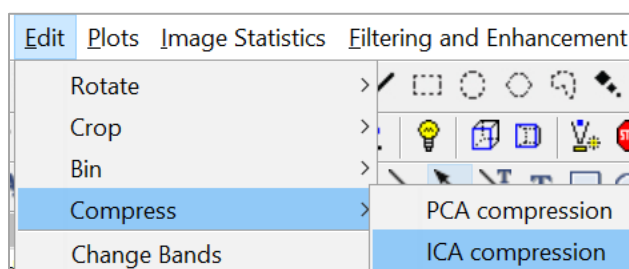
- Reshapes the datacube into a 2D matrix, where each row represents a spatial location and each column represents a spectral band. Also, center and scale the data to have zero mean and unit variance along each band.
- Computes the covariance matrix of the centered and scaled data matrix. Computes the eigenvectors and eigenvalues of the covariance matrix. Then, sorts the eigenvectors in descending order of their corresponding eigenvalues.
- Computes the cumulative variance explained by each principal component.

- Chooses the number of principal components to retain based on the desired percent variance (input from the user) views to preserve. For example, to retain 95% of the variance, you can find the index of the first principal component whose cumulative variance is greater than or equal to 0.95.
- Projects the centered and scaled data matrix onto the selected principal components to obtain the compressed data matrix. Reshapes the compressed data matrix back into the original 3D datacube.

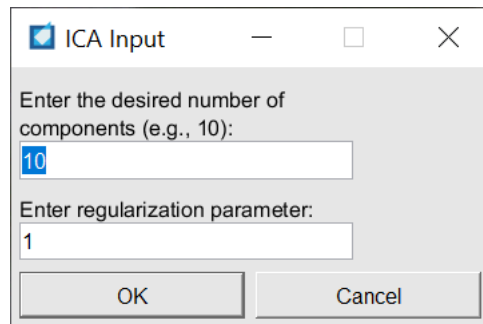
The saved compressed dataset contains the compressed hyperspectral datacube, where the number of spectral bands has been reduced to number of principal components.

ICA compression

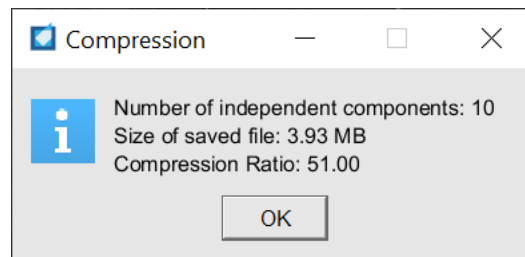
Step 1. Select a compression method: **Edit** → **Compress** → **ICA compression**.



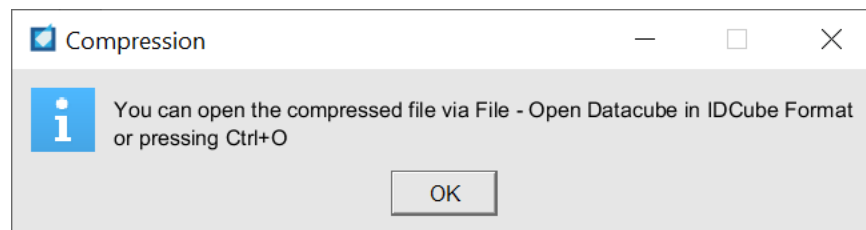
Step2: ICA Input. The function prompts the user to enter the number of independent components to be extracted (used as a measure of how much to compress the data, the default value is 10 components) and the regularization parameter lambda. The default value is 1. The regularization parameter is used in the ICA algorithm to control the trade-off between data fit and complexity of the model.



After completion, IDCube calculates the compression ratio by comparing the size of the original data and the size of the compressed data. This information, along with the number of independent components and the size of the saved file, is then displayed to the user.



The message box indicates that the new compressed datacube file can be opened in a usual way.



Additional Information:

Independent Component Analysis (ICA) is a computational method for separating a multivariate signal into independent non-Gaussian signals. It is a method that attempts to decompose a multivariate signal into independent subcomponents. It is a more general form of Principal Component Analysis (PCA), which only decorrelates signals.

For instance, imagine you have multiple microphones placed in different positions in a room and multiple people are speaking simultaneously. Each microphone captures all the voices, but the volume of each speaker's voice will vary based on their distance from the microphone. ICA can be used to separate the individual voices (independent components) from the mixed recordings (multivariate signal).

Compared to PCA, which only looks for uncorrelated factors in the data, ICA goes a step further to find independent factors. While uncorrelated components can be statistically related, independent components are not. PCA tends to find the axes in the data that account for the most variance, but it does not necessarily find the actual source signals.

ICA assumes that the signal sources are statistically independent, while PCA does not require this assumption. Because of this, ICA can often provide a more meaningful decomposition of complex datasets and is often used when we expect some underlying factors are driving the patterns in the data.

ICA assumes that the hyperspectral image is a linear mixture of spectrally pure components, or endmembers. The purpose of applying ICA is to unmix the hyperspectral datacube into these endmembers and their corresponding abundances. The number of independent components to be extracted is typically less than the number of original bands in the hyperspectral image, leading to data compression.

The actual compression in this case does not involve any physical compression or data encoding. Rather, the datacube is compressed in the sense that it is represented by a smaller set of independent components (endmembers) and their abundances. This is an example of data reduction rather than data compression in the traditional sense.

PCA vs ICA:

PCA is often used for dimensionality reduction in hyperspectral imaging, projecting the data onto a new coordinate system where the variance of the data is maximized. This results in a set of Principal Components (PCs) that are ordered by the amount of variance they explain in the data, which is beneficial for noise reduction and data compression. However, the PCs are not necessarily physically meaningful and do not correspond to actual material spectra.

On the other hand, ICA attempts to find a set of statistically independent spectral signatures (endmembers) and their abundances, which can be physically meaningful in the context of hyperspectral imaging. These independent components can represent the spectra of different materials present in the hyperspectral image. In this sense, ICA can not only compress the hyperspectral data but also unmix it into its constituent material spectra, making it more interpretable.

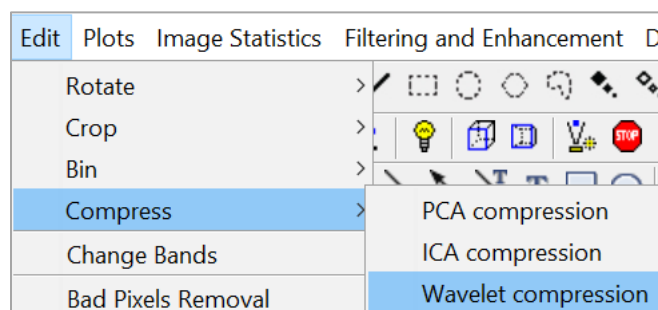
Wavelet Compression

NOTE: This function performs compression in combination with spectral cropping as specified below.

Features:

The Wavelet Compression function performs wavelet-based compression on hyperspectral data and generates a dataset w. It prompts the user to enter the type of wavelet and the level of decomposition. The hyperspectral data is loaded, and the wavelet transform is applied to each pixel's spectral signature. The resulting compressed data is saved in a separate file.

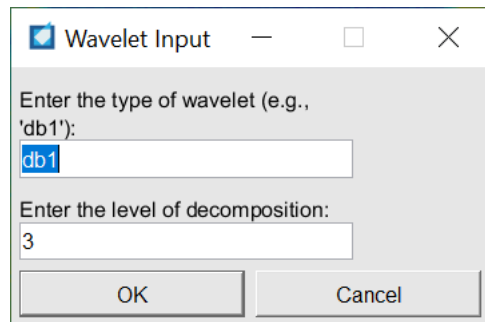
Step 1. When the file is opened, select Wavelet compression method: **Edit → Compress → Wavelet compression.**



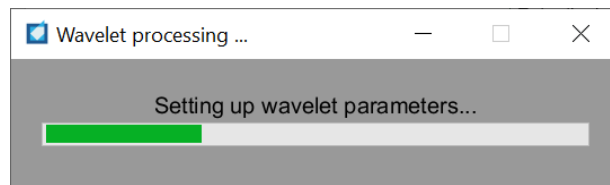
The function will prompt you to enter the type of wavelet (e.g., 'db1') and the level of decomposition (a positive integer). Specify the wavelet type and decomposition level in the input dialog and click OK. The function will apply the wavelet transform to the hyperspectral data, compressing it.

Currently supported wavelets families:

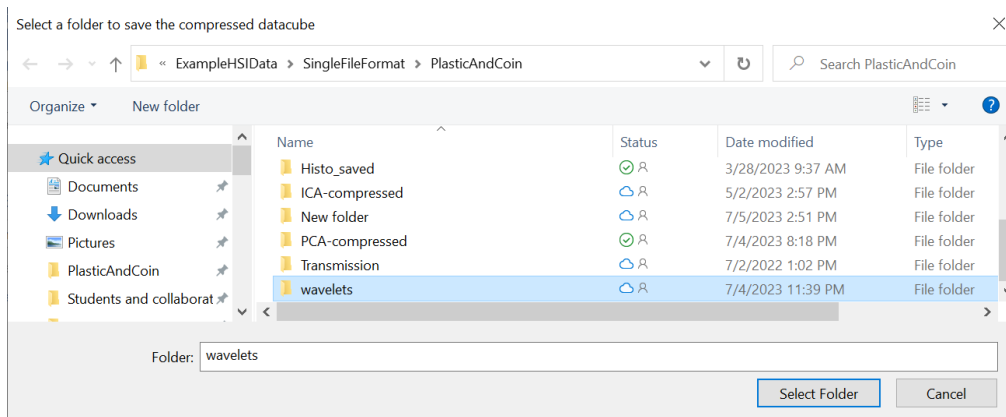
| Wavelet Family Code | Vanishing number(N) | Wavelet Family Name |
|---------------------|---------------------|---------------------|
| haar | none | Haar wavelet |
| dbN | From 1 to 10 | Daubechies wavelets |
| symN | From 2 to 8 | Symlets |
| coifN | From 1 to 5 | Coiflets |



A waitbar will show the progress of the compression.

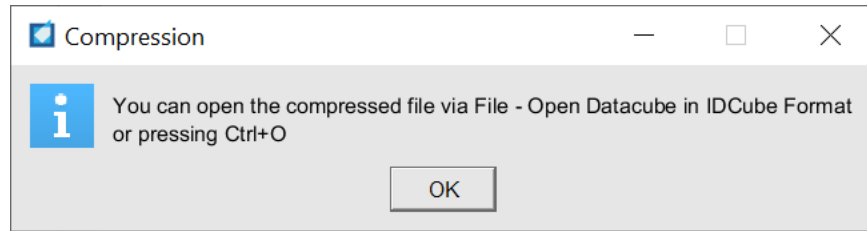


After setting parameters, a popup dialogue will ask for a folder to store the wavelet processed file.

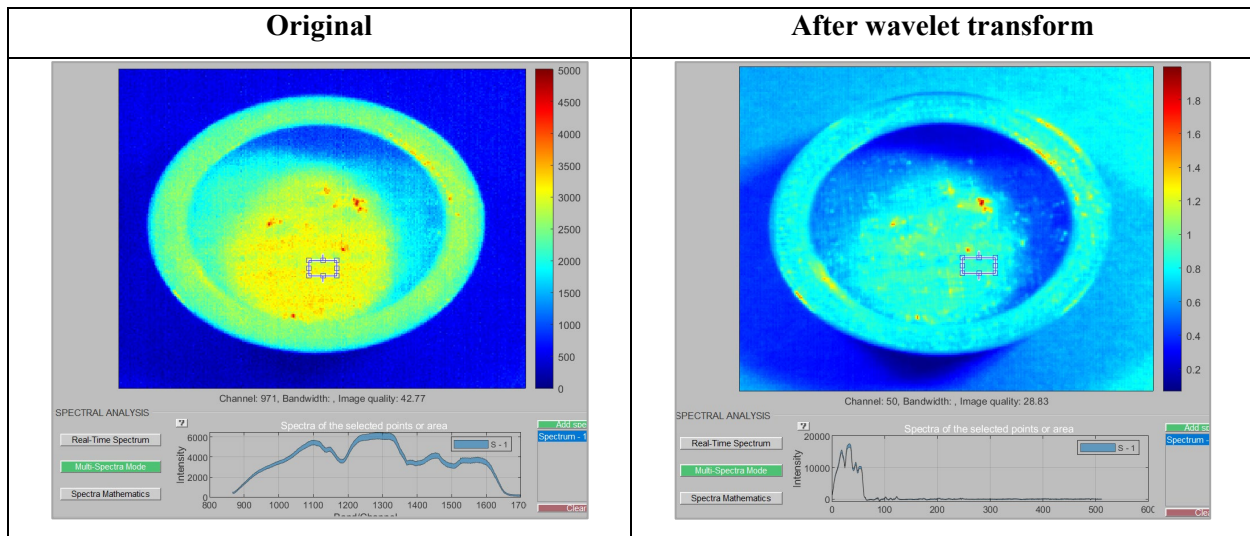


After compression, a dialog box will appear showing the wavelet type, level of decomposition, the size of the saved file.

The message box indicates that the new compressed datacube file can be opened in a usual way. Click OK on the dialog box. Another dialog box will appear indicating that compression is complete. The name of the file will be generated automatically as *Wavelet_compressed_datacube_db1_3.mat*, where the db1 corresponds to the type of wavelet and "3" to the level of decomposition.



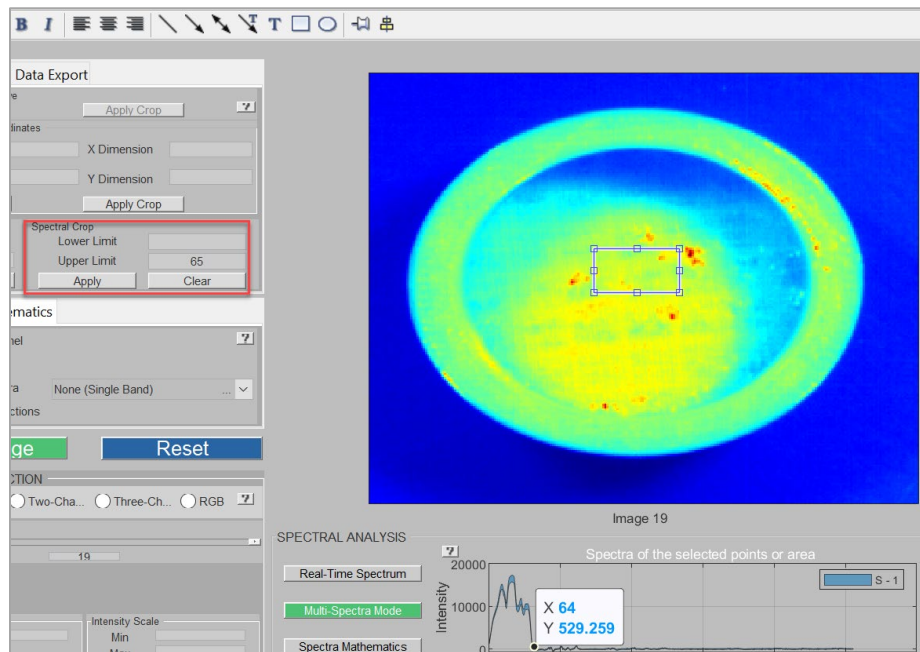
Step 3. Open the saved file and explore the spectrum of the region of interest.



You will find that the spectrum seems to be “compressed”.

NOTE: after a wavelet transform, the bands in the spectral analysis window do not correspond to the actual physical values such as wavelengths.

Step 4. Perform Spectral Cropping. Using **Data Tips** from the **Strip Toolbar** identify the end of the spectrum as shown below and enter a similar value in the **Upper Limit** field in the **Spectral Crop** panel. Click **Apply**. You can save the datacube as a new dataset. The new dataset will have significantly lower number of bands and therefore significantly smaller size.



NOTE: different types of wavelets and different level of decomposition will provide a different level and quality of compression.

Additional Information:

Wavelets are small waves. Wavelet compression methods for hyperspectral data offer several advantages by achieving good compression ratios while preserving important spectral information and minimizing data loss. Additionally, wavelet compression methods can exploit the inherent spectral redundancy present in hyperspectral data, leading to efficient compression.

IDCube wavelet compression method for hyperspectral data relies on transform-based methods. These methods involve decomposing the hyperspectral data into wavelet coefficients using the discrete wavelet transform (DWT). The coefficients with smaller magnitudes (Y-value on the spectrum) can be discarded, resulting in compression.

Notation:

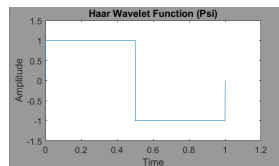
Family of wavelets: Wavelets come in many families, each with different characteristics that make them useful and unique for different types of signal analysis. IDCube supports most common families of wavelets. *Haar Wavelets:* These are the simplest type of wavelets and the first to be introduced. Haar wavelets are discontinuous and resemble step functions. *Daubechies Wavelets:* Named after Ingrid Daubechies, these most common wavelets are designed to have a maximal number of vanishing moments for a given support width. This means they can compactly represent polynomial signals. *Symlets:* These are nearly symmetric wavelets that are also designed by Daubechies. They're similar to the Daubechies wavelets but have better symmetry, which can be advantageous in imaging applications. The symlets are nearly symmetrical wavelets proposed by Daubechies as modifications to the db family. This characteristic can be advantageous in certain applications, for example, in image processing where symmetric filters are often preferred (Gaussian filter is an example of a symmetric filter). *Coiflets:* Another type of wavelets designed by Daubechies, Coiflets are designed to have 2N moments equal to 0 and have good localization in both the spatial and frequency domains.

Vanishing moments: Some common families of wavelets denoted by 'nameN', are characterized by having N vanishing moments. For example, for a 'db6' wavelet, there are 6 vanishing moments. This property means that the 'db6' wavelet is orthogonal to all polynomials of degree less than 6, making it able to effectively represent polynomial signals of up to degree 5. This characteristic contributes to the ability of the 'db6' wavelet to compactly represent smooth signals. Wavelets with more vanishing moments can more effectively capture smooth parts of a signal, but can make it less effective at capturing abrupt changes or discontinuities in the signal

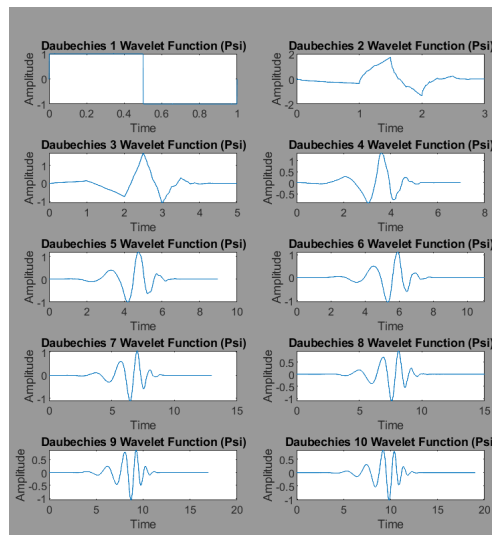
Levels of decomposition: Decomposition in wavelet transforms is a process that involves breaking down imaging data set into different frequency subbands. This process is crucial for data compression, as it helps to analyze the frequency characteristics of the data, which can then be exploited for efficient compression. Higher levels of decomposition divide the data into a more granular set of frequency bands. This allows for a more precise analysis of the data, which can result in more efficient compression, especially for complex signals or images. This allows for a more precise analysis of the data, which can result in more efficient compression, especially for complex signals or images. High levels of decomposition enables the algorithm to capture small-scale features that may be missed at lower levels of decomposition. By using higher levels of decomposition, the wavelet transform can better capture the correlations or redundancies within the data, leading to better compression ratios. However, the trade-off for using higher levels of decomposition is that it increases the computational complexity of the wavelet transform and hence, the compression process. More levels require more computations, which can slow down the compression.

The shapes of the supported wavelets are given below:

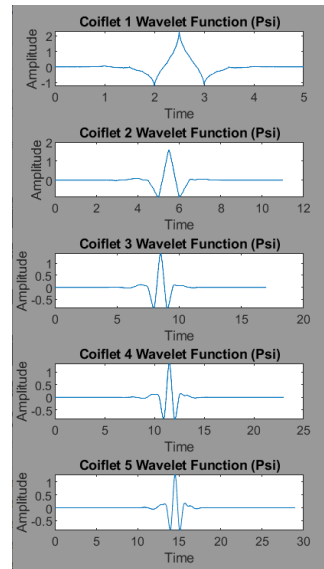
Haar (Equivalent to Db1)



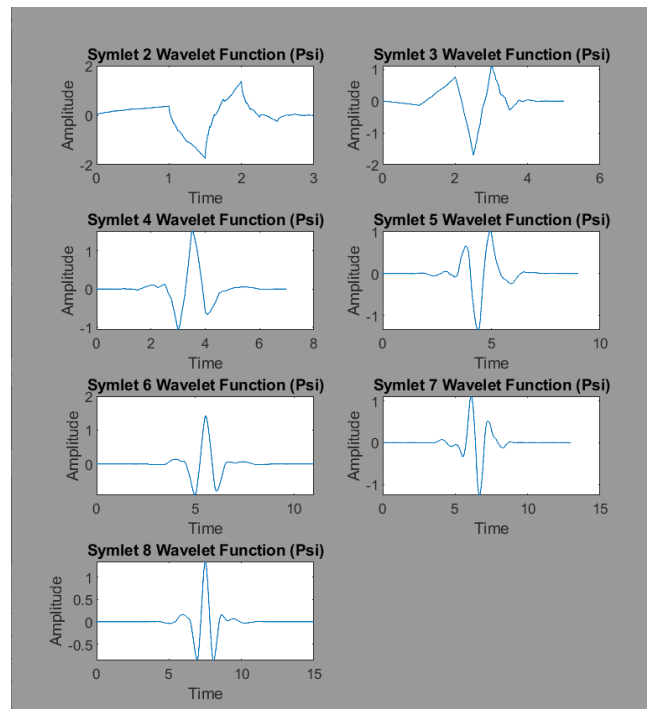
Daubechies wavelet (DbN) N=1-10



Coiflets (coifN) N= 1-5



Symlets (symN), N= 2-8



Levels of decomposition:

Decomposition in wavelet transforms is a process that involves breaking down a signal or data set into different frequency subbands. This process is crucial for data compression, as it helps to analyze the frequency characteristics of the data, which can then be exploited for efficient compression.

Higher levels of decomposition divide the data into a more granular set of frequency bands. This allows for a more precise analysis of the data, which can result in more efficient compression, especially for complex signals or images. It enables the algorithm to capture small-scale features that may be missed at lower levels

of decomposition. By using higher levels of decomposition, the wavelet transform can better capture the correlations or redundancies within the data, leading to better compression ratios. However, the trade-off for using higher levels of decomposition is that it increases the computational complexity of the wavelet transform and hence, the compression process. More levels mean more computations are required, which can slow down the compression.

One of the advantages of wavelet-based compression is that it can be "lossy" or "lossless", depending on how much data is discarded during compression. However, too many levels of decomposition might lead to the loss of essential information, causing the quality of the reconstructed data to decrease after decompression. Overly high levels of decomposition can also introduce artifacts or distortions into the compressed data. This is because the decomposition process itself is not entirely free from introducing errors into the data, and these errors can accumulate as the level of decomposition increases.

Choosing the appropriate level of decomposition is a balancing act that depends on the specific requirements of the compression task, including the complexity of the data, the acceptable loss of information, and the computational resources available.

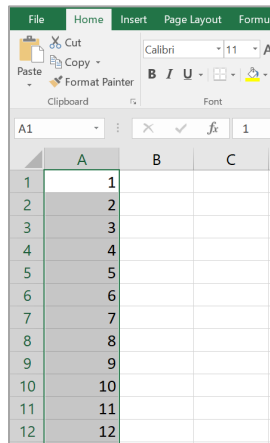
References:

MATLAB documentation on wavelet transforms describes a variety of wavelets: <https://www.mathworks.com/help/wavelet/>

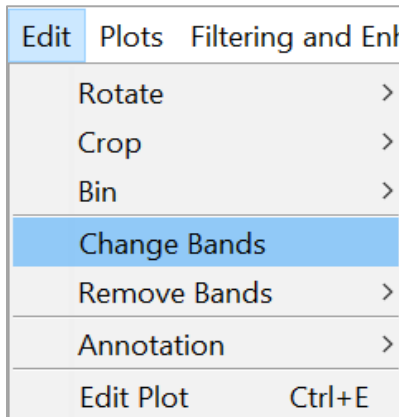
Change Bands

Features:

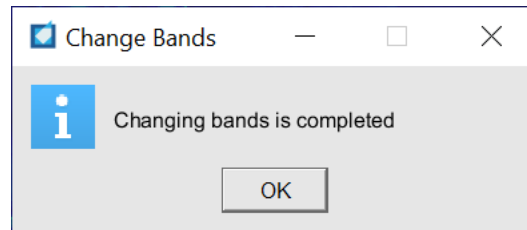
- Changes set of bands to another set of bands. The new bands has to be set either in the excel or text file as a column. The dimension of the new set of bands ($l \times n$) **must** be equivalent of the current dimension.



For changing the bands, click **Edit – Change Bands** and select the file



After completion, the changes will be confirmed by a message box.



Confirm the changes by looking at the spectra.

Remove Bands

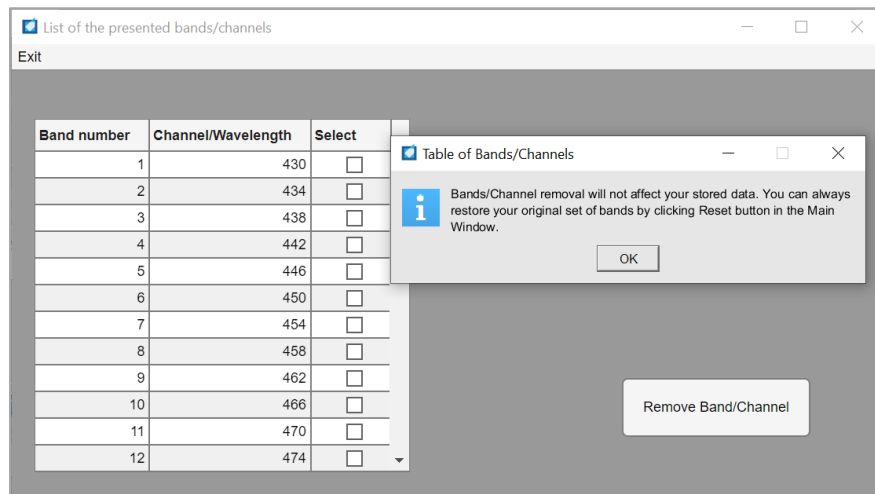
NOTE: PAVIA dataset is used as an example.

Features:

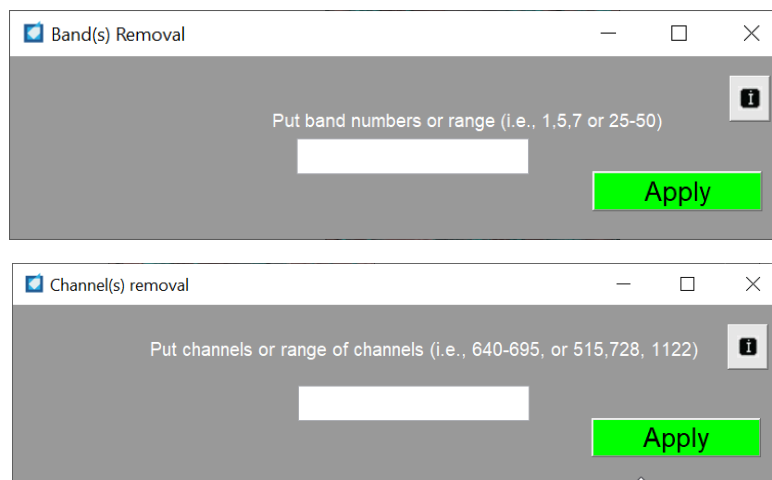
- Enables removing specific bands or groups of bands from the dataset.
- IDCube uses the following notation: bands are assigned the order number (1, 2, 3, etc.), while the channels have units (i.e., wavelengths, 430, 434, 438, etc.). Removal of any band/channel will reassign the band numbers, but not the channels.

Steps:

1. Open a hyperspectral imaging file through the **Main interface: File → Open dataset in IDCube format.**
2. **Click Edit → Remove bands/channels** to see the following options:
 - a. Individual bands/channels removal (Table)
 - b. Range of bands removal
 - c. Range of channels removal
3. To delete individual bands or channels select **Individual bands/channels removal (Table)** and click on the appropriate one or many checkboxes.
4. Click **Remove Band/Channel** button. **The bands/channels** will be removed from further consideration. To cancel the deletion, click the blue **Reset** button on the **Main Interface**.



To delete the range of either bands or channels select **Range of Bands Removal** or **Range of Channels Removal** and add the bands/channels in the box using the specified format.



Click **Apply** button. **The bands/channels** will be removed from further consideration.

To cancel the deletion, click **Reset** on the **Main Interface**.

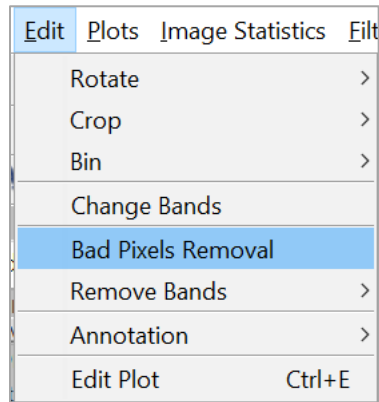
Bad Pixel Removal

NOTE: Plastic and Coin dataset is used as an example.

Features: Enables rapid removing of spikes from the dataset

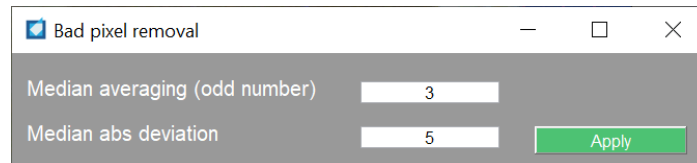
Bad pixel removal is a common preprocessing step for hyperspectral datasets to remove pixels that are noisy or have other artifacts. One way to do this is to use a median filter to smooth the data and identify pixels that are more than a certain distance from the median.

Steps: Select **Edit** → **Bad Pixel Removal**.

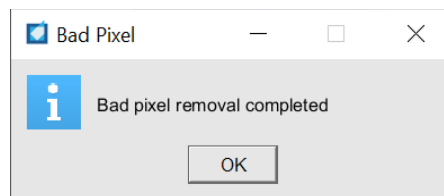


In the dialog box enter the Median average value n that will perform $(n \times n)$, the default value is 3.

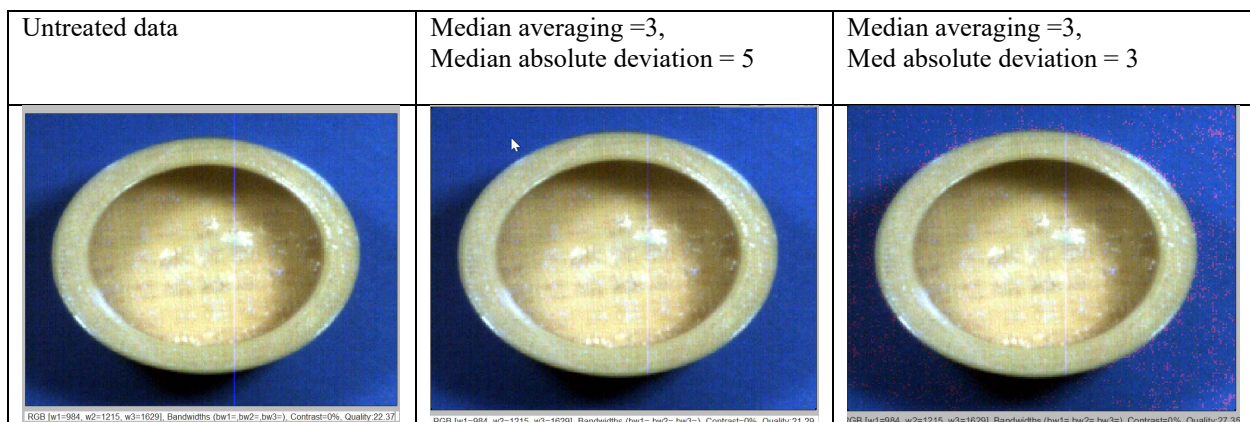
Enter Median absolute deviation (MAD) for each pixel using the median function. The algorithm identifies bad pixels as those that are more than m MADs from the median, the default value is 5.



The completion of the algorithm will be notified with the message box



The example below shows the effect of **Bad Pixel Removal** different values on the dataset



Click **Reset** to return to the original dataset

Additional Information:

This algorithm first applies a median filter to each individual band of the dataset using function. The resulting filtered data is temporarily stored. The algorithm then calculates the Median and Median absolute deviation (MAD) for each pixel using the median function. The algorithm identifies bad pixels as those that are more than m MADs from the median, and replace them with the median value. Finally, the algorithm displays the corrected hyperspectral image.

The median absolute deviation (MAD) is a robust measure of variability or dispersion of a dataset. It is defined as the median of the absolute deviations of the data points from the median of the dataset. In other words, it measures the average distance of each data point from the median. MAD is calculated using the following formula:

$$\text{MAD} = \text{median}(|x_i - \text{median}(X)|)$$

where X is the dataset, x_i is the i -th data point, and $|\cdot|$ denotes the absolute value.

MAD is a useful measure of dispersion when the dataset contains outliers or is not normally distributed. It is less sensitive to extreme values than the standard deviation, which makes it a better choice for skewed or heavy-tailed distributions. MAD is often used in conjunction with the median to estimate the spread of a dataset. In hyperspectral data analysis, the median $\pm m \times \text{MAD}$ is used to define the range of "normal" values, where m is a scaling factor chosen to reflect the variability of the dataset.

Annotations


NOTE: PAVIA dataset is used as an example.

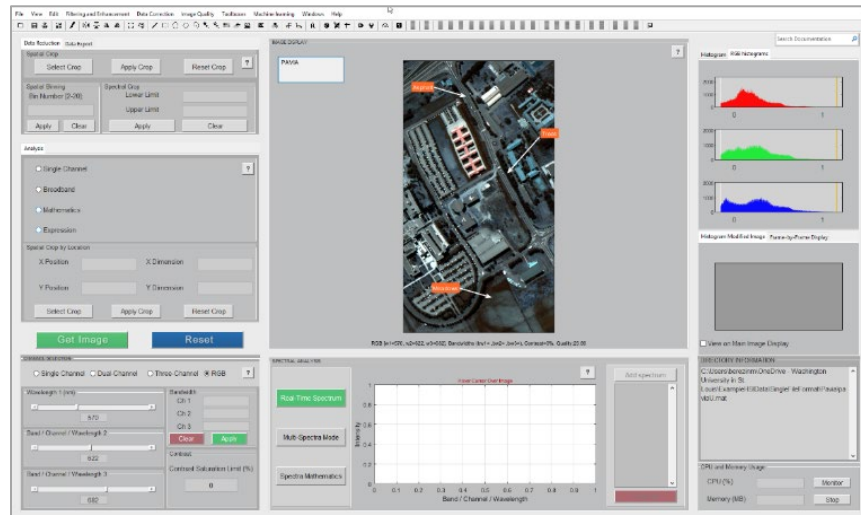
Features: Enables adding interactive textboxes and arrows into the image display.

Steps:

1. Open a hyperspectral imaging file through the **Main interface: File → Open dataset in IDCube format.**
2. Click **Edit → Annotations.** Two options are available.
 - a. Add Textbox
 - b. Add Arrow.

These objects have preset feature designs and are different from the general use annotations that are available from the **Annotation Toolbar**.

3. Select an option and it will be placed on the **Image Display**.
4. The user can type text, move, or resize the annotations.
5. **NOTE:** this tool automatically activates the **Edit Plot**. To disconnect the **Edit Plot**, click the icon  or deactivate through **Edit → Edit Plot** or **Ctrl+E**.
6. Annotations can be changed or deleted at any time by activating **Edit Plot** mode.
7. When the **Edit Plot** is activated, use **Ctrl+Z** to cancel the changes.



Use the **Strip Toolbar** in the upper right-hand corner of the image display to copy the image with the annotations.


Edit Plot Mode

NOTE: PAVIA dataset is used as an example.

Features:

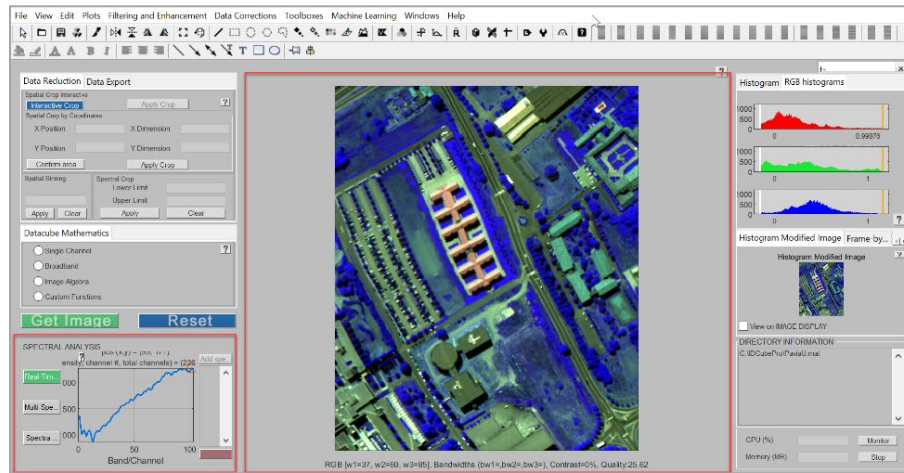
- Allows the user to activate the interactive mode and rearrange the home page for a more personalized visualization experience.
- Allows the user to modify and delete annotations (see **Toolbar** → **Edit Mode**).

Steps to modify the layout:

1. Open a hyperspectral imaging file through the main interface **File** → **Open dataset in IDCube format**.
2. Click on **Edit** → **Edit Plot** or select the icon  or press **Ctrl+E**.
3. Click on any of the static frames to visualize the boundaries of the frame and move, expand or delete. You can cancel the change by pressing **Ctrl+Z**.

NOTE: some of the panels are fixed. That includes the HISTOGRAM panel, DATACUBE MATHEMATICS panel, and DATA REDUCTION panel. Buttons can be moved within the parent frame.

Click on the **Edit Plot** icon to return to the functional view.



The changes in the layout cannot be returned back by the **Reset** button. Instead, you can go all the way back to the original layout by activating the **Edit Plot** again and repositioning the frames, or by pressing **Ctrl+Z** several times until you get to the original layout. In the screenshot below, the SPECTRAL ANALYSIS panel went to the left, and the IMAGE DISPLAY panel was increased.

7.5. Plots Tab

NOTE: Plastic and Coin dataset (cropped) is used as an example.

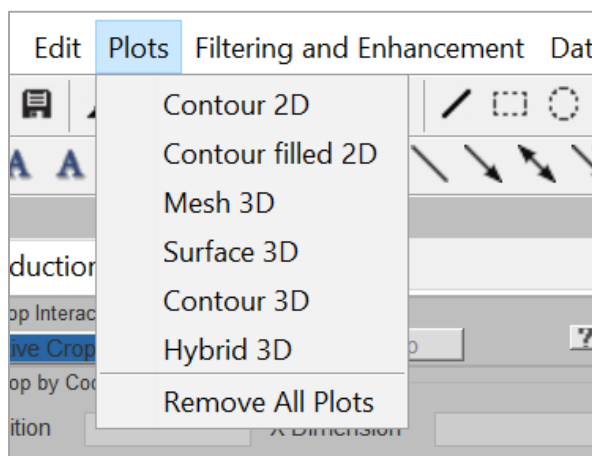
Features:

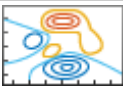

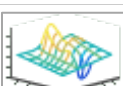
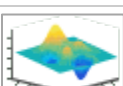

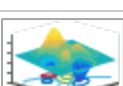
Enables the user to visualize the current image in a variety of 2D and 3D ways. The visualization is temporary and will return to the default view with further data manipulation.

Steps:

1. Load the image file and select **File** → **Plots** and choose a type of plot. Available options are given in the table below.

| Tabs | Function | Additional info |
|-----------|------------------------|--|
| Plots Tab | Contour 2D plot | |
| | Contour-filled 2D plot | |
| | Mesh 3D plot | Activates Camera Toolbar. |
| | Surface 3D plot | Activates Camera Toolbar. |
| | Contour 3D plot | Activates Camera Toolbar. |
| | Remove All Plots | Returns to the default single channel image. |



| Type of plot | Graphical Description | Description |
|-------------------|---|--|
| Contour 2D |  | Creates a contour plot containing the isolines of matrix Z, where Z contains intensity values on the x-y plane as height. IDCube automatically selects the contour lines to display. |
| Contour filled 2D |  | Creates a filled contour plot containing the isolines of matrix Z, where Z contains height values on the x-y plane. IDCube automatically selects the contour lines to display. |
| Mesh 3D |  | Creates a 3D mesh plot that has solid edge colors and no face colors. The function plots the intensity values Z as heights above a grid in the x-y plane defined by X and Y. The edge colors vary according to the heights specified by Z. |
| Surface 3D |  | Creates a 3D surface plot that has solid edge colors and solid face colors. The function plots the intensity values Z as heights above a grid in the x-y plane defined by X and Y. The edge colors vary according to the heights specified by Z. |
| Contour 3D |  | Creates a 3D contour plot containing the isolines of matrix Z, where Z presents intensity values on the x-y plane as height. IDCube automatically selects the contour lines to display. |
| Hybrid 3D |  | Creates a 3D surface plot with a contour 2D plot underneath. A combination of a Surface 3D and Contour 2D. |

Selection of 3D plots automatically adds a **Rotate 3D** button to the **Strip Toolbar** menu located in the right corner of the image. You can click it to rotate.

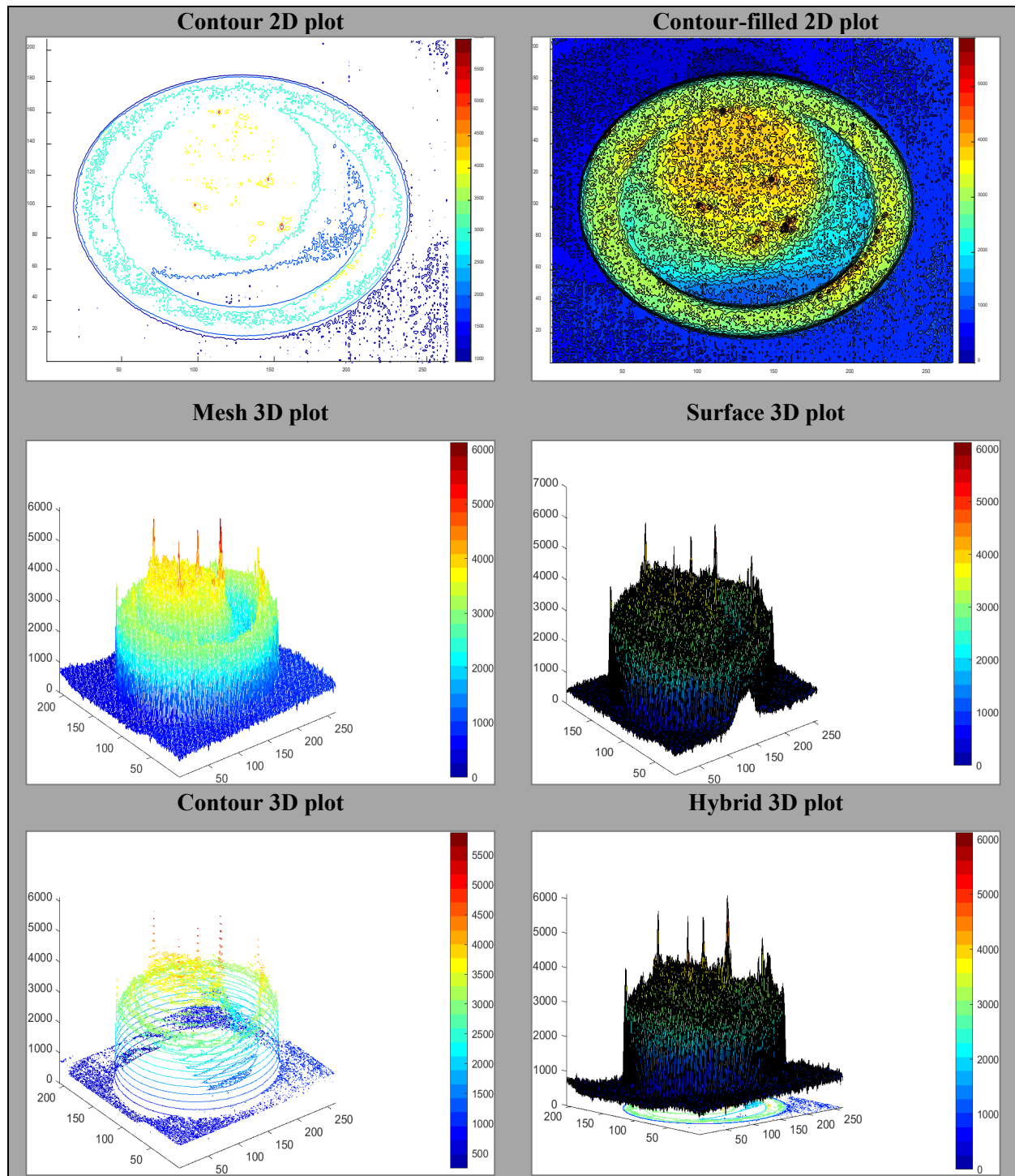


The selection of 3D plots also automatically activates a **Camera Toolbar** that enables a large variety of manipulations of three-dimensional objects.



Tip: You can use different color LUTs from the toolbar or Interactive colorbar functions (via the **Right click** on the colorbar) to fine-tune the colors of the plots.

To return to the default plots, click  or move any band/channel functions. Examples of the plots are shown below



7.6. Image Statistics Tab

| Tabs | Function | Additional info |
|-------------------------------|-----------------------------|-----------------|
| Filtering and Enhancement Tab | Image Quality Plot | Additional menu |
| | Anomaly Pixels | Pop-up window |
| | Texture features | Pop-up table |
| | Hausdorff Fractal Dimension | Pop-up value |

Image Quality Plot (BRISQUE, NIQE and PIQE algorithms)

NOTE: PAVIA dataset is used as an example.

Features:

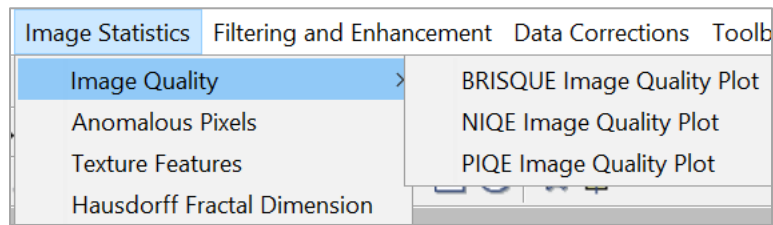
- **Image Quality** calculates the no-reference image quality score for the image using several methods. The range of the Quality Score is from 0 to 100. A smaller score indicates better perceptual quality.
- Calculates the quality of the images as the function of the wavelength.

Steps (could be used in random order)

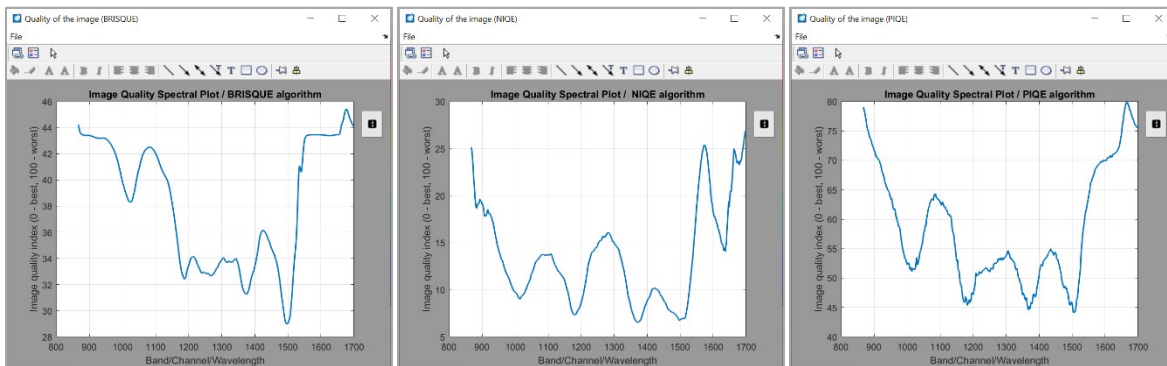
1. Load the data using **File** → **Open...** The **Quality** score of the image is located in the text box under the image as shown below. This value is calculated using BRISQUE algorithm.



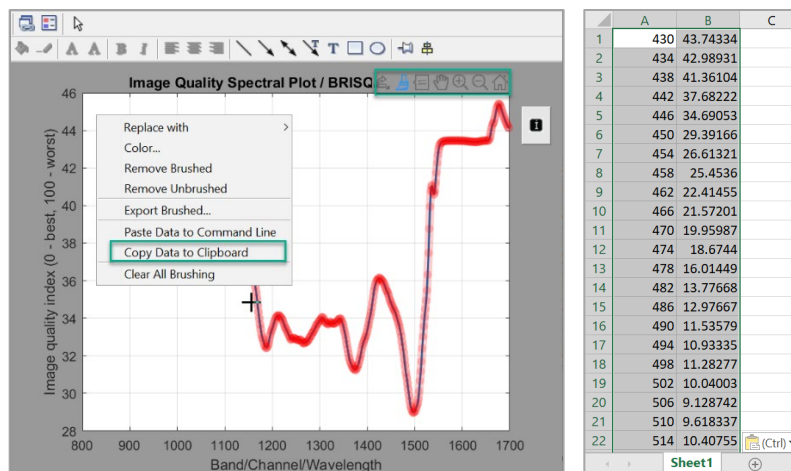
2. Go to the **Filtering and Enhancement** → **Image Quality** and select **Image Quality Plot** to visualize the image quality as the function across the entire z-axis (band/channel/wavelength). The available algorithms are:
 - a. BRISQUE
 - b. NIQE
 - c. PIQE



The plots below indicate relatively poor-quality images at wavelengths <450 nm corresponding to large values of indices.



Tip: You can save Quality plots spectra in Excel format using a **Brush** button from a **Strip Toolbar**. Hover over the spectral window to activate a **Strip Toolbar** and click the **Brush** icon. When clicked, the **Brush** icon will turn blue. Brush the entire or part of the plotted spectrum and right-click. Select **Copy Data to Clipboard**. Paste the copied data into Excel or a text file.



Additional Information:

The algorithm predicts the BRISQUE score by using a Support Vector Regression (SVR) model trained on an image database with the corresponding differential mean opinion score (DMOS) values. The database used for this algorithm contains images with known distortion such as compression artifacts, blurring, and noise, and it contains pristine versions of the distorted images. The image to be scored must have at least one of the distortions for which the model was trained.

PIQE (Perception-based Image Quality Evaluator) scores the image distorted due to blocking artifacts and Gaussian noise. The algorithm generates spatial quality masks that indicate the high spatially active blocks, noticeable artifacts blocks, and noise blocks in the image.

NIQE (Naturalness Image Quality Evaluator) measures the distance between the natural scene statistics (NSS) based features calculated from the image to the features obtained from an image database used to train the model. The features are modeled as multidimensional Gaussian distributions.

References:

BRISQUE:

Mittal, A., A. K. Moorthy, and A. C. Bovik. "No-Reference Image Quality Assessment in the Spatial Domain." *IEEE Transactions on Image Processing*. Vol. 21, Number 12, 2012, pp. 4695–4708.

Mittal, A., A. K. Moorthy, and A. C. Bovik. "Referenceless Image Spatial Quality Evaluation Engine." Presentation at the *45th Asilomar Conference on Signals, Systems, and Computers*, Pacific Grove, CA, 2011.

PIQE:

Venkatanath, N., D. Praneeth, Bh. M. Chandrasekhar, S. S. Channappayya, and S. S. Medasani. "Blind Image Quality Evaluation Using Perception Based Features", In *Proceedings of the 21st National Conference on Communications (NCC)*. Piscataway, NJ: IEEE, 2015.

Sheikh, H. R., Z. Wang, L. Cormack, and A.C. Bovik, "LIVE Image Quality Assessment Database Release 2 ", <https://live.ece.utexas.edu/research/quality/>.

NIQE:

Mittal, A., R. Soundararajan, and A. C. Bovik. "Making a Completely Blind Image Quality Analyzer." *IEEE Signal Processing Letters*. Vol. 22, Number 3, 2013, pp. 209–212.

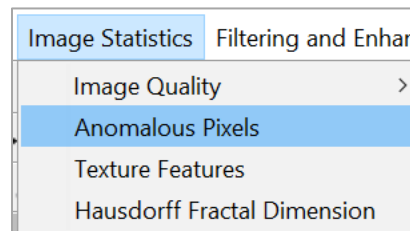
Anomalous Pixels

NOTE: Plastic and Coin dataset is used as an example dataset.

Features: Identifies anomalous pixels in the 3D datasets using Reed-Xialoi (RX) detection algorithm.

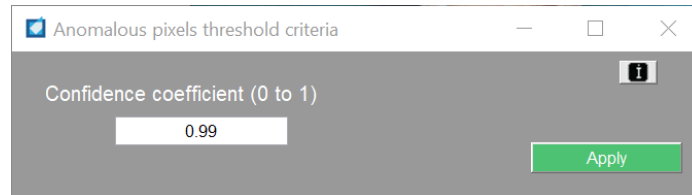
Steps:

1. Select **Filtering and Enhancement** → **Anomalous pixels**

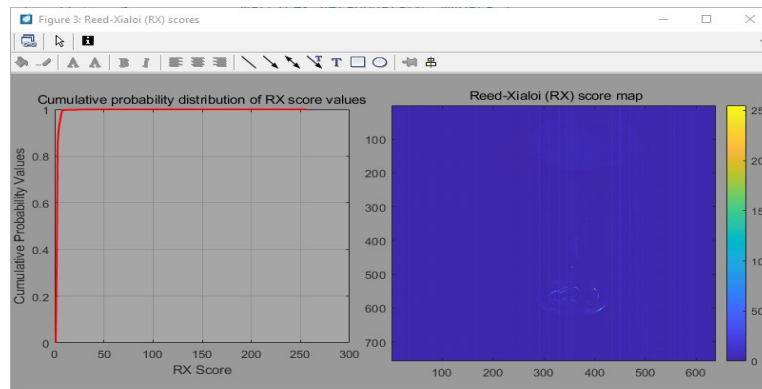


2. Enter the **Confidence coefficient** to set a threshold at which any pixels with a higher confidence coefficient will be considered anomalous. The default level is 0.99. This threshold represents the RX score above which a pixel is an anomaly with 99.0 % confidence.

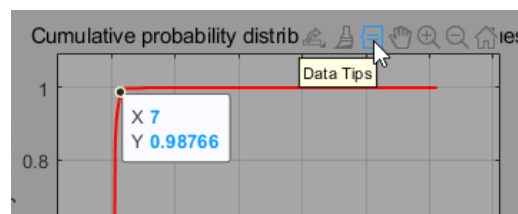
3. As the first step, we suggest using the default value and pressing **Apply**. You can identify a more suitable **Confidence coefficient** value by analyzing the **Plot of the cumulative probability distribution of RX score values** (see below).



IDCubePro® will compute the plot of the **Cumulative probability distribution of RX score values** (scale from 0 to 1). Pixels with a high RX score are likely anomalous pixels. IDCubePro® also displays the **RX score map** where each pixel in the dataset is assigned the raw RX score. Both graphs appear in a pop-up panel **Reed-Xialoi (RX) Scores** side-by-side as shown below:



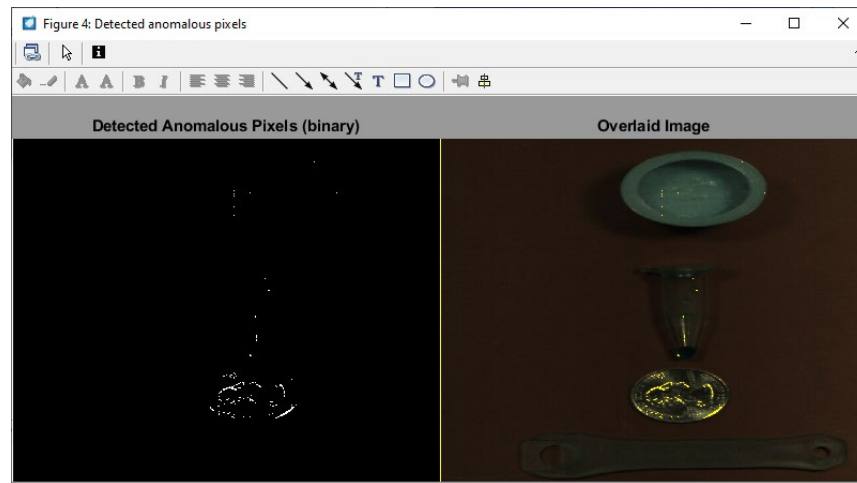
Tip 1: Use the **Strip Toolbar** from the right upper corner of the graph (to see this toolbar, hover over the right upper corner of the graph) to identify the threshold (shown 0.988). Enter this new threshold value into the **Confidence coefficient** field to tune the anomalous pixel detection.



Tip 2: Right-click on the **Colorbar** to change the colorscheme or adjust the colors using an interactive colorbar shift.

IDCubePro® automatically applies a threshold criterion to detect anomalous pixels with an RX score greater than the computed threshold. The result is a binary image in which the anomalous pixels are assigned the intensity value 1 and other pixels are assigned 0. This binary image is generated in a second pop-up panel named **Detected Anomalous Pixels (binary)**. The detected anomalous pixels are overlaid with the automatically generated pseudo-RGB image shown in **Overlaid Image** panel.

NOTE: many anomalous pixels found in the coin. These anomalous pixels correspond to highly reflective areas of the coin's surface.



Additional Information:

The method detects anomalous pixels in the hyperspectral data using the Reed-Xialoi (RX) detector. The RX detector calculates a score for each pixel as the Mahalanobis distance between the pixel and the background. The background is characterized by the spectral mean and covariance of the datacube.

The RX score for each pixel is computed according to the following equation.

$$D_{RX} = (r - \mu_C)^T \Sigma_C^{-1} (r - \mu_C)$$

Where r is the pixel under test and μ_C and Σ_C are the spectral mean and covariance respectively. Anomalous pixels typically have high RX scores.

References:

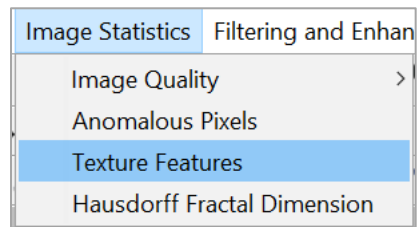
- [1] Reed, I.S., and X. Yu. "Adaptive Multiple-Band CFAR Detection of an Optical Pattern with Unknown Spectral Distribution." *IEEE Transactions on Acoustics, Speech, and Signal Processing* 38, no. 10 (October 1990): 1760–70. <https://doi.org/10.1109/29.60107>.
- [2] Chein-I Chang and Shao-Shan Chiang. "Anomaly Detection and Classification for Hyperspectral Imagery." *IEEE Transactions on Geoscience and Remote Sensing* 40, no. 6 (June 2002): 1314–25. <https://doi.org/10.1109/TGRS.2002.800280>.

Texture Features

NOTE: Only works for monochromatic images. Some features result in NaN or equal to 0 (zero) need to be ignored. Does not produce meaningful results on RGB type images.

Features: The function calculates 14 image parameters known as Haralick Features.

To compute the Haralick features select **Image Statistics** and select **Texture Features**.



A table of Haralick texture features will pop-up.

Image Statistics

Haralick Texture Features

| Feature | Value |
|---|----------|
| Angular Second Moment (Energy) | 0.9995 |
| Contrast | 0.0096 |
| Correlation | 0.2387 |
| Variance | 63.7422 |
| Inverse Difference Moment (Homogeneity) | 0.9998 |
| Sum Average | 15.9982 |
| Sum Variance | 255.8875 |
| Sum Entropy | 0.0022 |
| Entropy | 0.0034 |
| Difference Variance | 0.0248 |
| Difference Entropy | 0.0010 |

| Texture | Meaning and range |
|---|---|
| Angular Second Moment (Energy) | Angular Second Moment measures the image homogeneity. Is high when image has very good homogeneity or when pixels are very similar. |
| Contrast | Equal to 0 for a constant image and become larger as the pixel intensities in a local neighborhood become more disparate. |
| Correlation | Measures the linear dependency of grey levels of neighboring pixels -1 to 1. |
| Variance | Increasing weight given to greater gray value differences. |
| Inverse Difference Moment (Homogeneity) | It is high when local gray level is uniform is close to 1 when only a few dominant gray-tones are present. |
| Sum Average | Average sum of gray levels. |
| Sum Variance | Variance of sum of gray levels. |
| Sum Entropy | Uniform (flat) distribution of sum of gray levels has maximum entropy. |
| Entropy | Reflects the amount of randomness in intensity of an image and increases with the images local complexity. |
| Difference Variance | Variance of difference of gray levels |
| Difference Entropy | Uniform (flat) distribution of difference of gray levels has maximum entropy |
| Information Measure of Correlation I | Normalized mutual information. |
| Information Measure of Correlation II | Difference between joint entropy and joint entropy assuming independence. |
| Maximal Correlation Coefficient | Relates to how fast the Markov chain converges. Calculates how transition matrix for a Markov chain of neighboring pixel gray levels. |

Additional Information:

Haralick texture features are common texture descriptors in image analysis. They are statistical features that describe the texture of an image. They are based on the co-occurrence matrix, which is a matrix that describes the frequency of occurrence of pairs of pixels with certain values in an image. The traditional histogram based methods (first order statistics) show only the distribution of grey-levels in individual pixels ignoring the spatial distribution of grey values. The texture analysis method uses higher-order statistics, and consider the relation between two or more pixels at a time. One advantage of Haralick features is that they are robust and can capture different types of texture information such as smoothness, coarseness, and regularity, making them suitable for a wide range of applications such as medical image analysis, remote sensing, and computer vision. Another advantage of Haralick features is their computational efficiency. They can be computed quickly and easily, even for large images, using algorithms such as the Gray-Level Co-occurrence Matrix (GLCM).

References:

- Haralick, Robert M., Karthikeyan Shanmugam, and Its'hak Dinstein. "Textural features for image classification." *IEEE Transactions on systems, man, and cybernetics* 6 (1973): 610-621.
- Kumar, Rekhil M., and K. Sreekumar. "A survey on image feature descriptors." *Int J Comput Sci Inf Technol* 5 (2014): 7668-7673.

Acknowledgment:

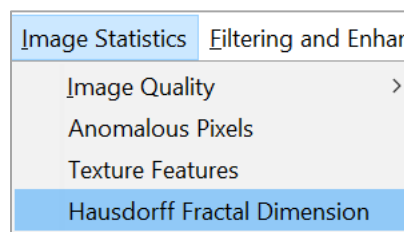
In part based on Rune Monzel (2023). haralickTextureFeatures, MATLAB Central File Exchange. Retrieved March 4, 2023, (<https://www.mathworks.com/matlabcentral/fileexchange/58769-haralicktexturefeatures>)

Hausdorff fractal dimension

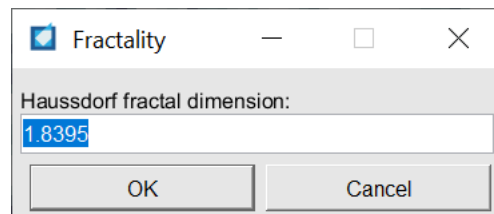
NOTE: Only works for monochromatic images. Does not work on RGB type images (produces NaN value).

Features: The function calculates Hausdorff fractal dimension of the presented image.

To compute the Hausdorff fractal dimension, select **Image Statistics** and select **Hausdorff Fractal Dimension**.



A value corresponding to the Hausdorff fractal dimension will pop-up.



Additional Information:

Hausdorff fractal dimension measurement is a mathematical method used to quantify the complexity or irregularity of an object or pattern. In imaging, this method can be used to measure the complexity of an image, such as the branching patterns of blood vessels or the surface texture of an object.

The Hausdorff fractal dimension measurement provides a way to describe the level of complexity in an image by measuring how much the pattern repeats itself at different scales. The measurement is based on the idea that fractals exhibit self-similarity, meaning that they have the same structure at different levels of magnification. The Hausdorff fractal dimension measurement calculates the degree of self-similarity by measuring the amount of space that is filled by the fractal pattern at different scales.

Applications of Hausdorff fractal dimension measurement in imaging include the analysis of medical images, such as identifying the level of complexity of tumors or analyzing the branching patterns of blood vessels. It can also be used in remote sensing, where it can help identify and quantify landscape features such as rivers, forests, and mountains. Additionally, it has applications in computer vision, where it can help identify and classify complex images, such as recognizing handwritten characters or classifying different types of textures.

References:

Bruno, Odemir Martinez, et al. "Fractal dimension applied to plant identification." *Information Sciences* 178.12 (2008): 2722-2733.

Ghosh, Jayanta Kumar, Ankur Somvanshi, and R. C. Mittal. "Fractal feature for classification of hyperspectral images of Moffit Field, USA." *Current Science* (2008): 356-358.

Acknowledgment:

Based on Alceu Costa (2023). Hausdorff (Box-Counting) Fractal Dimension, (<https://www.mathworks.com/matlabcentral/fileexchange/30329-hausdorff-box-counting-fractal-dimension>), MATLAB Central File Exchange. Retrieved March 5, 2023.

7.7. Filtering and Enhancement Tab

Functions implemented in the **Filtering and Enhancement Tab** allow you to modify your dataset by removing noise as well as other modifications outlined in the table below. Additional functions allow for evaluating the quality of the data and the results of filtering. All changes to the dataset are global, which means the changes are saved internally and replace the original dataset during the computation session. However, no changes are applied to the original data stored in your folder. Your original data are will not be affected.

| Tabs | Function | Additional info |
|-------------------------------|---|----------------------|
| Filtering and Enhancement Tab | Mean Spatial Filter | Dialogue window |
| | Mean Spectral Filter | Applied to the Image |
| | Gaussian Filter | Applied to the Image |
| | NGmeet Filter | Applied to the Image |
| | Spatio-Spectral Total Variation (SSTV) Filter | Dialogue window |
| | FFT Filters (low and high pass) | Dialogue window |
| | Savitzky-Golay Filter | Dialogue window |
| | Asymmetric Least Square Smoothing | Dialogue window |
| | Standard Deviation | Applied to the Image |
| | Decorrelation Stretch | Applied to the Image |
| | Color Inversion | Applied to the Image |
| | Normalization | Additional menu |
| | Contrast Enhancement | Additional menu |
| | Structure Similarity Index | Generates a value |

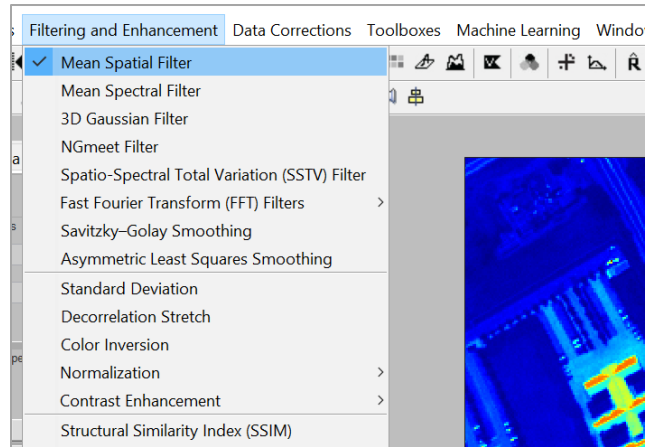
Mean Spatial Filter

NOTE: PAVIA dataset is used as an example.

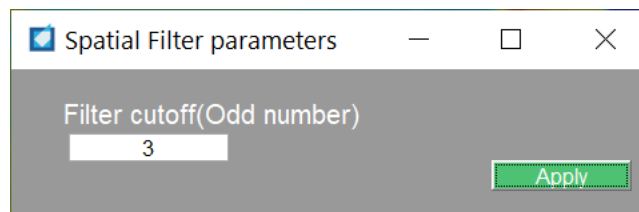
Features: Removes spatial noise in the entire datacube by averaging nearby pixels. This filtering is global and will be retained for all other functions and treatments.

Steps:

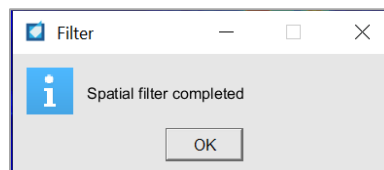
1. Select **Filtering and Enhancement** → **Mean Spatial Filter**.



2. Select the filter cutoff (N) as an odd number from the pop-up dialogue window. The default value is N=3. The filter applies an N-by-N median spatial filter in two spatial dimensions. Each output pixel in the output image contains the median value in the N-by-N neighborhood around the corresponding pixel in the original dataset. The original image is padded by mirroring border elements. Press **Apply**.



3. After completion click **Apply** and visualize the filtered image.



The filtered image can be returned to the original by using **Filtering and Enhancement** → **Remove all Filters and Enhancements** or **Reset** button.

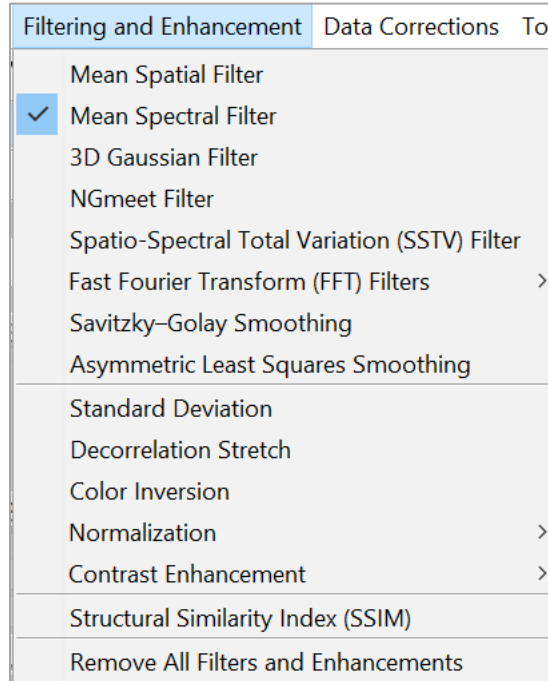
Mean Spectral Filter

NOTE: PAVIA dataset is used as an example.

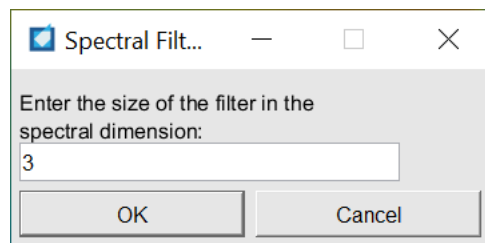
Features: Removes spectral noise in the entire datacube by averaging nearby bands/channels. This filtering is global and will be retained for all other functions and treatments.

Steps:

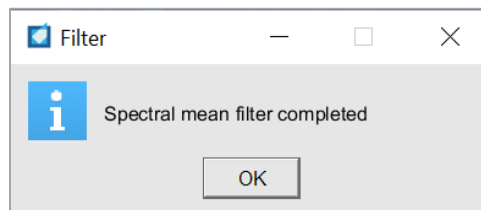
1. Select **Filtering and Enhancement** → **Mean Spectral Filter**.



2. Select the filter parameters. The entered value indicates how many N bands will be averaged. If $N=3$, three signals will be averaged over three bands.



- a. After completion, click **OK** and visualize the filtered image.



- b. The filtered image can be returned to the original by using **Filtering and Enhancement** → **Remove all Filters and Enhancements** or **Reset** button.

NOTE: The **Reset** button is global and will revert all changes.

Additional Information:

The filter applies an N -median spectral filter along the spectral dimensions. Each band/channel in the output dataset contains the median value in the N neighborhood bands/channels around the corresponding band in the original dataset. The original spectral dimension is padded by mirroring border elements.

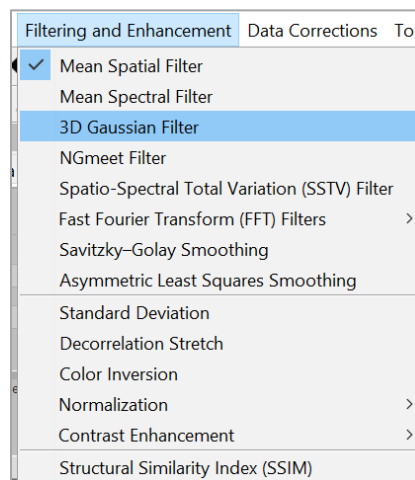
Gaussian Filter

NOTE: PAVIA dataset is used as an example.

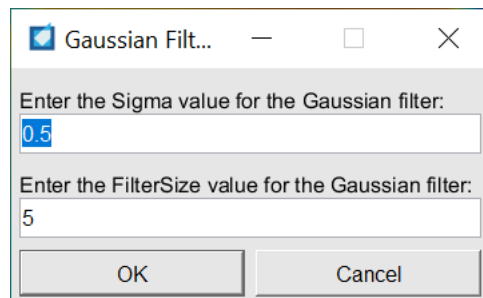
Features: Removes spatial and spectral noise in the entire datacube by applying a Gaussian Filter. This filter is global and will be retained for all other functions and treatments.

Steps:

1. Select **Filtering and Enhancement** → **3D Gaussian Filter**.



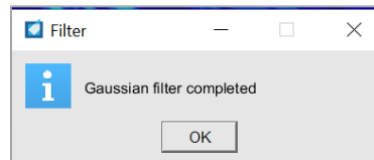
2. A dialogue window will popup:



Sigma: The Sigma is a smoothing parameter and represents the standard deviation of a three-dimensional Gaussian smoothing kernel. This value can either be a scalar (single value) or a vector comprising three positive elements. When Sigma is specified as a scalar, a cubic Gaussian kernel is applied, where the same standard deviation is used in all three dimensions. The default value is 0.5

Filter Size: This is a parameter which can be either a scalar or a three-element vector, consisting of positive, odd integers that determine the dimensions of the Gaussian filter. If a single number Q is provided, the Gaussian filter becomes a cubic filter with dimensions $[Q\ Q\ Q]$. By default, the filter size is calculated as $2\text{ceil}(2\text{Sigma})+1$ (where $\text{ceil}(x)$ rounds the elements of x to the nearest integers towards infinity) which ensures the filter is large enough to cover about two standard deviations on each side of the mean in a Gaussian distribution.

3. After completion, click **OK** and visualize the filtered image.



4. The filtered image can be returned to the original by using **Filtering and Enhancement** → **Remove all Filters and Enhancements** or **Reset** button.

Additional Information:

The algorithm filters the datacube with a 3D Gaussian smoothing kernel with a standard deviation of 0.5 and returns the filtered image. All voxels in the image must have values.

NGMeet filter

NOTE: PAVIA dataset is used as an example.

Features: You can use the NGMeet function to remove noise from hyperspectral data by using the non-local meets global approach.

Steps:

1. Select **Filtering and Enhancement** → **NGmeet Filter**.

| Filtering and Enhancement | Data Corrections | To |
|---|------------------|----|
| Mean Spatial Filter | | |
| Mean Spectral Filter | | |
| 3D Gaussian Filter | | |
| NGmeet Filter | | |
| Spatio-Spectral Total Variation (SSTV) Filter | | |
| Fast Fourier Transform (FFT) Filters | | > |
| Savitzky-Golay Smoothing | | |
| Asymmetric Least Squares Smoothing | | |
| Standard Deviation | | |
| Decorrelation Stretch | | |
| Color Inversion | | |
| Normalization | | > |
| Contrast Enhancement | | > |
| Structural Similarity Index (SSIM) | | |

2. A dialogue window will popup:

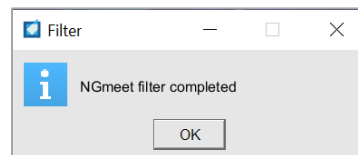
Sigma (level of smoothing): A positive scalar value that controls the level of smoothing. Increasing this value results in more smoothing of input datacube. The default value is 0.1 times of estimated noise variance.

Spectral Subspace: A positive scalar integer value which specifies the number of channels in the reduced datacube on which the denoising process can be applied which improves the algorithm performance and reduces computational complexity. The value of Spectral Subspace must be greater than 0 and less than or equal to number of channels present in CUBE. The default value is 6.

Number of Iterations: A positive scalar integer value which specifies the number of iterations used for denoising process. Increasing this value improves the denoising performance. The default value is 2.

Notes:

1. Increasing Number of Iterations increases the accuracy and execution time. A non-default, smaller Number of Iterations can be specified to trade-off accuracy for execution time.
2. To estimate the value for Spectral Subspace, count Endmembers from running the Endmembers Toolbox.
3. The default value of Sigma is 0.1 times of estimated noise variance. Used standard deviation of a middle channel of the CUBE for estimation of noise.
3. After completion, click **OK** and visualize the filtered image.



4. The filtered image can be returned to the original by using **Filtering and Enhancement** → **Remove all Filters and Enhancements** or **Reset** button.

Additional Information:

The NGMeet method estimates the denoised datacube by using these steps. For each iteration, i

1. Compute spectral low-rank approximation of the noisy input data (Y_i) by using singular value decomposition. The approximation results in a reduced datacube (M_i) and the related orthogonal basis A_i .

2. Perform spatial de-noising of the reduced datacube M_i by using non-local similarity filtering. You can control the degree of smoothing by specifying the smoothing parameter 'Sigma'.
3. Perform inverse projection. Map the denoised reduced datacube M_i to the original space by using the orthogonal basis A_i . The result is the denoised output (X_i) obtained at iteration i .
4. Perform iterative regularization. Update the noisy input data, $Y_{i+1} = \lambda X_i + (1-\lambda)Y_i$.
5. Repeat steps 1 to 4, for the specified number of iterations. The final value X_i is the denoised hyperspectral data.

References:

He, Wei, Quanming Yao, Chao Li, Naoto Yokoya, and Qibin Zhao. "Non-Local Meets Global: An Integrated Paradigm for Hyperspectral Denoising." In *2019 IEEE/CVF Conference on Computer Vision and Pattern Recognition (CVPR)*, 6861–70. Long Beach, CA, USA: IEEE, 2019. <https://doi.org/10.1109/CVPR.2019.00703>.

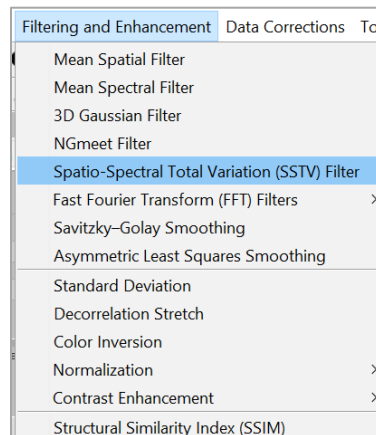
Spatio-Spectral Total Variation (SSTV) Filter

Notes: Plastic and Coin dataset is used as an example.

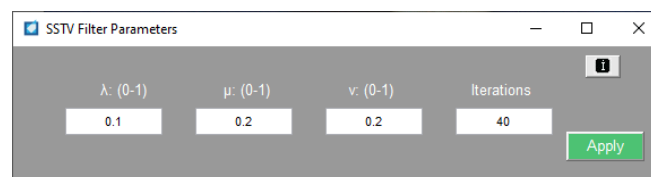
Features: Removes Gaussian and sparse mixed noise.

Steps:

1. Open a file and select **Filtering and Enhancement** → **Spatio-Spectral Total Variation (SSTV) Filter**.

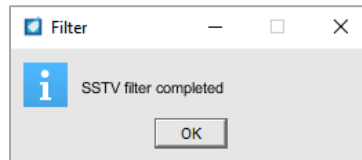


2. Select SSTV filter parameters from the pop-up dialogue window.

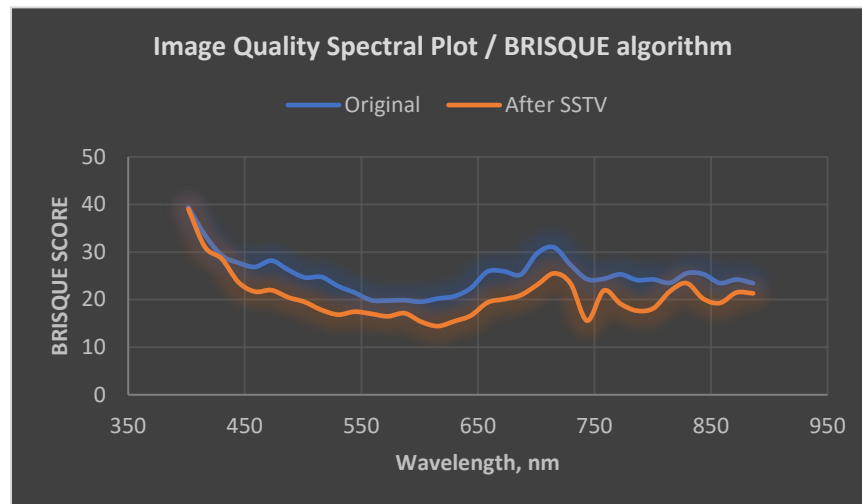


- a. The value of parameter λ adjusts the de-noising strength corresponding to sparse noise, whereas parameters μ and ν provide the tradeoff between retaining the original image and smoothness by total-variation regularization, respectively.

- b. The default parameter values $\lambda = 0.1$, $\mu = 0.2$, and $\nu = 0.2$ have been found empirically (see the ref. below). These parameters can be adjusted to get the desired denoising strength.
 - c. The algorithm seems to be weakly sensitive to the specific values of these parameters and allows a broad range of values. The number of iterations = 40 seems to be optimal to achieve convergence (see the graph below).
 3. After completion, click **OK** and visualize the filtered image.



4. Visualize the results. You can also run **Filtering and Enhancement** → **Image Quality** → **Image Quality (BRISQUE)**. The improvement of the image quality is shown in the chart below. A lower level of BRISQUE score indicates a higher quality of the image.



Notes: The algorithm is computationally demanding. Decreasing the number of iterations might significantly decrease the computation time.

Tip: Optimize the filter's parameters on a smaller size by first cropping the image.

Additional Information:

Gaussian noise is a kind of signal noise that has a probability density function (pdf) equal to that of the normal or Gaussian distribution. Major sources of Gaussian noise in digital images arise during acquisition e.g., sensor noise caused by poor illumination and/or high temperature, electronic circuit noise, and others. The sparse noise includes random valued impulse noise, salt-and-pepper noise, and horizontal and vertical deadlines.

References:

H. K. Aggarwal and A. Majumdar, "Hyperspectral Image Denoising Using Spatio-Spectral Total Variation," in *IEEE Geoscience and Remote Sensing Letters*, vol. 13, no. 3, pp. 442-446, March 2016, doi: 10.1109/LGRS.2016.2518218.

FFT Filters

Low Pass Frequency Domain Spectral Filtering

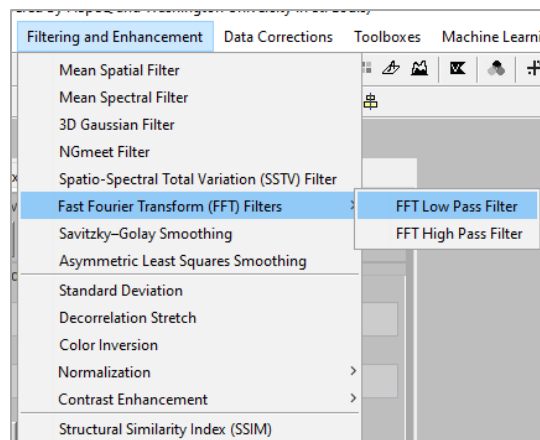
NOTE: PAVIA dataset is used as an example. Can be used in conjunction with the Low Pass FFT function from the SPECTRA MATHEMATICS panel.

Features:

- Use this filter to remove high-frequency components from the spectral coordinate in the entire dataset. No filtering is applied to the spatial coordinates.
- The Fast Fourier Transform (FFT) is used to transform the input spectra. To perform the FFT filters efficiently, IDCube enables users to first optimize and visualize the performance of these filters on a spectrum from the selected regions of interest (available from the SPECTRAL ANALYSIS panel).
- The FFT filtering of the image is performed in three steps automatically. First, the filter executes a pixel-by-pixel Fourier transform of the spectrum, converting the original spectra into their corresponding frequency domain spectra. In the second step, a low-pass filter with a specified cut-off frequency is applied. In the third step, the inverted Fourier transform algorithm is applied to generate a new dataset where only low frequencies are kept.

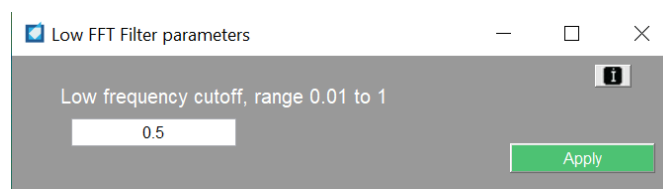
Steps:

1. Load the file.
2. Select **Spectra Mathematics Select** → **FFT Low Pass Filter**.



A pop-up dialog will ask you to enter a **Low-Frequency cutoff** value. A higher value indicates that high frequencies will be removed before the reconstruction resulting in the low-frequency image where 50% of the high frequencies are cut. **NOTE:** that the scale is between 0 and 1.

(To **Visualize Spectra** after FFT analysis, go to the **Spectral Analysis** chapter of this manual).



The resulting image with 50% cutoff high frequencies will be shown in the IMAGE DISPLAY panel.



Similar to other filters, the processed dataset is temporarily stored and available for other processing algorithms.

References:

The algorithm is built using part of the *fftl* library developed by Shmuel Ben-Ezra in 2009:

https://www.mathworks.com/matlabcentral/fileexchange/25017-fft-filter-clean-your-signals-and-display-results?s_tid=srchtitle

High Pass Frequency Domain Spectral Filtering

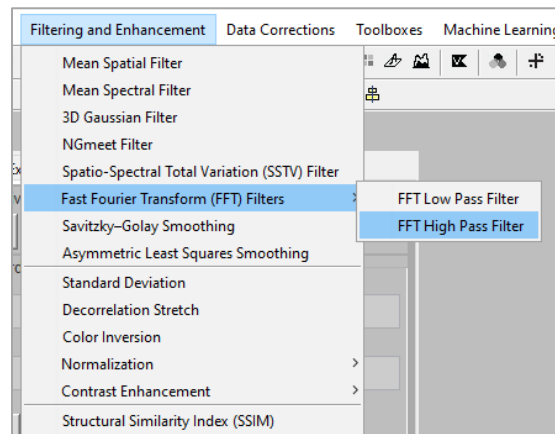
NOTE: PAVIA dataset is used as an example. Can be used in conjunction with the **High Pass FFT** function from the SPECTRA MATHEMATICS panel.

Features:

- Use this filter to remove low-frequency components from the spectral coordinate in the entire dataset. No filtering is applied to the spatial coordinates.
- The Fast Fourier Transform (FFT) is used to transform the input spectra. To perform the FFT filters efficiently, IDCube enables users to first optimize and visualize the performance of these filters on a spectrum from the selected regions of interest.
- The FFT filtering of the image is performed in three steps automatically. First, the filter executes a pixel-by-pixel Fourier transform of the spectrum, converting the original spectra into their corresponding frequency domain spectra. In the second step, a high pass filter with a specified cut-off frequency is applied. In the third step, the inverted Fourier transform algorithm is applied to generate a new dataset where only high frequencies are kept.

Steps:

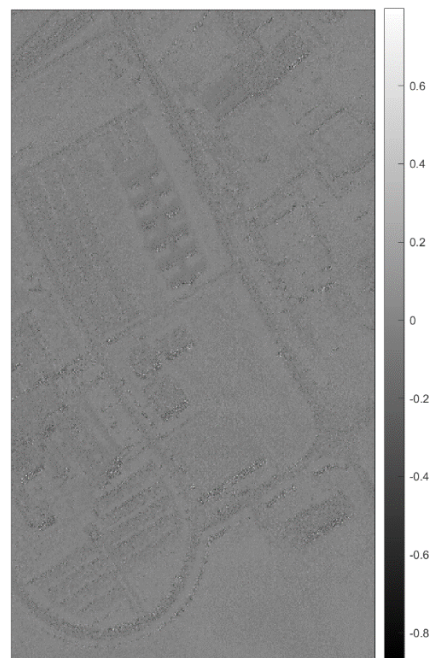
1. Load the file.
2. Select **Spectra Mathematics Select** → **FFT High Pass Filter**.



3. Press **Generate** and put a **Cutoff** value number in the pop-up dialog. The number reflects the % of Nyquist frequency in the range between 0 and 1. A higher value indicates that more low frequencies will be removed before the reconstruction. The value of 0.5 means that 50% of the low frequencies are cut.



(To **Visualize Spectra** after FFT analysis, go to the **Spectral Analysis** chapter of this manual).



Channel: 450, Bandwidth: , Image quality: 42.68

Like most other filters, the filtered dataset is temporarily stored and available for other processing algorithms.

References:

The algorithm is built using part of the *fftl* library developed by Shmuel Ben-Ezra in 2009:

https://www.mathworks.com/matlabcentral/fileexchange/25017-fft-filter-clean-your-signals-and-display-results?s_tid=srchtitle

Savitzky-Golay Filter

NOTE: Plastic dataset is used as an example. Can be used in conjunction with the Savitzky-Golay smoothing from the SPECTRA MATHEMATICS panel.

Features: The filter smooths raw noisy signal data from the spectral coordinate using a least-squares digital polynomial filter.

Steps:

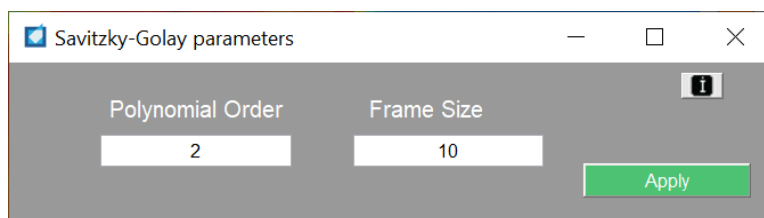
1. Select **Filtering and Enhancement** → **Savitzky-Golay**.

| Filtering and Enhancement | Data Corrections | Tools |
|---|------------------|-------|
| Mean Spatial Filter | | |
| Mean Spectral Filter | | |
| 3D Gaussian Filter | | |
| NGmeet Filter | | |
| Spatio-Spectral Total Variation (SSTV) Filter | | |
| Fast Fourier Transform (FFT) Filters | | > |
| Savitzky-Golay Smoothing | | |
| Asymmetric Least Squares Smoothing | | |
| Standard Deviation | | |
| Decorrelation Stretch | | |
| Color Inversion | | |
| Normalization | | > |
| Contrast Enhancement | | > |
| Structural Similarity Index (SSIM) | | |

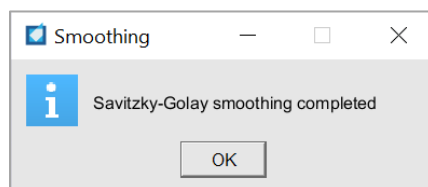
2. The pop-up dialogue window will ask for additional parameters **Polynomial Order** and **Frame size**.

Polynomial Order corresponds to the degree of the polynomial fitted to the points in the moving frame. The default value is 2. Polynomial Order value must be smaller than Frame Size if the frame size is a positive integer. The default value is 10.

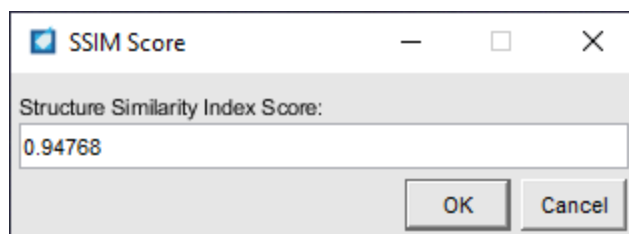
Frame Size modifies the frame size for the smoothing function. If the **Frame Size** value is greater than 1, the rolling window is the size of the input number (i.e., 10) and independent of the number of bands/channels. Higher values smooth the signal more with an increase in computation time. If the **Frame Size** is less than 1, the window size is a fraction of the number of points in the total number of channels. For example, if the **Frame Size** value is 0.05, the window size is equal to 5% of the number of points in the total number of channels.



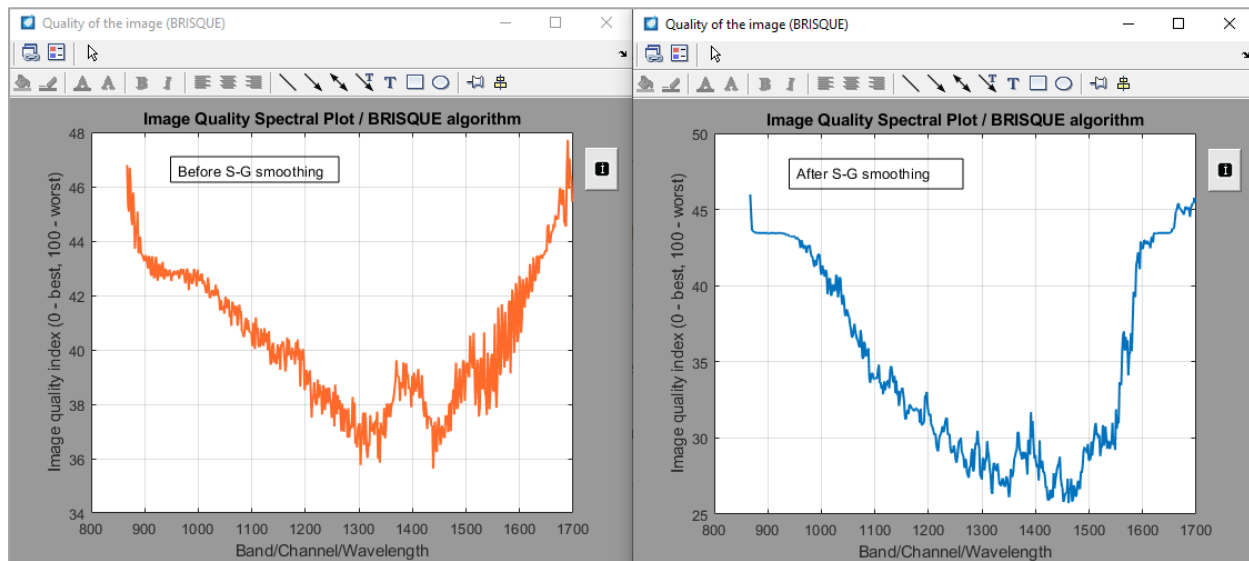
The smoothing of the spectra occurs in a pixel-by-pixel manner. When the process is complete, the new image will replace the original image. A pop-up message box will inform that the process is complete. Click **OK** to remove the message box.



(Optional) You can estimate the effect of the filter on the resulting image by running **the Structure Similarity Index**. For that, select **Filtering and Enhancement** → **Structure Similarity Index** from the menu bar. This index calculates the structural similarity (SSIM) index comparing the original dataset with the filtered one. A value closer to 1 indicates higher similarity and a value closer to 0 indicates low similarity.



(Optional) You can also estimate the result of filtering the images using image quality measurements. For that select **Filtering and Enhancement** → **Image Quality** → **Image Quality (BRISQUE)**. A new window with the image quality index for every channel will be calculated. Lower values correspond to better quality. In this example, Savitzky-Golay smoothing with the default values significantly increases the quality of the images between 1100 nm and 1550 nm.



Additional Information:

IDCubePro® uses a modified version of the Savitzky-Golay algorithm. The original algorithm developed by Savitzky and Golay assumes the input vector corresponding to the band/channel dimension has uniformly spaced separation units, while the current algorithm also allows one that is not uniformly spaced.

When the input bands/channels vector is evenly spaced, the least-squares fitting is performed once so that the signal is filtered with the same coefficients, and the speed of the algorithm increases considerably.

The algorithm specifies the degree of the polynomial fitted to the points in the moving frame. The default order of the polynomial fitted to the points in the moving frame is equal to 2. The default frame size is 10 samples. Both parameters can be modified in the IDCubePro®.

Asymmetric Least Square Smoothing

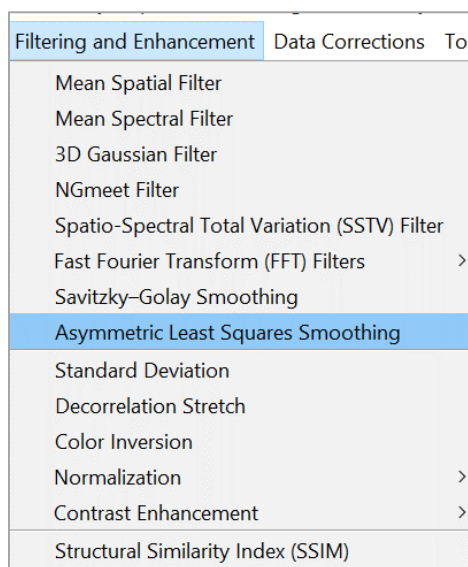
NOTE: Plastic and Coin dataset (cropped) is used as an example.

Features: The filter is based on asymmetric least squares smoothing for multiple spectra baseline correction. The algorithm also eliminates scatter effects on the spectra.

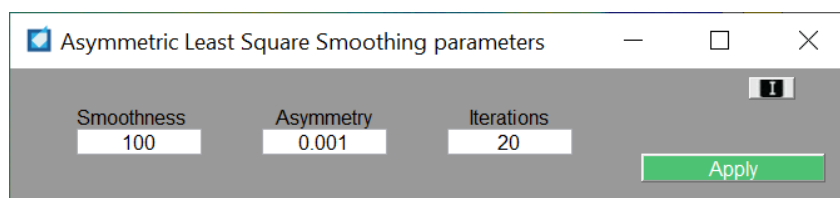
For large images, Asymmetric Least Square Smoothing might be computationally expensive. The algorithm might take several minutes depending on the size of the image and the number of iterations. We recommend using **Spectrum Background Removal** implemented in the **Feature Finder toolbox** from the **Toolbox** menu to optimize parameters.

Steps:

1. Load a file and select **Filtering and Enhancements** → **Asymmetric Least Square Smoothing**.



2. Select the smoothing parameters from the pop-up dialog.

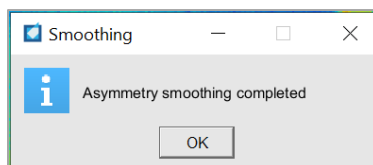


Smoothness defines how smooth the baseline should be (default 100).

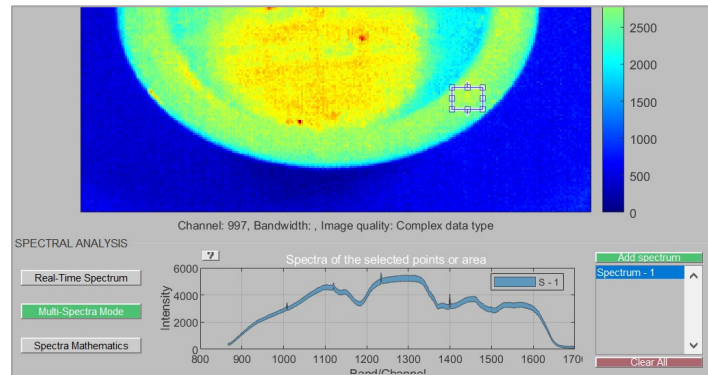
Asymmetry defines how "low" the baseline should be. The range is from 0 to 1. Lower peaks require asymmetry approaching 0, while high peaks require asymmetry value approaching 1.

Iterations define the number of iterations to reach the converge (default 20). The calculation time is proportional to the number of iterations.

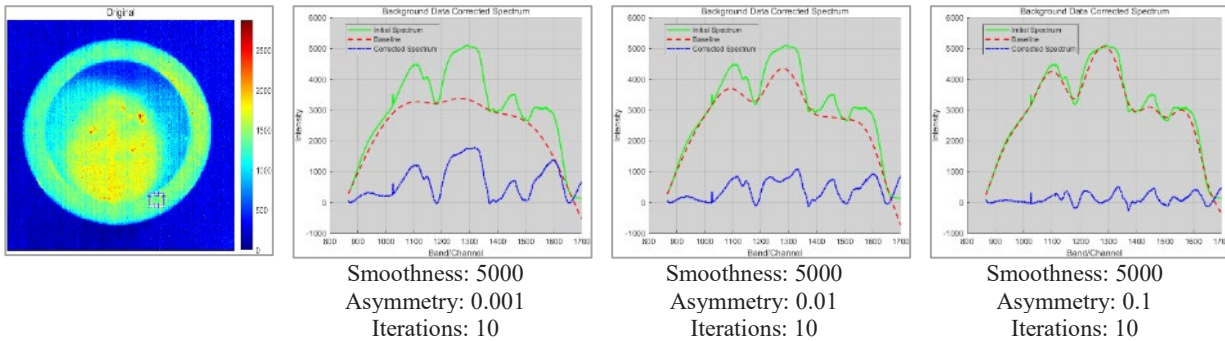
3. Press **Apply** and visualize the smoothed image after the computation is complete.



4. (optional) Click **Multi-Spectra Mode** in the SPECTRAL ANALYSIS panel and draw a region of interest to visualize the spectrum before and after the smoothing procedure. The original spectrum (shown as mean \pm standard deviation) shows numerous sharp peaks related to noise. After filtering, the new spectrum shows no sharp peaks and a much smaller standard deviation.



We recommend using the **Feature Finder** toolbox to optimize filter parameters. **Feature Finder** toolbox has an option to generate three spectra: the original spectrum (green line), the baseline spectrum (red dotted line), and the corrected spectrum (blue solid line). *Corrected spectrum = Original spectrum – Baseline Spectrum*. An example of this optimization with the adjusted Asymmetry parameter is shown below.



Reference:

Eilers, P. H., & Boelens, H. F. (2005). Baseline correction with asymmetric least squares smoothing. *Leiden University Medical Centre Report*, 1(1), 5.

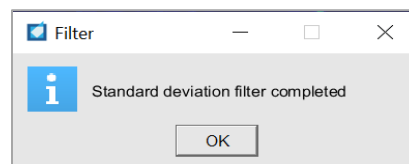
Standard Deviation Filter

NOTE: PAVIA dataset is used as an example.

Features: Modifies the dataset with a Standard Deviation filter to visualize the edges of the objects. This filter is global and will be retained for all other functions and treatments.

Steps:

Select **Filtering and Enhancement** → **Standard Deviation filter**. After completion, click **OK** and visualize the filtered image.



The filtered image can be returned to the original image by using **Filtering and Enhancement** → **Remove all Filters and Enhancements** or **Reset** button.

Additional Information:

The algorithm performs standard deviation filtering of the dataset (spatial only) for each frame and returns the filtered image. The value of each output pixel is the standard deviation of the 3-by-3 neighborhood around the corresponding input pixel. For pixels on the borders, the algorithm uses symmetric padding where the values of padding pixels are a mirror reflection of the border pixels.

Decorrelation Stretch

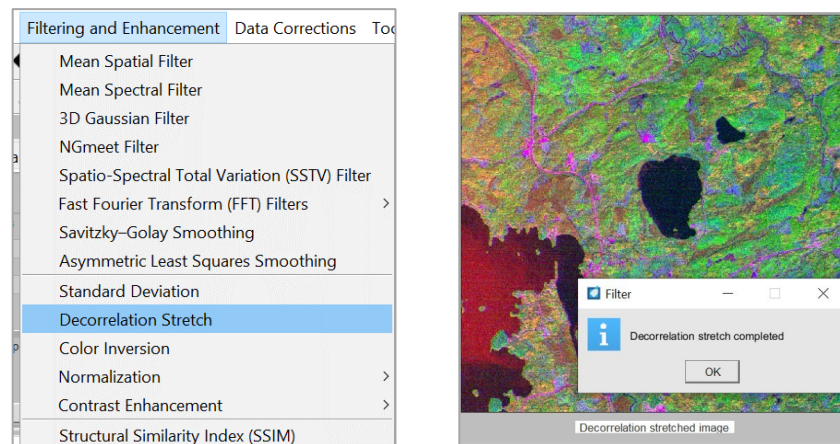
NOTE: PAVIA dataset is used as an example.

Features:

- Applies a decorrelation stretch to the dataset. The primary purpose of decorrelation stretch is visual enhancement.
- Decorrelation stretching is a way to enhance the color differences in an image.
- This filter is global and will be retained for all other functions and treatments.

Steps:

1. Select **Filtering and Enhancement** → **Decorrelation Stretch**. Visualize the resulting image after the decorrelation stretch is completed.



The image can be returned to the original by using the **Filtering and Enhancement** → **Remove all Filters and Enhancements** or **Reset** button. **NOTE:** **Reset** button is global and will revert the processed dataset back to the original dataset.

Color Inversion

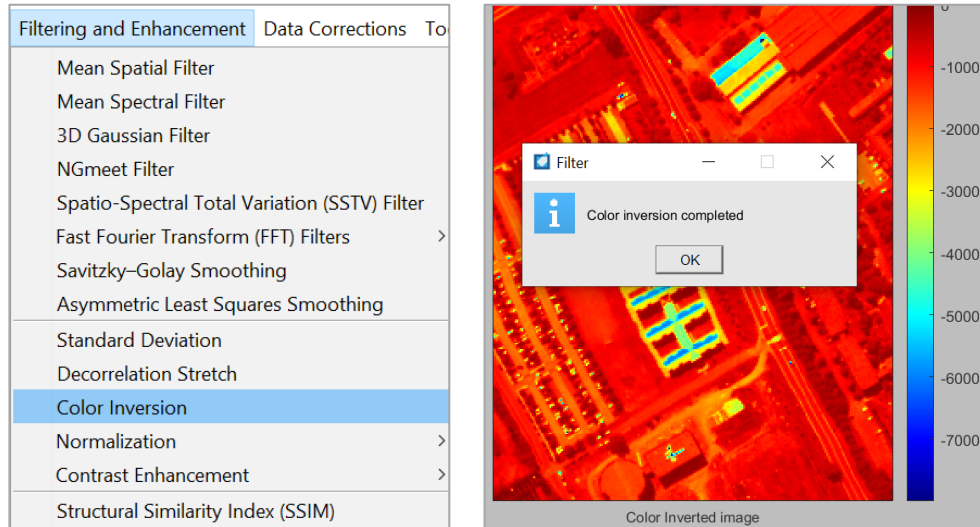
NOTE: PAVIA dataset is used as an example.

Features: The algorithm computes the complement of the image where black and white colors are reversed. In the output image, dark areas become lighter and light areas become darker. For color images, reds become cyan, greens become magenta, blues become yellow, and vice versa.

This operation is global and will be retained for all other functions and treatments.

Steps:

1. Select **Filtering and Enhancement** → **Color Inversion**. Visualize the complement (inverted) image.



The Color Inversion algorithm can also be applied to the **RGB** presentation. Each color channel of the resulting image is the complement of the corresponding complementary color channel in the original image. Dark regions become light, red colors become cyan, green colors become magenta, blue becomes yellow, and vice versa. Below is an example of the original pseudo RGB image [w1=466 nm, w2=725 nm, w3=671 nm] (Left) and its complement (Right).

Original pseudo RGB image

Complement pseudo RGB



This inverted image can be returned to the original by using the **Filtering and Enhancement** → **Remove All Filters and Enhancements** or **Reset** button.

Additional Information:

In the complement of a grayscale or color image, each pixel value is subtracted from the maximum pixel value. The difference is used as the pixel value in the output image. In the output image, dark areas become lighter and light areas become darker. For color images, reds become cyan, greens become magenta, blues become yellow, and vice versa.

Normalization

Normalization [0 1]

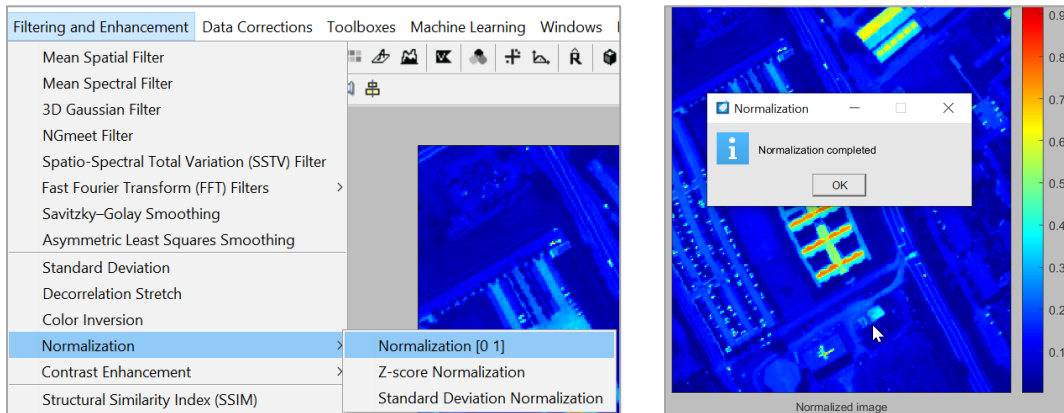
NOTE: PAVIA dataset is used as an example.

Features:

- Applies a normalization algorithm to the spectral axis of the dataset having all intensity values in the range between 0 and 1.
- This operation is global and will be retained for all other functions and treatments.

Steps:

Select **Filtering and Enhancement** → **Normalization** → **Normalization [0 1]**. Visualize the normalized image. The colorbar values are between 0 and 1.



This rescaled image can be returned to the original by using **Filtering and Enhancement** → **Remove all Filters and Enhancements** or **Reset** button.

NOTE: PAVIA is used as an example.

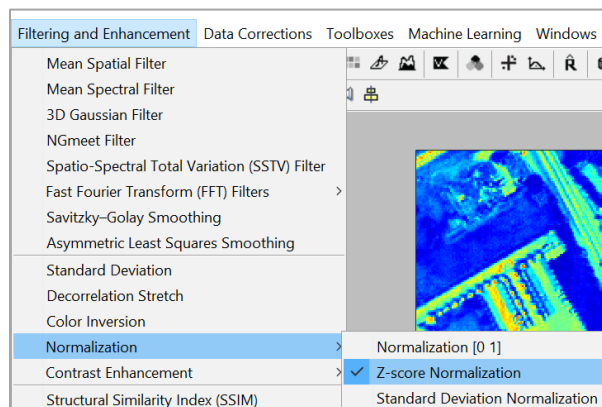
Features:

Applies a normalization algorithm to the spectral axis of the dataset having all intensity values in the range of the Z-score. Z-score describes the deviation from the mean in a number of standard deviations. The Z-score is positive when the sample is above the mean and negative when below.

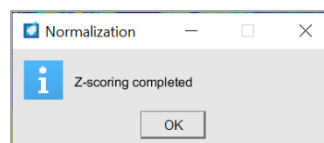
This operation is global and will be retained for all other functions and treatments.

Steps:

1. Select **Filtering and Enhancement** → **Normalization** → **Z-score Normalization**



2. After completion, click **OK** and visualize the normalized image. The colorbar values are within the Z-score.



3. This rescaled image can be returned to the original by using **Filtering and Enhancement** → **Remove all Filters and Enhancements** or **Reset** button.

Tip: Use the histogram to visualize parts of the image with positive or negative Z score values.

Additional Information:

Z-Score calculation:

$$z = (x-m)/\sigma$$

where x is the sample value, m is the sample mean, and σ is the standard deviation of the distribution. z describes the deviation from the mean in a number of standard deviations and is positive, when the sample is above the mean, and negative when below.

Contrast Enhancement

NOTE: PAVIA dataset is used as an example.

Features: Improves the visualization of the image through image-improving algorithms such as Image Adjustment, Histogram Equalization, and Contrast-Limited Adaptive Histogram Equalization (CLAHE). The algorithms convert the low-contrast image into a higher contrast.

Image Adjustment increases the contrast of the image by mapping the values of the input intensity image to new values, by default, 10% of the data is saturated at low and high intensities of the input data.

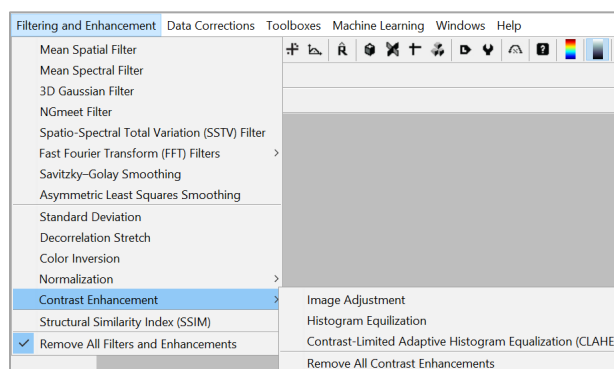
Histogram Equalization performs image histogram equalization. It enhances the contrast of images by transforming the values in an intensity image so that the histogram of the output image approximately matches a specified histogram (uniform distribution by default).

Contrast-Limited Adaptive Histogram Equalization (CLAHE) performs contrast-limited adaptive histogram equalization. Unlike **Histogram Equalization**, it operates on small data regions (tiles, default 8x8) rather than the entire image. Each tile's contrast is enhanced so that the histogram of each output region approximately matches the specified histogram (uniform distribution by default). The contrast enhancement can be limited to avoid amplifying the noise which might be present in the image.

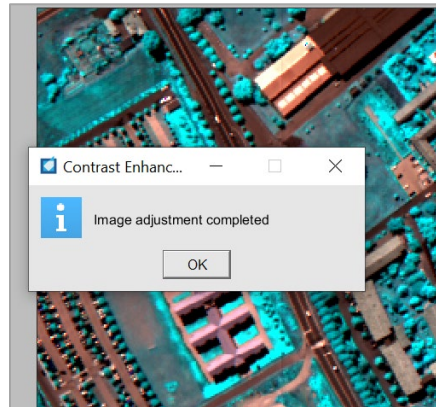
NOTE: to apply these algorithms, the image will be first converted into a pseudo-RGB mode with random channels.

Steps:

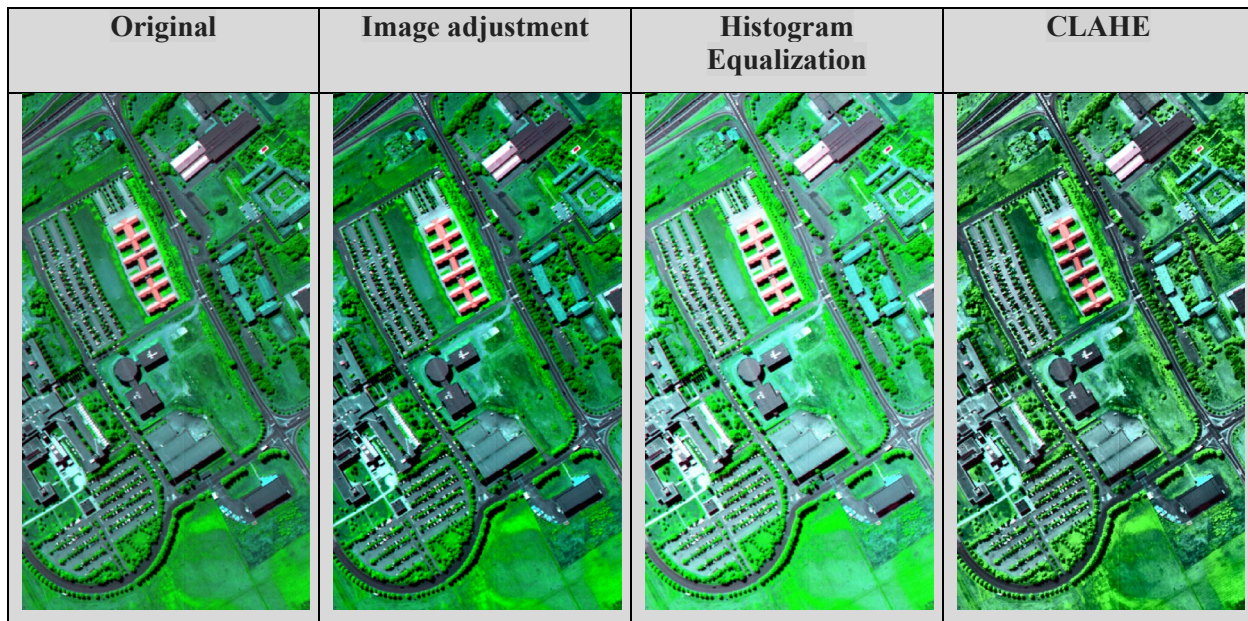
1. Select **Filtering and Enhancement** → **Contrast enhancement** → **Image adjustment (Histogram Equalization, or CLAHE)**.



2. After completion, click **OK** and visualize the image in the pseudo-RGB format.



Examples of different image adjustments.



- This resulting image can be returned to the original by using **Filtering and Enhancement** → **Remove all Filters and Enhancements** or **Reset** button.

Reference

Zuiderveld, Karel. “Contrast Limited Adaptive Histogram Equalization.” *Graphic Gems IV*. San Diego: Academic Press Professional, 1994. 474–485.

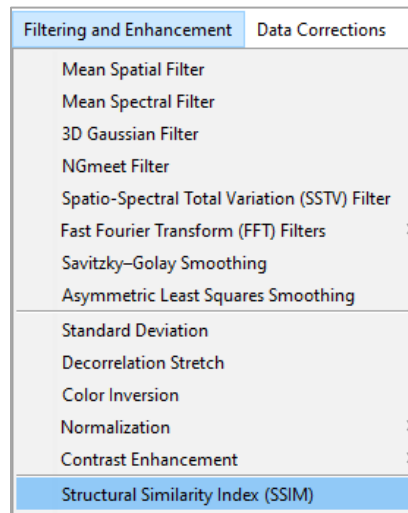
Structure Similarity Index (SSIM)

NOTE: The structural similarity index (SSIM) is only possible between two datasets of the same dimensions.

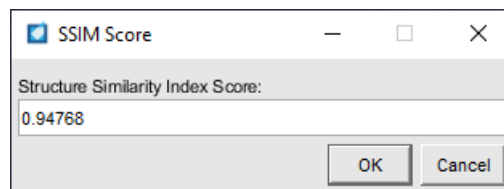
Features: Calculates the SSIM score for 3D datasets after datacube processing using the original datacube as the reference image. This metric quantifies image changes caused by processing such as data filtering. A value closer to 1 indicates a higher similarity to the original image.

Steps:

1. Open a file and perform one of the image processing algorithms. For example, remove Gaussian noise by selecting **Filtering and Enhancement** → **3D Gaussian filtering**.
2. After the filter is applied and completed, select **Filtering and Enhancement** → **Structure Similarity Index**.



A new pop-up window **SSIM Score** will produce the calculated structural similarity index. A value closer to 1 indicates higher similarity and a value closer to 0 indicates low similarity.

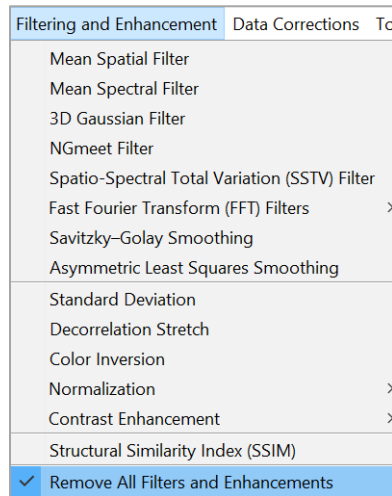


References:

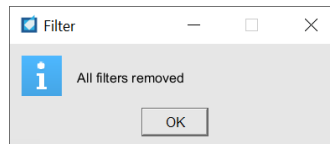
Wang, Z., Simoncelli, E.P., Bovik, A.C. *Multiscale Structural Similarity for Image Quality Assessment*. In: *The Thirty-Seventh Asilomar Conference on Signals, Systems & Computers*, 2003, 1398–1402. Pacific Grove, CA, USA: IEEE, 2003. <https://doi.org/10.1109/ACSSC.2003.1292216>

Remove All Filters and Enhancements

Feature: The function is equivalent to Reset. It removes all changes and return the dataset to the original one.



After completion a window will pop-up



7.8. Data Corrections Tab

Functions under the Data Corrections tab apply corrections to hyperspectral data related to issues with data acquisition or object properties. The tab handles issues with uneven illumination, light scattering in thick materials, distortion of optics, and other common problems.

| Tabs | Function | Additional info |
|----------------------|---|------------------|
| Data Corrections Tab | Background Data Correction | Interactive menu |
| | Continuum Hull Removal | Method selection |
| | Polynomial Baseline Removal | Method selection |
| | Flat Field Correction | Interactive menu |
| | Multiplicative Scatter Correction (MSC) | Interactive menu |
| | Standard Normal Variate (SNV) | Interactive menu |

Background Data Correction

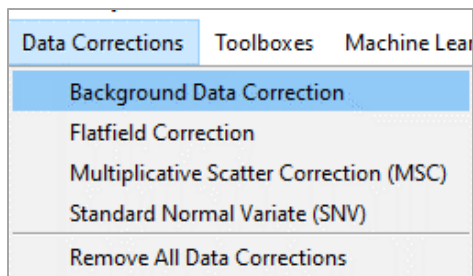
NOTE: PAVIA dataset is used as an example.

Features: Performs background data correction of the entire dataset based on the selected area (background area).

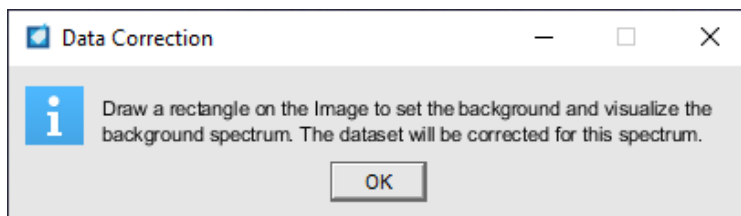
Steps:

1. Open a file.

2. Select **Data Corrections** → **Background data correction**.

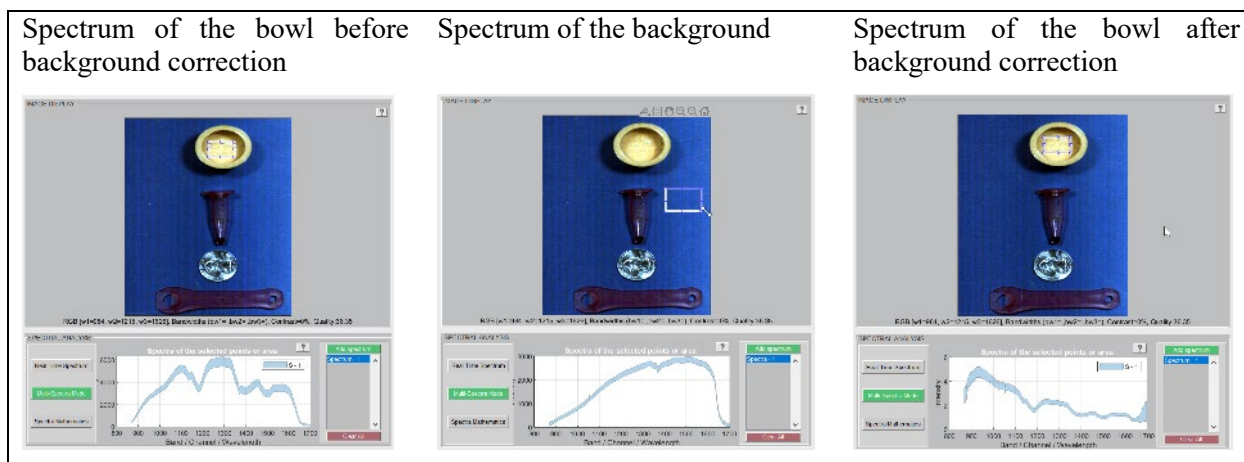


A pop-up message will ask to draw a region on the image that will be used as a background.



3. Draw an area that can be used as a background. The spectrum of the background will appear in the SPECTRAL ANALYSIS panel. The entire dataset will be corrected for the selected background within a few seconds.

The effect of this procedure is illustrated in the following table.



Continuum Hull Removal from the Image

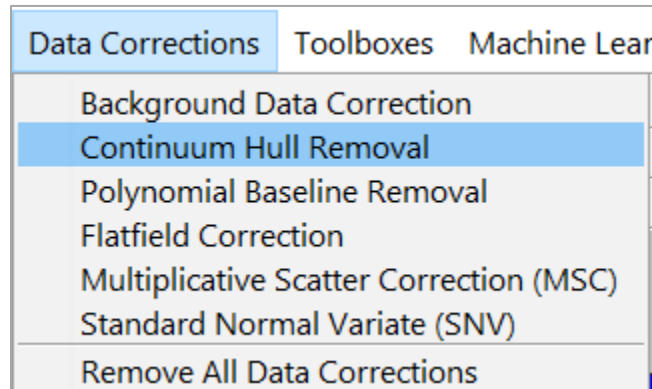
NOTE: Plastic and Coin dataset is used as an example. See also **Continuum Hull Removal** from the SPECTRAL MATHEMATICS panel.

Features: Enables rapid removal of continuum hull from the spectra across the entire dataset. See also **Continuum hull removal from spectrum** section.

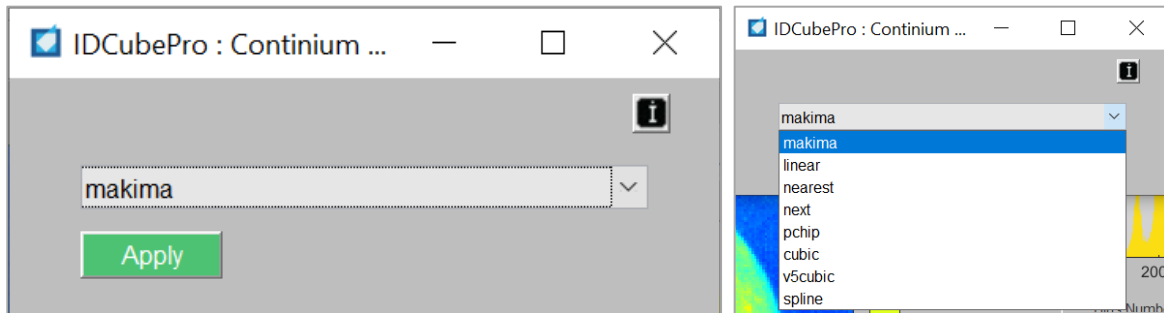
Additional Information

Continuum hull removal is a pre-processing technique used in hyperspectral image analysis to remove the spectral continuum from the data. The spectral continuum refers to the background signal in the image that is not associated with any specific spectral features or information. This background signal can obscure or distort the spectral information of interest, making it more difficult to analyze and interpret the data.

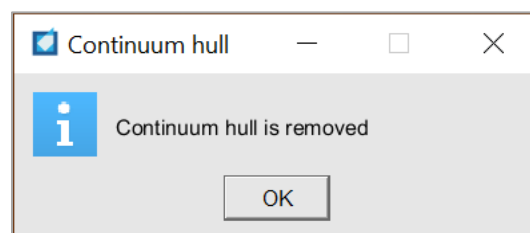
Step 1. Select **Data Correction** Tab and press **Continuum Hull Removal**.



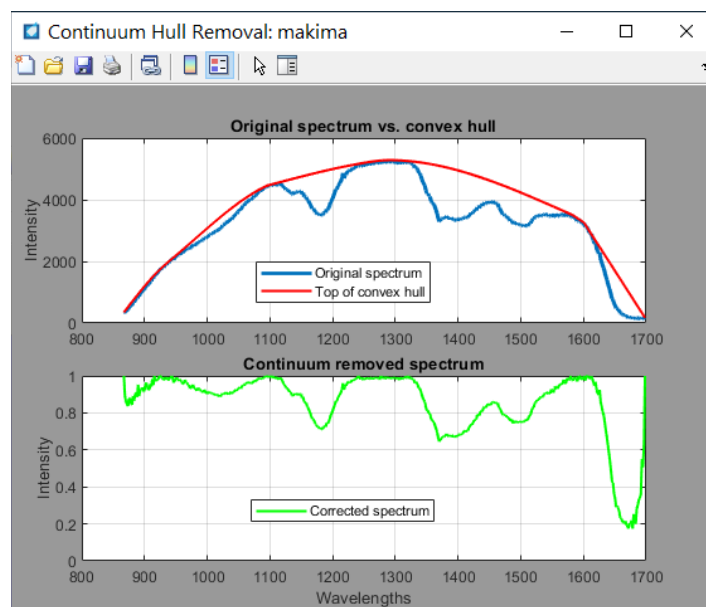
Step 2. Select a method from a popup dialogue and press **Apply**.



Step 3. The completion of the algorithm will be informed by a message box.



The choice of the method is usually made by trial and error (use also **Continuum Hull Removal** from the SPECTRAL MATHEMATICS panel to visualize the removal on a specific region of interest. For example, after application of 'makima' the corrected spectrum will look like shown below:



| Method | Description | Comments |
|-----------|--|--|
| 'makima' | Modified Akima cubic Hermite interpolation. The data is modeled using a cubic polynomial that is based on a set of Hermite basis functions, which are used to interpolate the data. The Modified Akima method improves upon the Akima method by adding a smoothing factor that reduces the impact of any noisy or erratic data points on the interpolation results | particularly useful in situations where the data is noisy or contains outliers, as it can provide a smooth interpolation. Memory requirements are like those of 'spline'. |
| 'linear' | Linear interpolation. The interpolated value at a query point is based on linear interpolation of the values at neighboring grid points in each respective dimension. This is the most common interpolation method. | Requires more memory and computation time than nearest neighbor. |
| 'nearest' | Nearest neighbor interpolation. The interpolated value at a query point is the value at the nearest sample grid point. | Modest memory requirements Fastest computation time |
| 'next' | Next neighbor interpolation. The interpolated value at a query point is the value at the next sample grid point. | Same memory requirements and computation time as 'nearest' |
| 'pchip' | Shape-preserving piecewise cubic interpolation. The interpolated value at a query point is based on a shape-preserving piecewise cubic interpolation of the values at neighboring grid points. | Requires more memory and computation time than 'linear'. |
| 'cubic' | Cubic convolution used in MATLAB 5. | Points must be uniformly spaced. |
| 'v5cubic' | Same as 'cubic'. | This method falls back to 'spline' interpolation for irregularly spaced data. Similar memory requirements and computation time as 'pchip' |
| 'spline' | A spline is a piecewise polynomial function that is defined by a set of control points, which are the known data points in the case of spline | Uses the cubic spline as it provides a good balance between smoothness |

| Method | Description | Comments |
|--------|--|---|
| | interpolation. The spline curve is constructed by fitting a series of polynomial segments to the control points, with the requirement that the curve is smooth and continuous at each control point. | and accuracy Requires more memory and computation time than 'pchip' |

The continuum hull removal technique involves estimating the continuum spectrum using a polynomial or other mathematical function and subtracting it from the original hyperspectral data. The goal is to remove the background signal while preserving the spectral information of interest. The specific method used for continuum hull removal may depend on the characteristics of the data and the analysis goals. After the continuum is estimated and subtracted, the resulting data is referred to as the "continuum-removed" spectrum. This spectrum represents the spectral features of the image without the background signal, making it easier to identify and analyze the specific spectral signatures associated with different materials or phenomena.

Acknowledgement

The code in part was developed by Marian-Daniel Iordache, Copyright (April 14, 2016):

Polynomial Baseline Removal from the Image

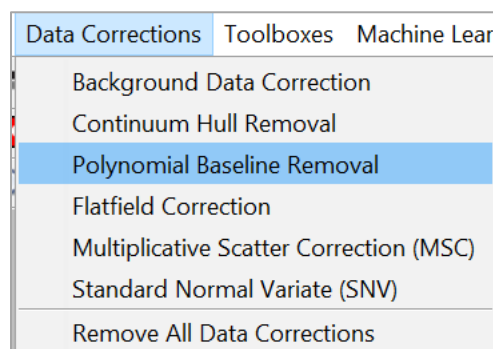
NOTE: Plastic and Coin dataset is used as an example. See also **Polynomial Baseline Removal** from the SPECTRAL MATHEMATICS panel.

Features: Enables removing of the baseline from the spectra across the entire dataset. It can improve the accuracy of data analysis by removing unwanted noise and artifacts in the signal.

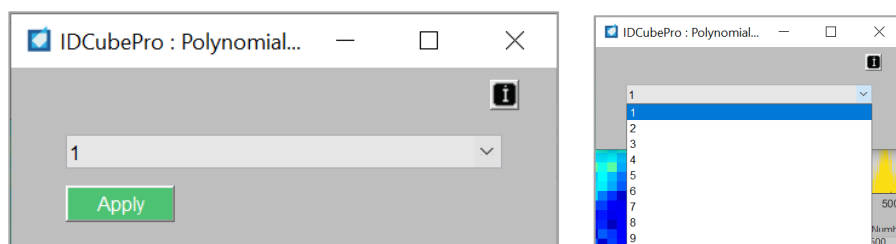
Additional Information

Polynomial baseline removal is a pre-processing technique used in hyperspectral image analysis to remove the baseline from the data. The idea behind Polynomial Baseline Removal is to fit a polynomial function to the baseline of the signal and then subtract it from the original signal to obtain the corrected signal.

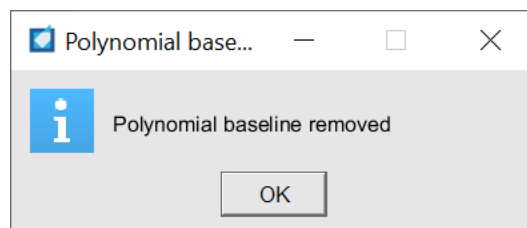
Here are the steps involved in performing **Polynomial Baseline Removal**. Go to **Data Corrections** tab and select **Polynomial Baseline Removal**.



Select the degree of polynomial (from 1 to 9) and click **Apply** to perform fitting



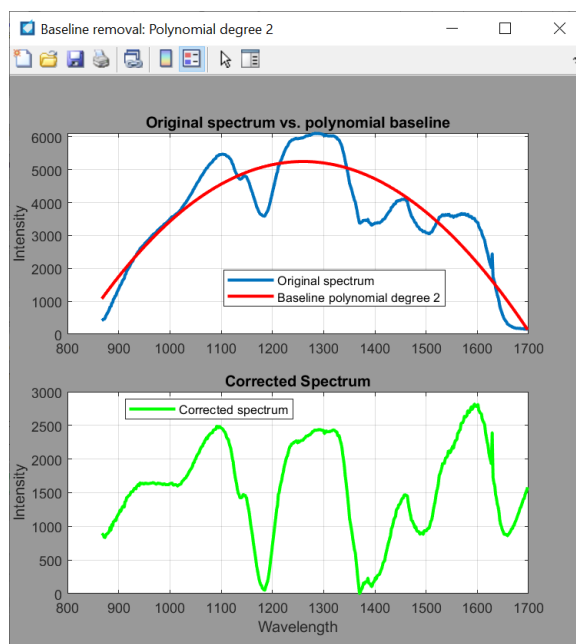
After the conversion a pop-up message will appear:



Additional Information

The algorithm performed four steps: **1.** Fits a polynomial function to the baseline with the selected degree of the polynomial function depends on the complexity of the baseline simple linear function (degree=1) or a higher-degree polynomial function (degree > 1). **2.** Subtracts the polynomial function from the original signal. **3.** Shifts the spectrum to have minimum values at zerois. **4.** Moves to another pixel and perform the procedures 1-3.

The choice of the degree of the polynomial function is usually made by trial and error (use **Polynomial Baseline Removal** from the SPECTRAL MATHEMATICS panel to visualize the removal on a specific region of interest. For example, after application of the 2 degree polynomial the corrected spectrum will look like shown below.



The polynomial function fits to the spectrum using a least-squares regression algorithm. The polynomial order is typically chosen based on the noise level and complexity of the data, with higher-order polynomials

providing more accurate fits but also increasing the risk of overfitting. After the baseline is estimated and subtracted, the resulting spectrum data are shifted to have minimum value at zero. The final spectrum is referred to as the "baseline-removed" spectrum. The entire algorithm is performed over all pixels in the image. This spectrum represents the spectral features of the image without the background signal, making it easier to identify and analyze the specific spectral signatures associated with different materials or phenomena.

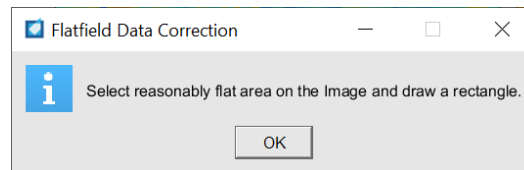
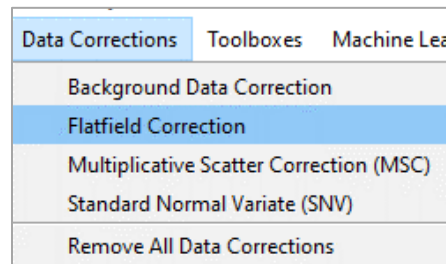
Flatfield Correction

NOTE: PAVIA dataset is used as an example.

Features: Performs flat field correction on the entire dataset. This post-imaging procedure cancels the effects of image artifacts caused by variations in the detector or the light sources resulting in a more uniform (flatfield) output with more uniform color and brightness across the frame.

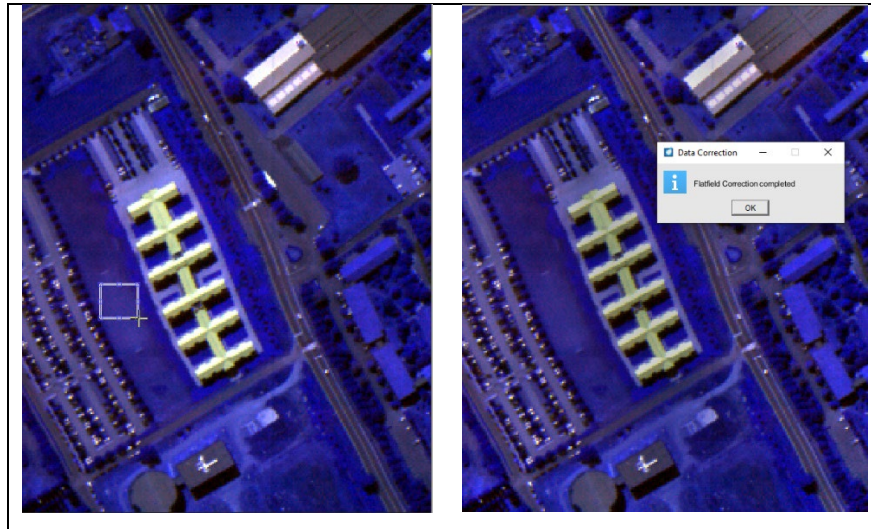
Steps:

1. Open a file.
2. Select **Data Corrections** → **Flatfield correction**. A pop-up dialogue window will ask to identify a reference spectrum.

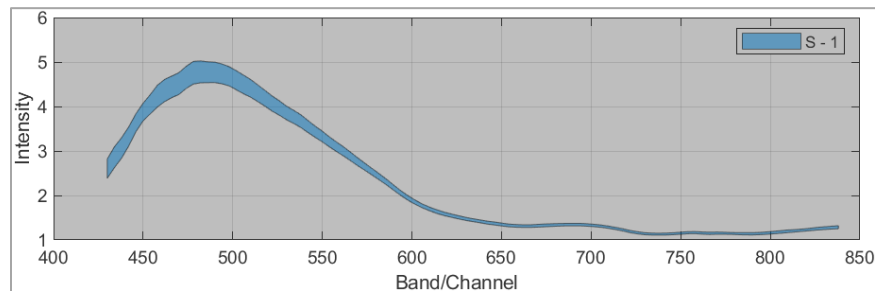


4. Click **OK** and draw an area that needs to be corrected. A valid ROI has these characteristics:
 - a. Topographically flat
 - b. Spectrally flat (uniform spectral response)
 - c. Shows a strong signal source to reduce the impact of random noise

| Original image | After flatfield correction |
|----------------|----------------------------|
|----------------|----------------------------|



The entire dataset will be corrected for the selected area. The spectrum of the middle structure is corrected for the flat field.



References:

Roberts, D. A., Yamaguchi, Y., and Lyon, R., "Comparison of various techniques for calibration of AIS data" in Proc. of the 2nd Airborne Imaging Spectrometer Data Analysis Workshop, 1986, JPL Publication, 86-35, pp. 21-30.

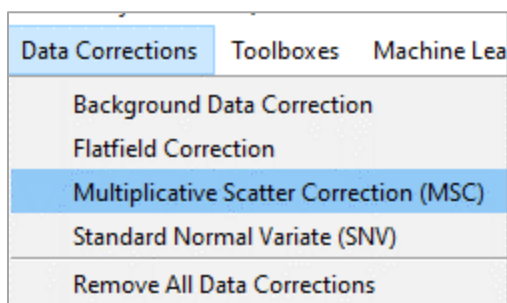
Multiplicative Scatter Correction (MSC)

NOTE: Plastic and Coin dataset is used as an example.

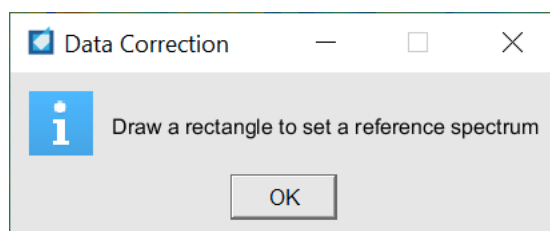
Features: Corrects spectra in the datacube.

Steps:

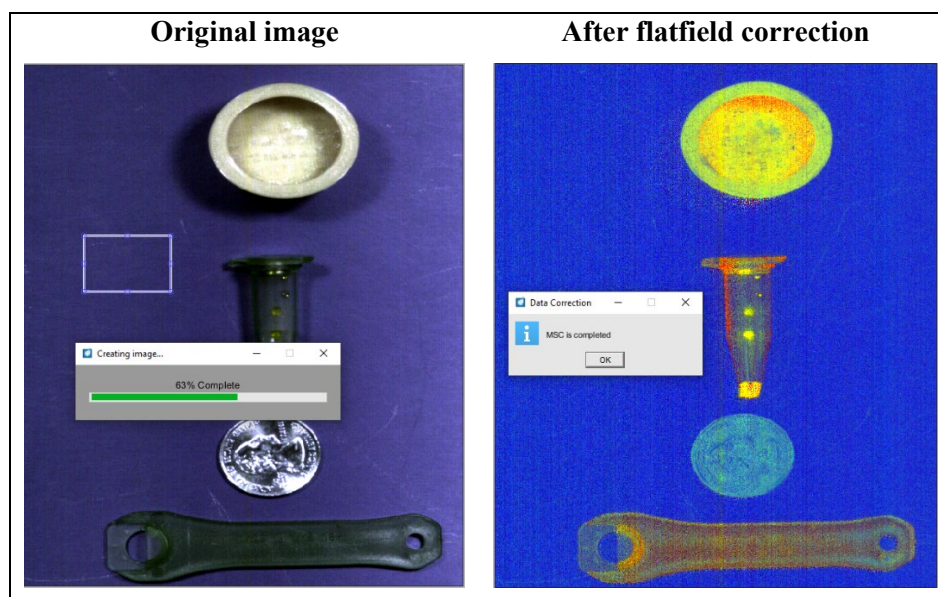
1. Open a file and select **Data Correction** → **Multiplicative scattering correction (MCS)**.



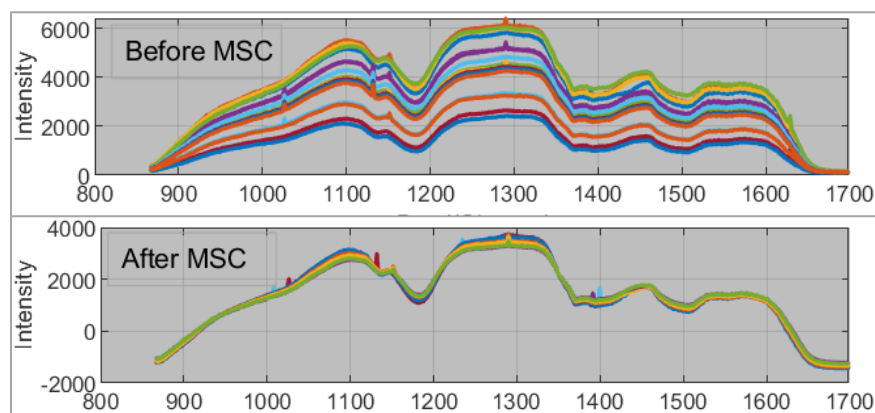
2. A pop-up dialogue window will ask to identify a reference spectrum.



3. Click OK and draw an area. A mean spectrum from this area will serve as a reference spectrum. When selecting an area select a more or less uniform part of the image. After the calculations are complete, visualize the resulting image that is corrected for scattering.



The effect of MSC can be visualized by looking at the individual spectra from one of the objects. For example, spectra from the multiple spots in the plastic bowl (located at the top of the image) show large changes. After correction with MSC, all spectra are much more similar.



Additional Information:

Performing scattering correction is generally a challenging task and ideally gets rid of all effects that are unrelated to the chemical nature of the sample, but it depends on the sample morphology and measurement geometry.

Multiplicative scatter correction (MSC) is a widely used classic normalization technique to correct spectra in such a way that they are as close as possible to a reference spectrum. In IDCube the reference spectrum is the mean of the selected area.

MSC requires a reference spectrum. This is the most important difference between MSC and SNV which is also implemented in IDCube.

The reference spectrum is ideally a spectrum free of scattering effects. For the reference spectrum, we suggest selecting a uniform area with minimum changes in morphology. If the spectral data are reasonably uniform, the average spectrum from the area is a close approximation to the ideal reference spectrum. This is the main assumption behind MSC.

Mathematically, if X_m is the mean spectrum from the area, the multiplicative scatter correction is done in two steps. We first regress a spectrum for each pixel X_i against the mean spectrum. This is done by ordinary least squares:

$$X_i \approx a_i + b_i X_m$$

The corrected spectrum for each pixel is then calculated:

$$X_{imsc} = (X_i - a_i) / b_i$$

References:

Isaksson, Tomas, and Tormod Næs. "The effect of multiplicative scatter correction (MSC) and linearity improvement in NIR spectroscopy." *Applied Spectroscopy* 42.7 (1988): 1273-1284.

Burger, James, and Paul Geladi. "Spectral pre-treatments of hyperspectral near-infrared images: analysis of diffuse reflectance scattering." *Journal of Near Infrared Spectroscopy* 15.1 (2007): 29-37.

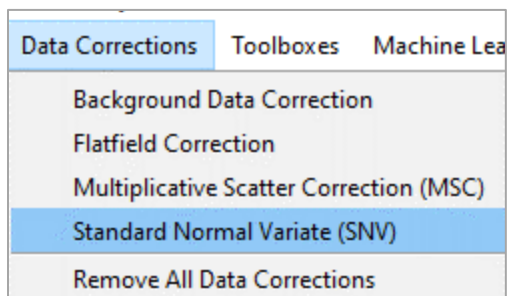
Standard Normal Variate (SNV)

NOTE: Plastic and Coin dataset is used as an example.

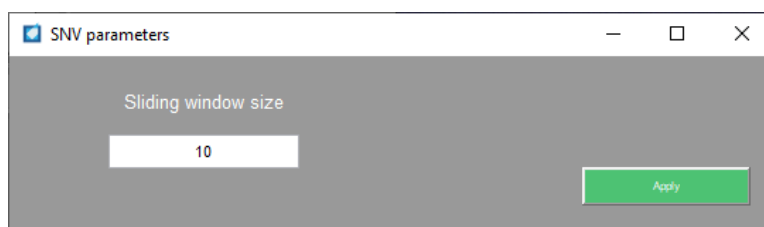
Features: Removes light scattering from the image and reduces differences in the global intensities of the signals.

Steps:

1. Open a file. Select the **Data Correction tab** and select **Standard Normal Variate (SNV)**.

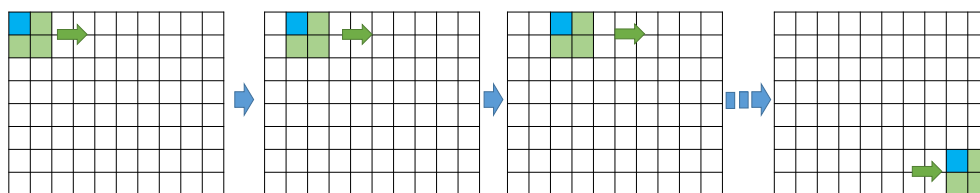


2. From the pop-up dialogue window, select a **Sliding window size**. The default value is 10, which is equivalent to 10x10 pixels.

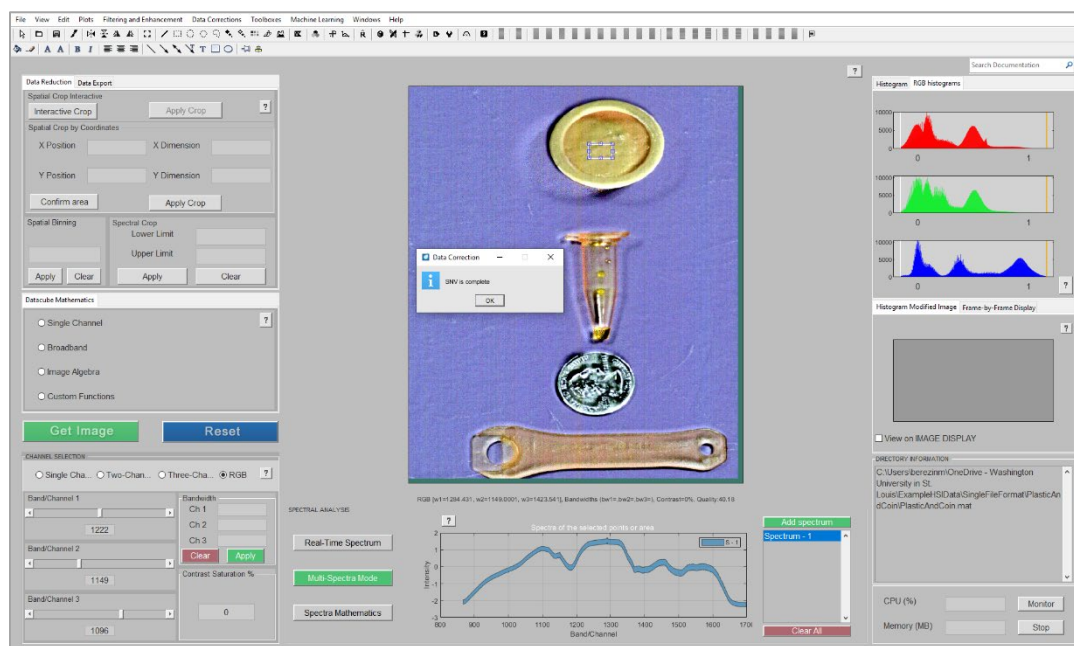


A sliding window is a computational imaging technique that uses a small number of pixels in a grid of cells, of a specified size (i.e., 2 x 2) to perform calculations and reduce the calculation time. The grid of cells passes through the spatial dimension of the image. At each pass, the calculation within the window is performed and the first pixel in the window takes the values from the calculation. IDCube uses the length of one dimension as the window size. Here is the illustration of the Window size = 2.

Sliding window



The resulting image shows an image with significantly less distortion of color. However, some additional artifacts, such as the apparent three-dimensionality of the objects can be observed.



The right and bottom border of the new image shown in green is the size of the sliding window in pixels (here is 10-pixel width).

Additional Information:

Performs a normalization of the spectra that consists in subtracting each spectrum by its own mean and dividing it by its own standard deviation. After SNV, each spectrum will have a mean of 0 and a standard deviation of 1.

When using SNV, the spectra always have positive and negative values centered on 0, which may make interpretation difficult.

SNV assumes that multiplicative effects are uniform over the whole spectral range, which is not always the case, so artifacts could be introduced by this transformation

References:

Barnes, R.J., Dhanoa, M.S., Lister, S.J. 1989. Standard normal variate transformation and detrending of near-infra-red diffuse reflectance spectra. *Applied Spectroscopy* 43, 772–777.

7.9. Toolboxes Tab

IDCubePro® offers a variety of toolboxes to perform diverse operations. Our toolboxes are standalone software packages connected to the **Main Interface** via a *one-way channel*. The datasets from the **Main interface** are the input for the toolboxes. Any changes to the datasets in toolboxes will not go back to the Main Interface and will not affect your data in the **Main Interface**. We suggest saving new datasets generated by toolboxes and opening them later. For the best performance, we suggest using only one toolbox at a time and closing it before opening another toolbox.

| Tabs | Function | Additional info |
|-----------|---|-----------------|
| Toolboxes | Principal Component Analysis (PCA) Toolbox | Pop-up toolbox |
| | Maximum Noise Fraction (MNF) Toolbox | Pop-up toolbox |
| | Image Classification Toolbox | Pop-up toolbox |
| | Spectral Signature Matching Toolbox | Pop-up toolbox |
| | Endmembers Extraction Toolbox | Pop-up toolbox |
| | Image Indices Toolbox | Pop-up toolbox |
| | Contrast Maximization Toolbox | Pop-up toolbox |
| | Correlation Matrix (R-Squared) | Pop-up toolbox |
| | t-SNE Clustering Toolbox | Pop-up toolbox |
| | Phasor Clustering Toolbox | Pop-up toolbox |
| | 3D Viewer Toolbox | Pop-up toolbox |
| | Feature Finder with Spectrum Background Removal | Pop-up toolbox |
| | Fusion MSI/HSI (Pansharpening) | Pop-up toolbox |

Principal Component Analysis (PCA) Toolbox

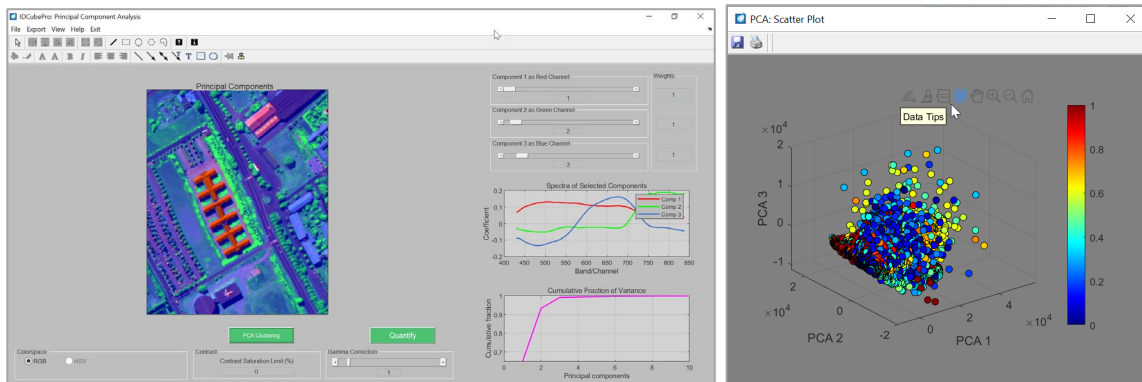
NOTE: PAVIA dataset is used as an example.

Features: transforms the data to a lower dimensional space and finds principal component vectors with their directions along the maximum variances of the input bands. The principal components are in descending order of the amount of total variance.

- Identifies the principal components from the hyperspectral data (Part A)
- Combines principal components in a pseudo-color image (Part A).
- Plots spectra of components (Part A).
- Plots Cumulative Fraction of Variance (Part A).
- Saves PCA data in IDCube format (Part A).
- Quantifies the area by each component (Part B).
- Performs scatter analysis and K-means to identify classes (Part C).
- Saves PCA segmented regions as labels for Machine Learning toolbox (Part B and C)
- Saves PCA clusters as new datacubes (Part C).
- Saves PCA inverted clusters as new datacubes (Part C)

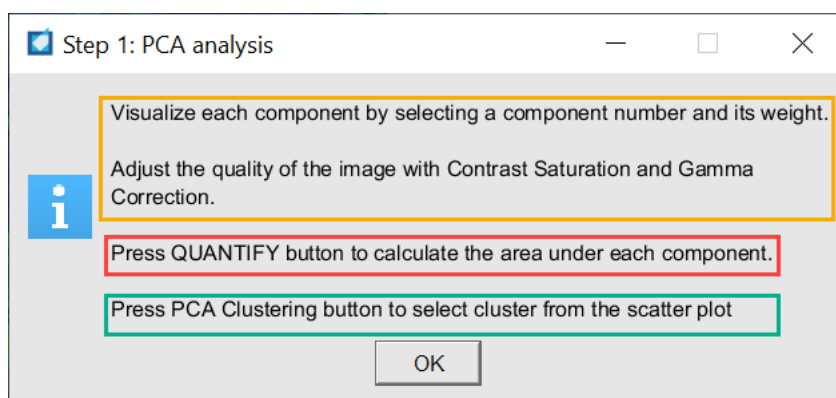
Steps:

Select **Principal Component Analysis** from the Toolbox tabs from the **Main Interface**. Two windows will popup: PCA and Scatter plot in 3D. The scatter plot PCA 1, 2 and 3 corresponds to the components selected in the PCA popup. Changing components will automatically change the image and the scatter plot.



In addition to visualizing the components the toolbox offers advanced segmentation either based on quantifying individual components (button **Quantify**), or cluster analysis (button **PCA Clustering**)

A message box with instructions will pop-up. **NOTE:** The instructions can be turned off by clicking **View** → **Turn Instructions Off**.



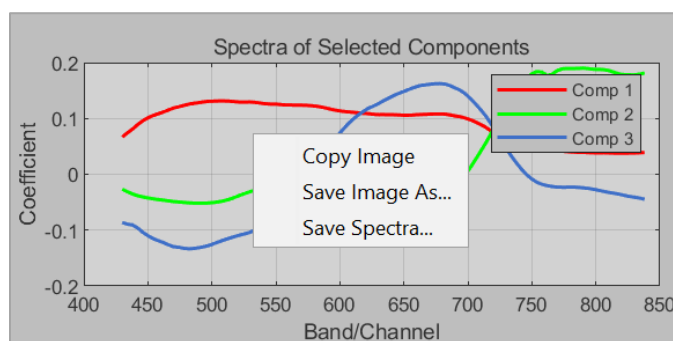
PCA toolbox analysis consists of three major parts. Part A: Visualization, Part B: Quantification, Part C: Scatter analysis.

PART A: Visualization of components

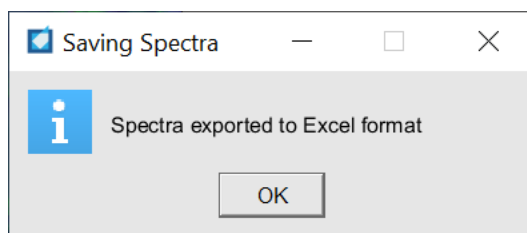
Move sliders of individual components to see the combined pseudo-RGB image. The default position of sliders in 1, 2, and 3 that corresponds to Red, Green, and Blue.

Adjust the weight of each component. The default value is 1 for each component.

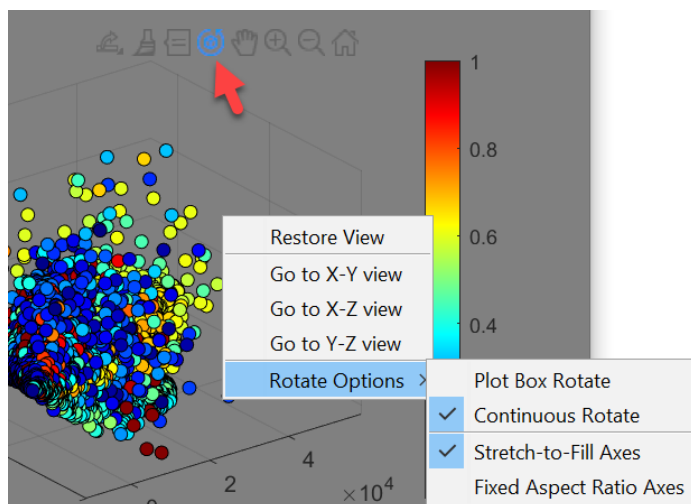
1. In the COMPONENT SELECTION panel, scroll through different principal components assigned to different color channels. (Default Component #1 is red, component #2 is green, and component #3 is blue). The combined image in a pseudo RGB format. **NOTE:** Only the first 20 principal components can be accessed.
2. Assign **Weight** to any of the channels to enhance the signal at a specific channel. Default values = 1 for each channel. Higher/lower weight of the component will increase/decrease the color of the corresponding component.
3. In the **Spectra of Selected Compounds** panel make a right click to activate a menu. You can save all three spectra of the principal components in the Excel format.



When spectra are saved an info box pops-up

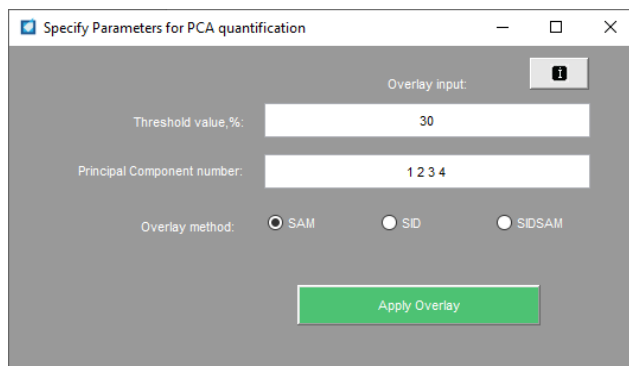


4. Image enhancement enables to improve the visualization. Current options are:
 - a. **Contrast Saturation Limit (%)**. The default value is 0. The range is from 0 to 49%.
 - b. **Gamma Correction**. Gamma Correction takes values between 0 and infinity. The default value is 1. If gamma is <1, the image is weighted toward brighter pixels, if gamma is >1, the image is weighted toward darker pixels.
5. To visualize the scatter plot in different view rotate the plot with a rotation tool shown with a red arrow, or make a right click and visualize options:



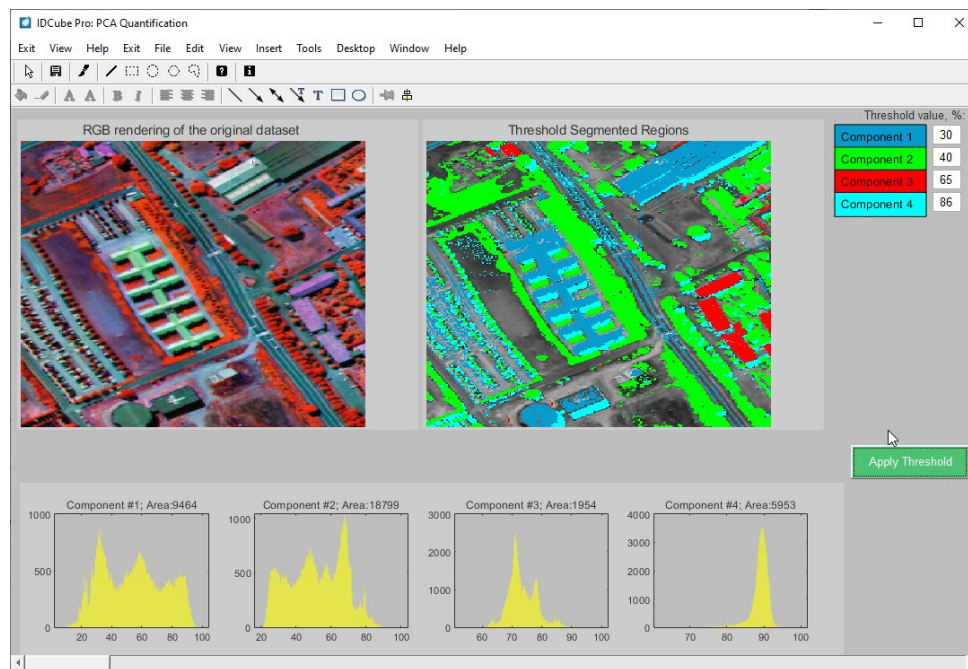
PART B. Quantification of Principal Components

1. Click **Quantify** to open a dialog with the following options.



2. Set **Threshold value, %**. The default level is 30% and will be applied to each component. You do not need to adjust the value; you can do that in the next step.

- a. Select the **Principal Components Number(s)** that you would like to quantify. Use the format such as 1 2 3 4 with spaces between the numbers. **NOTE:** The limit is 10 components.
- b. Select an **Overlay method**. The available options are:
 - i. **SAM** (Spectral Angle Map) – default.
 - ii. **SID** (Spectral Information Divergence).
 - iii. **SIDSAM** (Spectral Information Divergence-Spectral Angle Mapper Hybrid method).
3. Click **Apply Overlay**. The new pop-up PCA Quantification will show the following information:
 - a. Pseudo RGB rendering of the original dataset.
 - b. Threshold values, % selection box for individual Principal Component (the limit is 10 components).
 - c. Threshold Segmented Regions (based on the input of the threshold value) image with the overlaid principal components.
 - d. Histograms that correspond to each of the components.
 - e. Area of each component in pixels (located in the title of each histogram plot component).




4. Adjust the **Threshold value** for each component. **NOTE:** The colors of each component might overlay with the map of the early listed principal component number. To verify overlap, assign the previous component Threshold value to 0.
5. Save the segmented image as a **Label file** for the **Machine Learning** toolbox. For that, select a single component in step 5. Make a **right click** on the segmented image to activate **Save as a Label File** tab. **NOTE:** we suggest using only one component as a label such as show below.



Click the tab and specify the file name. The .png and .mat files will be generated

Additional Information:

- Each image can be zoomed and panned by using a mouse. Each image can be also modified using shortcuts. Click  to see the list of standard mouse functions.
- You can click on each image to see it in a larger separate window. Each image can be saved.

The toolbox includes the following algorithms: a) **PCA** and b) **Overlay** which includes three algorithms: SAM, SID, and SAMSID. The calculations are similar to the abundance method used in the endmembers mapping but using principal components instead of endmembers.

References:

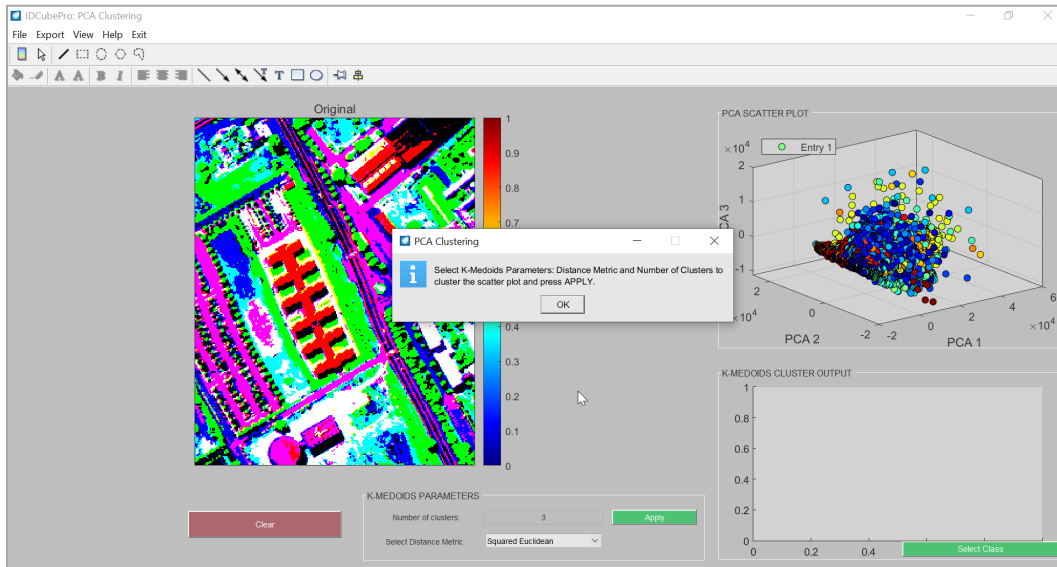
SAM: Kruse, F. A., A. B. Lefkoff, J. B. Boardman, K. B. Heidebrecht, A. T. Shapiro, P. J. Barloon, and A. F. H. Goetz. "The Spectral Image Processing System (SIPS) - Interactive Visualization and Analysis of Imaging spectrometer Data." *Remote Sensing of Environment* 44 (1993): 145-163.

SID: Chein-I Chang. "An Information-Theoretic Approach to Spectral Variability, Similarity, and Discrimination for Hyperspectral Image Analysis." *IEEE Transactions on Information Theory* 46, no. 5 (August 2000): 1927-32. <https://doi.org/10.1109/18.857802>.

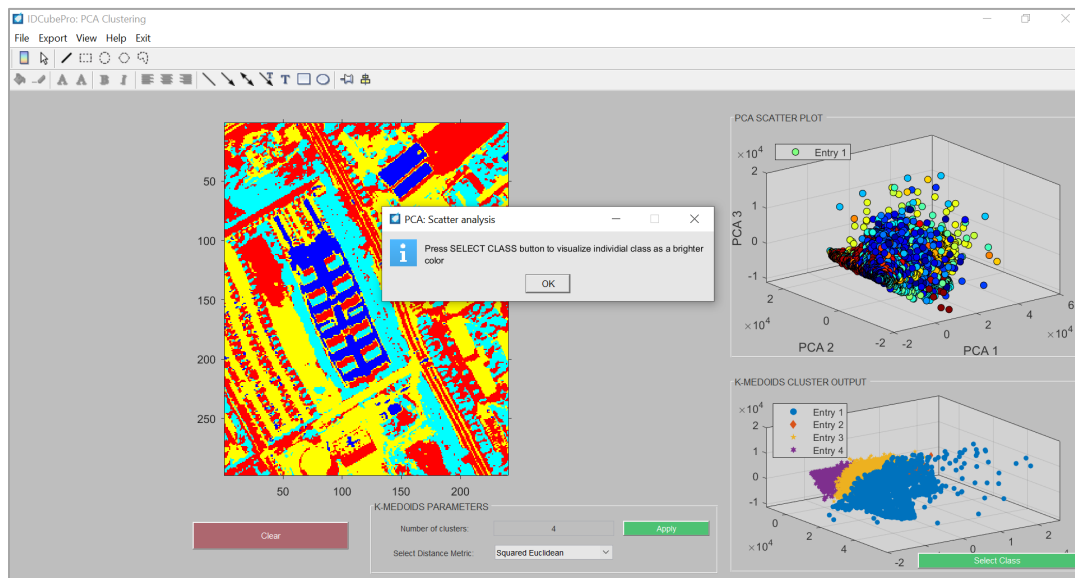
SIMSAD: Chang, Chein-I. "New Hyperspectral Discrimination Measure for Spectral Characterization." *Optical Engineering* 43, no. 8 (August 1, 2004): 1777. <https://doi.org/10.1117/1.1766301>.

PART C: Cluster analysis with K-medoids

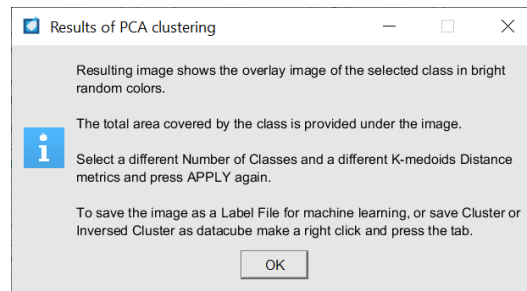
1. Click **PCA Clustering** to start PCA segmentation based on k-medoids of the clusters.



2. Select the **Number of clusters** and the **Distance Metric**. The results of clustering will be seen in the CLUSTER OUTPUT panel on the right lower panel.

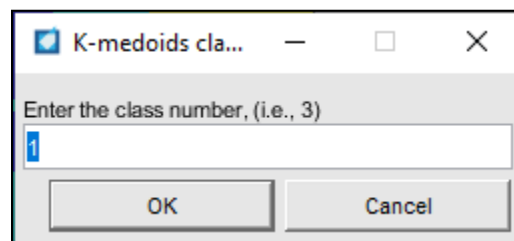


A pop-up instructions will suggest further steps.

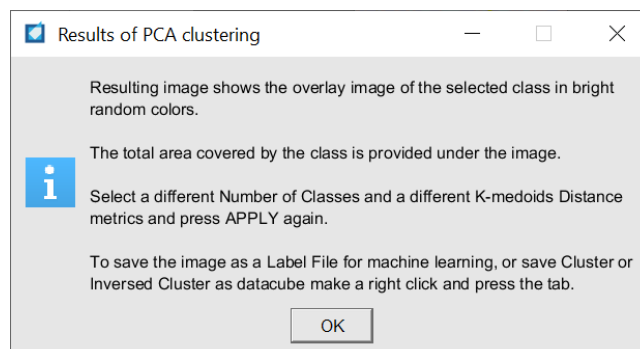
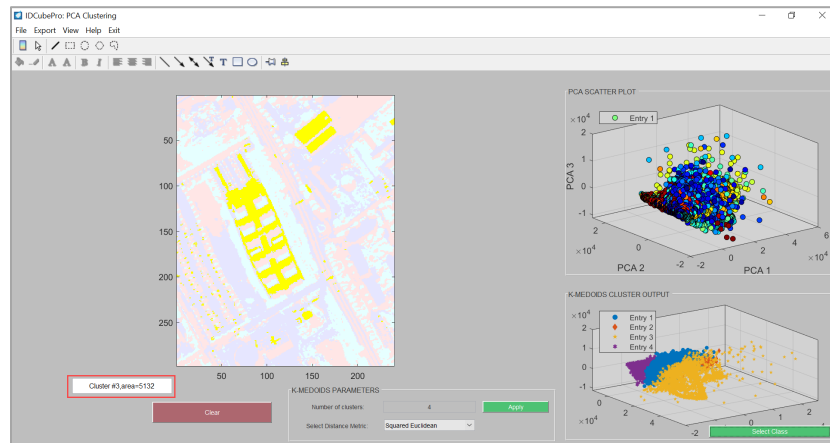


Click the green button **Select Class** button to visualize the cluster in the image.

A pop-up will appear asking for which class/cluster the user would like to view.



The area covered by the selected cluster (in a bright color with the area measured in pixels) will appear at the bottom of the image.



1. Save the segmented image as a **Label file** for the **Machine Learning** toolbox. After selecting the class, make a **right click** on the segmented image to activate **Save as a Label File** tab. Click the tab and specify the file name. The *.png* and *.mat* files will be generated.
2. You can also save only the data that belongs to the cluster area as a new datacube by selecting **Save Cluster as a Datacube file**. In this case others the pixel values of the object will be preserved as original, while the other pixels will be assigned as 0 (zeroes) across the entire datacube. By selecting **Save Inverted Cluster as a Datacube File**, the saving will be inverted. The pixels from the area occupied by the cluster will be assigned to zero, while the other values across the object will remain.



Additional Information:

Distance Metrics

A distance metric is a function that defines a distance between two observations. Distance metrics can be specified by one of the following. Definitions of the distance metrics are given in the Table:

| Value | Description |
|------------------|--|
| euclidean | Euclidean distance. |
| squaredeuclidean | Squared Euclidean distance. (This option is provided for efficiency only. It does not satisfy the triangle inequality.) |
| seuclidean | Standardized Euclidean distance. Each coordinate difference between observations is scaled by dividing by the corresponding element of the standard deviation, |
| mahalanobis | Mahalanobis distance using the sample covariance of X, $C = \text{cov}(X, 'omitrows')$. |
| cityblock | City block distance. |
| minkowski | Minkowski distance. The default exponent is 2. |
| chebychev | Chebychev distance (maximum coordinate difference). |
| cosine | One minus the cosine of the included angle between points (treated as vectors). |
| correlation | One minus the sample correlation between points (treated as sequences of values). |
| hamming | Hamming distance, which is the percentage of coordinates that differ. |
| jaccard | One minus the Jaccard coefficient, which is the percentage of nonzero coordinates that differ. |

| Value | Description |
|----------|---|
| spearman | One minus the sample Spearman's rank correlation between observations (treated as sequences of values). |

Maximum Noise Fraction (MNF) Toolbox

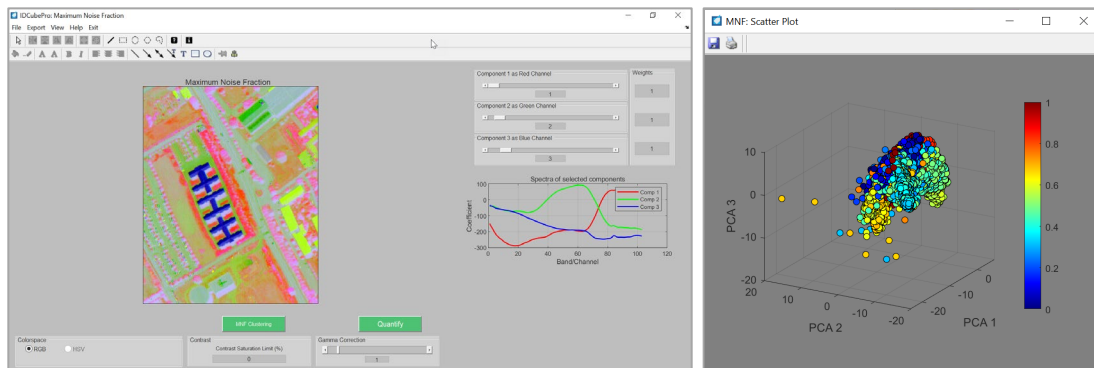
NOTE: PAVIA dataset is used as an example.

Features: transforms the data to a lower dimensional space and finds principal component vectors after noise removal with their directions along the maximum variances of the input bands. The principal components are in descending order of the amount of total variance.

- Identifies the noise removed principal components from the hyperspectral data (Part A)
- Combines principal components in a pseudo-color image (Part A).
- Plots spectra of components (Part A).
- Saves MNF data in IDCube format (Part A).
- Quantifies the area by each component (Part B).
- Performs scatter analysis and K-means to identify classes (Part C).
- Saves MNF segmented regions as labels for Machine Learning toolbox (Part B and C)
- Saves MNF clusters as new datacubes (Part C).
- Saves MNF inverted clusters as new datacubes (Part C).

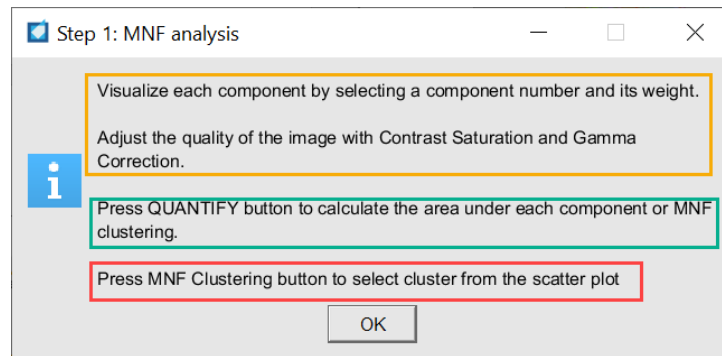
Steps:

Select **Maximum Noise Fraction** from the **Toolboxes** tab from the **Main Interface**. Two windows will popup: PCA and Scatter plot in 3D. The scatter plot PCA 1, 2 and 3 corresponds to the components selected in the PCA popup. Changing components will automatically change the image and the scatter plot.



In addition to visualizing the components the toolbox offers advanced segmentation either based on quantifying individual components (button **Quantify**), or cluster analysis (button **MNF Clustering**)

A message box with instructions will pop-up. **NOTE:** The instructions can be turned off by clicking **View** → **Turn Instructions Off**.

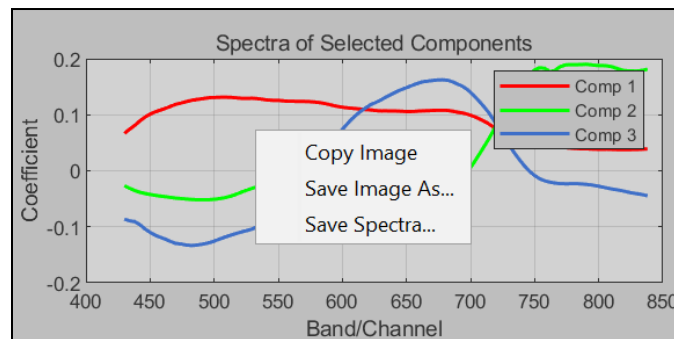


MNF toolbox analysis consists of three major parts. **Part A:** Visualization, **Part B:** Quantification, **Part C:** Scatter analysis.

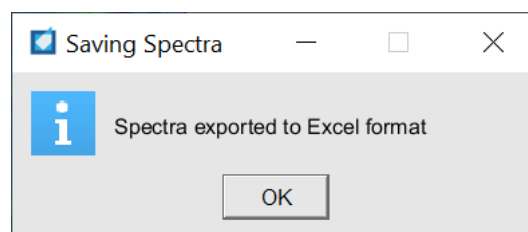
PART A: Visualization of principle components

Move sliders of individual components to see the combined pseudo-RGB image. The default position of sliders in 1, 2, and 3 that corresponds to Red, Green, and Blue.

1. In the COMPONENT SELECTION panel scroll through different principal components assigned to different color channels. (Default Component #1 is red, component #2 is green, and component #3 is blue). **NOTE:** Only the first 20 principal components can be accessed.
2. Assign **Weight** to any of the channels to enhance the signal at a specific channel. Default values =1 for each channel. Higher/lower weight of the component will increase/decrease the color of the corresponding component.
3. In the **Spectra of Selected Compounds** panel make a right click to activate a menu. You can save all three spectra of the principal components in the Excel format.

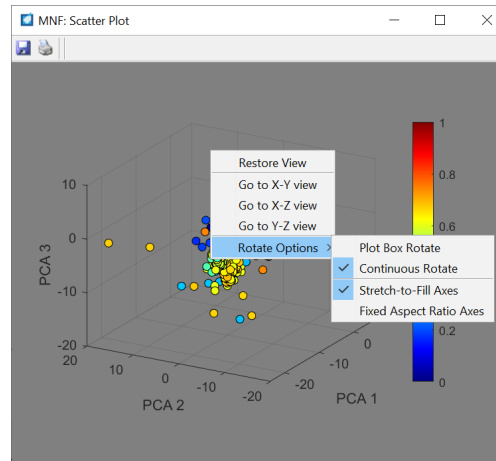


When spectra are saved an info box pops-up:



4. Image enhancement enables to improve the visualization. Current options are:
 - a. **Contrast Saturation Limit (%)**. The default value is 0. The range is from 0 to 49%.

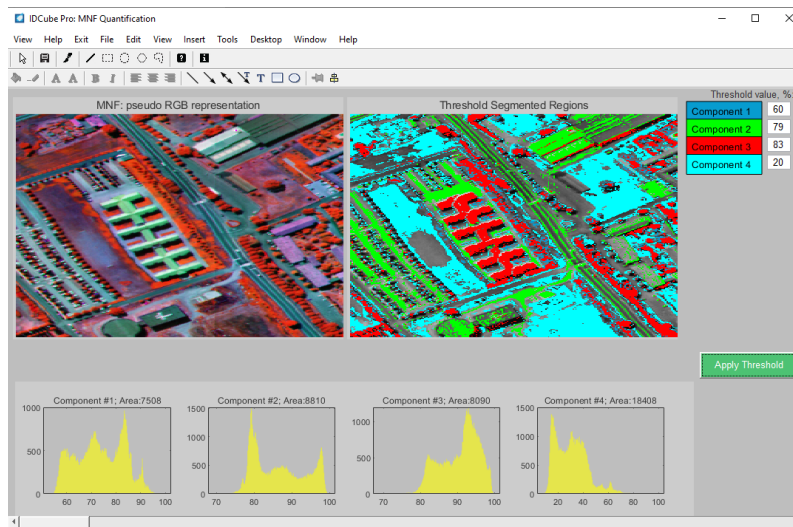
- b. **Gamma Correction.** Gamma Correction takes values between 0 and infinity. The default value is 1. If gamma is <1, the image is weighted toward brighter pixels, if gamma is >1, the image is weighted toward darker pixels.



PART B. Quantification of Principal Components

1. Click **Quantify** to open a dialog with the following options.

2. (Optional) Set **Threshold value, %**. The default level is 30% and will be applied to each component. You do not need to change the value at this moment; you can do that in the next step.
3. Select the **Principal Components number(s)** that you would like to quantify. Use the format such as 1 2 3 4 with spaces between the numbers. **NOTE:** The limit is 10 components.
4. Select an **Overlay method**. The available options are:
 - a. **SAM** (Spectral Angle Map) – default.
 - b. **SID** (Spectral Information Divergence).
 - c. **SIDSAM** (Spectral Information Divergence-Spectral Angle Mapper Hybrid Method).
5. Click **Apply Overlay**. The new pop-up NMF Quantification will show the following information:
 - a. RGB rendering of the original dataset.
 - b. Threshold values, % selection box for individual Principal Component (the limit is 10 components).
 - c. Thresholded image (based on the input of the threshold value) with the overlaid principal components.
 - d. Histograms that correspond to each of the components.
 - e. Area of each component in pixels (located in the title of each histogram plot component).



Adjust the **Threshold value** for each component. Note that the colors might overlay with the map of the early listed principal component number being on top. To verify overlap, assign the early component **Threshold value** to 0.

6. Save the segmented image as a **Label file** for the **Machine Learning** toolbox. Make a **right click** on the segmented image to activate **Save as a Label File** tab. **NOTE:** we suggest to use only one component as a label such as show below.



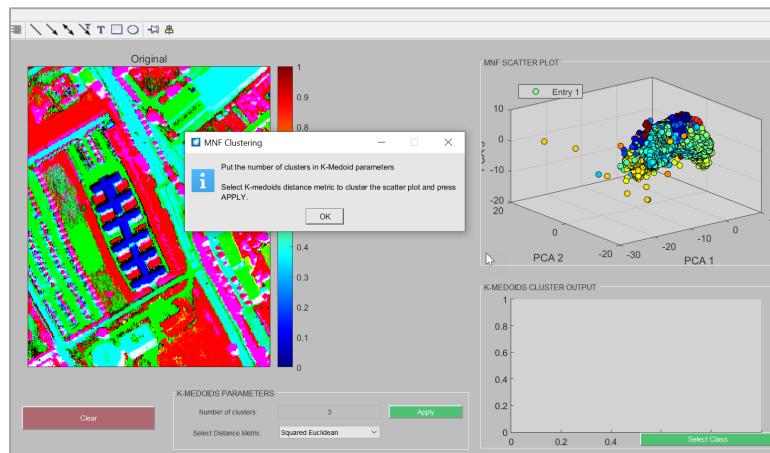
Click the tab and specify the file name. The *.png* and *.mat* files will be generated.

Tips:

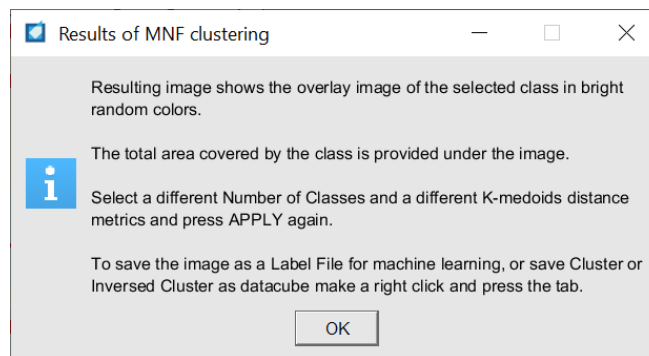
- Each image can be zoomed and panned by using a mouse. Each image can be also modified using shortcuts.
- You can click on each image to see it in a larger separate window. Each image can be saved.

PART C: Cluster analysis with K-medoids

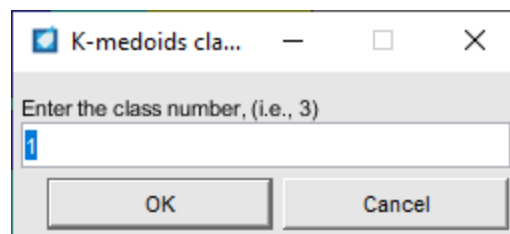
1. Click **PCA Clustering** to start PCA segmentation based on k-means of the clusters.
2. Select the **Number of clusters** and the **Distance Metric**. The results of clustering will be seen in the CLUSTER OUTPUT panel on the right lower panel.



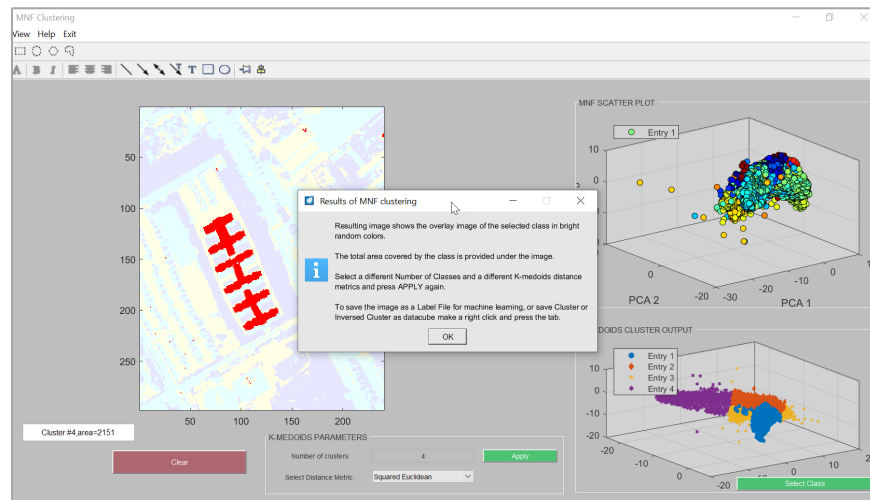
A pop-up instructions will suggest further steps.



3. Click the green button **Select Class** button to visualize the cluster in the image. A pop-up will appear asking for which class/cluster the user would like to view.

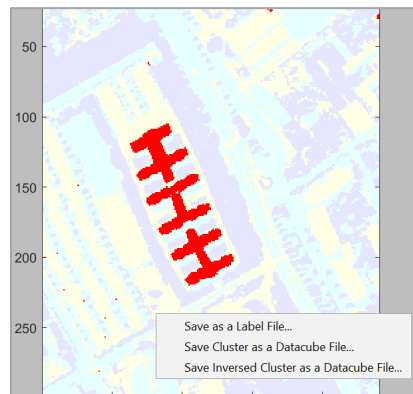


The area covered by the selected cluster (in a bright color with the area measured in pixels) will appear at the bottom of the image.



4. Save the segmented image as a **Label file** for the **Machine Learning** toolbox. After selecting the class, make a **right click** on the segmented image to activate **Save as a Label File** tab. Click the tab and specify the file name. The **.png** and **.mat** files will be generated.

You can also save only the data that belongs to the cluster area as a new datacube by selecting **Save Cluster as a Datacube file**. In this case others the pixel values of the object will be preserved as original, while the other pixels will be assigned as 0 (zeroes) across the entire datacube. By selecting **Save Inverted Cluster as a Datacube File**, the saving will be inverted. The pixels from the area occupied by the cluster will be assigned to zero, while the other values across the object will remain.



Additional Information:

MNF toolbox computes a specified number of principal component bands by using the Maximum Noise Fraction (MNF) transform. To achieve spectral dimensionality reduction, the specified number of principal components must be less than the number of spectral bands in the input datacube. MNF computes the principal components that maximize the signal-noise-ratio, rather than the variance. MNF transform is particularly efficient at deriving principal components from noisy band images. The principal component bands are spectrally distinct bands with low interband correlation.

The components derived using MNF transform are also called non-adjusted principal components and the MNF transform arranges principal components in the decreasing order of the principal component's image quality.

MNF transform is equivalent to a two-stage transformation in which the data are first transformed so that the noise covariance matrix is the identity matrix and the second stage is the principal components transform.

MNF transformation gives a better signal-to-noise ratio (SNR) than PCA transformation when signal-dependent noise is present in the input data. PCA transformation works better than MNF transformation when Gaussian white noise is present in the input data.

The toolbox includes the following set of algorithms: a) **MNF** (noise removal +PCA) and b) **Overlay** which includes three algorithms: SAM, SID, and SAMSID. The calculations are similar to the abundance maps method used in the endmembers mapping but using principal components instead of endmembers.

Distance Metrics

A distance metric is a function that defines a distance between two observations. Distance metrics can be specified by one of the following. Definitions of the distance metrics are given in the Table:

| Value | Description |
|------------------|--|
| euclidean | Euclidean distance. |
| squaredeuclidean | Squared Euclidean distance. (This option is provided for efficiency only. It does not satisfy the triangle inequality.) |
| seuclidean | Standardized Euclidean distance. Each coordinate difference between observations is scaled by dividing by the corresponding element of the standard deviation, |
| mahalanobis | Mahalanobis distance using the sample covariance of X, $C = \text{cov}(X, \text{'omitrows'})$. |
| cityblock | City block distance. |
| minkowski | Minkowski distance. The default exponent is 2. |
| chebychev | Chebychev distance (maximum coordinate difference). |
| cosine | One minus the cosine of the included angle between points (treated as vectors). |
| correlation | One minus the sample correlation between points (treated as sequences of values). |
| hamming | Hamming distance, which is the percentage of coordinates that differ. |
| jaccard | One minus the Jaccard coefficient, which is the percentage of nonzero coordinates that differ. |
| spearman | One minus the sample Spearman's rank correlation between observations (treated as sequences of values). |

References:

MNF: Green, A.A., M. Berman, P. Switzer, and M.D. Craig. "A Transformation for Ordering Multispectral Data in Terms of Image Quality with Implications for Noise Removal." *IEEE Transactions on Geoscience and Remote Sensing* 26, no. 1 (January 1988): 65–74. <https://doi.org/10.1109/36.3001>.

SAM: Kruse, F. A., A. B. Lefkoff, J. B. Boardman, K. B. Heidebrecht, A. T. Shapiro, P. J. Barloon, and A. F. H. Goetz. "The Spectral Image Processing System (SIPS) - Interactive Visualization and Analysis of Imaging spectrometer Data." *Remote Sensing of Environment* 44 (1993): 145-163.

SID: Chein-I Chang. "An Information-Theoretic Approach to Spectral Variability, Similarity, and Discrimination for Hyperspectral Image Analysis." *IEEE Transactions on Information Theory* 46, no. 5 (August 2000): 1927–32. <https://doi.org/10.1109/18.857802>.

SIMSAD: Chang, Chein-I. “New Hyperspectral Discrimination Measure for Spectral Characterization.” *Optical Engineering* 43, no. 8 (August 1, 2004): 1777. <https://doi.org/10.1117/1.1766301>.

Image Classification Toolbox

NOTE: PAVIA dataset is used as an example.

Features:

- Performs Classification using several algorithms based on the selected seed areas.
- Quantifies the area and other parameters.

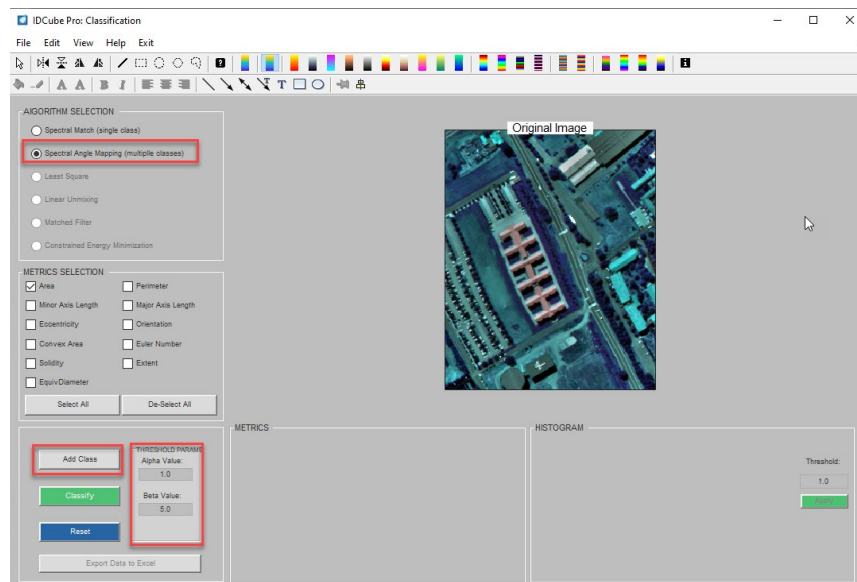
Steps:

1. Open a hyperspectral file through the **Main Interface**.
2. Navigate to **Toolboxes** → **Classifications**. A new window will pop up.
3. Select an algorithm from the ALGORITHM SELECTION panel. Currently available options are:
 - a. **Spectral Matching** - supports only one class.
 - b. **Spectral Angle Mapping** (default) - supports several classes (areas of interest).

Spectral Angle Mapping

4. Select **Spectral Angle Mapping**.
5. Click **Add Class** and select a region of interest. Click **Classify** to perform classification. Adjust the output by specifying **Threshold Parameters Alpha** and **Beta Values**.

Tip: Start by changing the **Beta Value** 0.5 units up and down. Click **Classify** to perform the mapping.



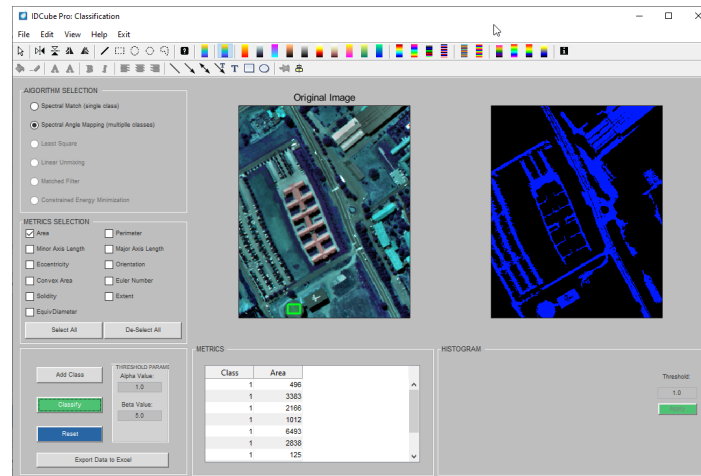
You can select many regions by clicking **Add Class** again and selecting another region.

NOTE: the colors in the classified image are assigned randomly. To change the colors click **Classify** again without changing any other parameters. If you need to select a different region or add another class after you performed classification, click **Reset** and repeat the steps.

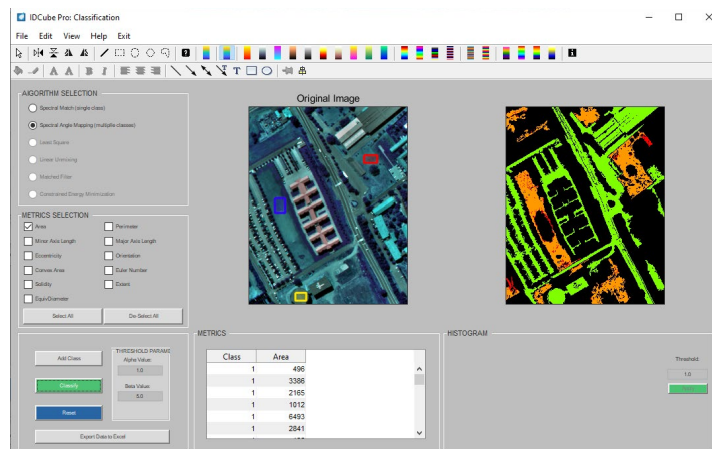
To copy results to Excel, click **Export Data to Excel**. Alternatively, highlight the results with **Ctrl+A** and copy (**Ctrl+C**). Paste the results to Excel or other software.

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With one selected class:

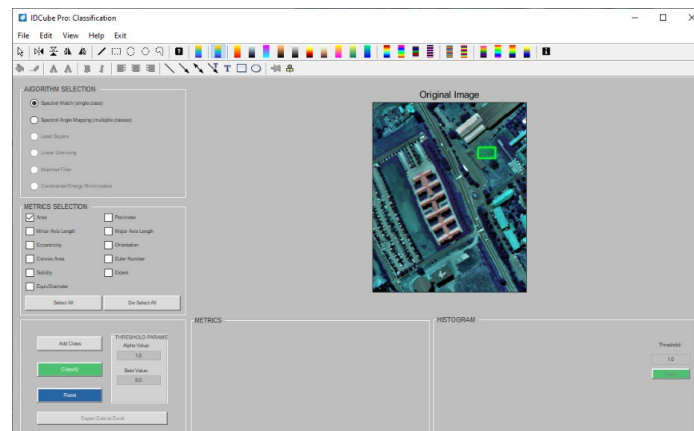


With three selected classes:

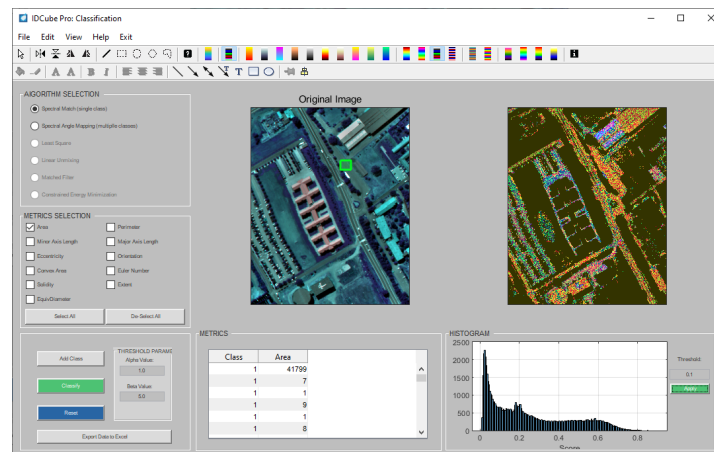


Spectral Matching

1. Select **Spectral Matching** (only one class can be selected).



- Click **Add Class** and select a region of interest. Click **Classify** to perform classification. A new pop-up window along with a dialog will appear. The left image will show a new map where each pixel is measured against the average spectrum from the selected region of interest. The lower Score (dark blue in the default colorscheme) corresponds to the higher similarity. The plot on the right shows the histogram **Number of Pixels vs. Score**.
- From the histogram, identify the first feature in the histogram, (i.e., the first peak) and put the value into the dialog window. Click **OK** to visualize the resulting image to the right. The segmented image can be viewed in different look-up tables (LUTs) that could be selected from the **Color Toolbar** menu. The colorschemes show the similarity between objects of the image but in different colors. Very close (matched) objects will have the same colors, slightly different will be colored differently.



- To copy results to Excel, click **Export Data to Excel**. Alternatively, select the results with **Ctrl+A** and copy (**Ctrl+C**), then paste the results to Excel or other software.

Additional Information:

Alpha and beta parameters: These parameters act as threshold values that binarize the output image based on the selected classification algorithm. The main threshold value is based on the following equation:

$$Level = ((graythreshold \cdot output) + alpha) \cdot beta$$

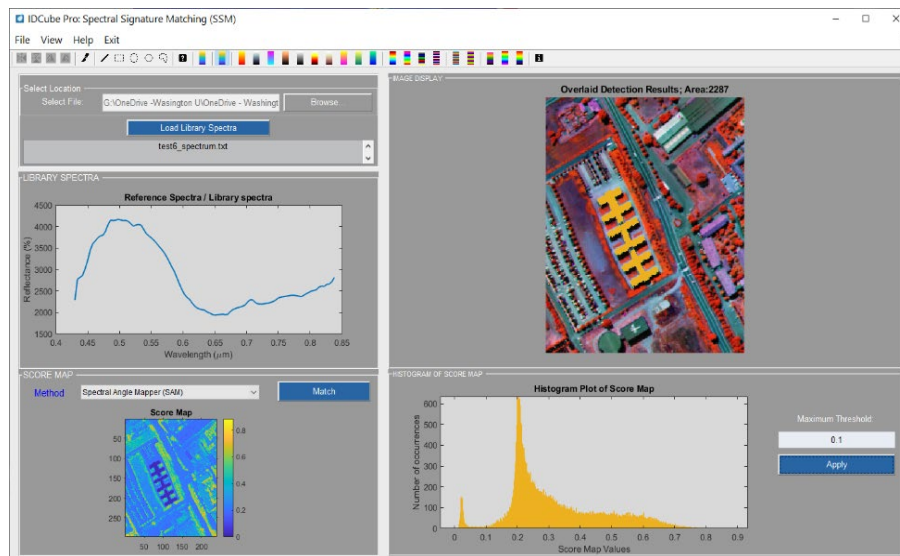
Here, *Level* is the threshold value to binarize the remapped output image.

Spectral Signature Matching Toolbox

NOTE: Requires spectra saved in the ECOSTRESS format (*name_spectrum.txt*).

Features:

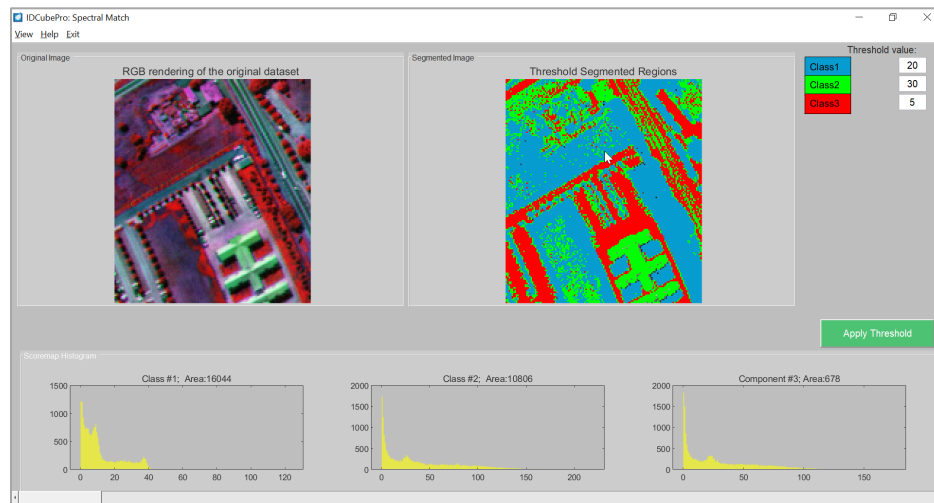
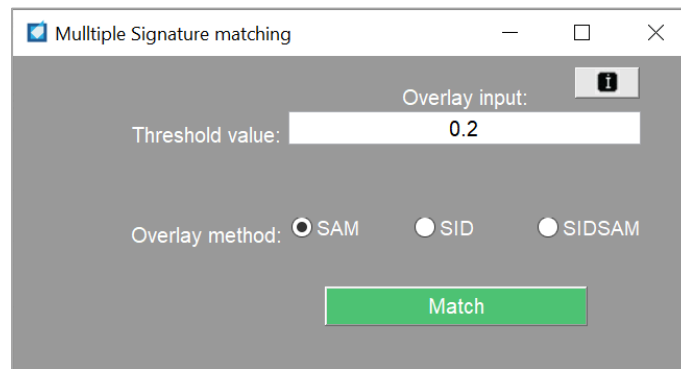
- Compares the similarity of each pixel spectrum to the reference spectrum.
- Detects a target in the hyperspectral image by using a specified spectral signature matching method.
- Shows the area that corresponds to the reference spectrum in the ECOSTRESS format (<https://www.mathworks.com/help/images/ref/readecostresssig.html>). Spectra can be recorded in the ECOSTRESS format from a SPECTRAL ANALYSIS panel and ENDMEMBERS EXTRACTION toolbox (see corresponding sections).
- Calculates the area (in pixels) that matches a specific spectrum with the user input threshold value.
- Enables batch processing.



Steps:

1. Browse your directory to select the reference spectrum *name_spectrum.txt* file in the ECOSTRESS format. You can select multiple spectra.
2. Click **Load Library Spectra**.
3. If only one spectrum is selected, you can select the **method** of spectral matching from the dropdown menu. The methods are described below. Available options are:
 - Spectral Angular Mapper (SAM)
 - Jeffries Matusita SAM (JM SAM)
 - Normalized Spectral Similarity (NS3)
 - Spectral Information Divergence (SID)
 - Spectral Information Divergence - Spectral Angular Mapper Hybrid (SIDSAM)

4. Click **Match** to visualize the matching score. A lower score indicates a *better* match with the uploaded spectrum.
5. The software automatically generates histograms of all score intensities under the HISTOGRAM OF SCORE MAP. Select a threshold close to the first feature (i.e., a peak) on the histogram.
6. The orange color object(s) are generated and overlapped with the original image. The total area of the match in pixels appears in the title of the IMAGE DISPLAY panel.
7. If multiple spectra are selected, the dropdown menu will become inactive. Click **Match** to activate a pop-up **Multiple Signature Matching** box. You can leave a threshold value as default (=0.2) or change with the range from 0 to 1 for SAM or other ranges for SID and SIDSAM. Select the **Overlay** method (SAM, SID, SIDSAM) and click **Match**.



You can adjust the threshold based on the corresponding histogram to visualize the location of the area with the matched spectrum

Additional Information:

Spectral Angle Mapper (SAM) is a spectral image processing classification that matches the spectra from pixels to reference spectra. The algorithm determines the spectral similarity between two spectra by calculating the angle α between the spectra. Smaller angles represent closer matches to the reference spectrum. Reference spectra can be uploaded from known sources or directly extracted from an image as a region of interest (ROI) mean spectra (from the Main Interface see Main Interface manual).

JMSAM is a spectral image processing classification that matches the spectra from each pixel (test spectrum) to a reference spectrum. The method computes spectral similarity based on the Jeffries Matusita (JM) and SAM distances between two spectra. A smaller JMSAM score indicates a strong match between the test spectrum and the reference spectrum.

NS3 computes spectral similarity based on the Euclidean and SAM distances between the test spectrum and the specified reference spectrum by using the normalized spectral similarity score (NS3) method.

SID measures the spectral similarity between the spectra of each pixel in the hyperspectral data and the specified reference by using the spectral information divergence (SID) technique. The method computes spectral similarity based on the divergence between the probability distributions of the two spectra.

SIDSAM measures the spectral similarity between the spectra of each pixel in the hyperspectral data and the specified reference by using a hybrid SID-SAM hybrid score.

References:

SAM: Kruse, F. A., A. B. Lefkoff, J. B. Boardman, K. B. Heidebrecht, A. T. Shapiro, P. J. Barloon, and A. F. H. Goetz. "The Spectral Image Processing System (SIPS) - Interactive Visualization and Analysis of Imaging spectrometer Data." *Remote Sensing of Environment* 44 (1993): 145-163.

JMSAM: Padma, S., and S. Sanjeevi. "Jeffries Matusita Based Mixed-Measure for Improved Spectral Matching in Hyperspectral Image Analysis." *International Journal of Applied Earth Observation and Geoinformation* 32 (October 2014): 138–51. <https://doi.org/10.1016/j.jag.2014.04.001>.

NS3: Nidamanuri, Rama Rao, and Bernd Zbell. "Normalized Spectral Similarity Score (NS3) as an Efficient Spectral Library Searching Method for Hyperspectral Image Classification." *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing* 4, no. 1 (March 2011): 226–40. <https://doi.org/10.1109/JSTARS.2010.208643>

SID: Chein-I Chang. "An Information-Theoretic Approach to Spectral Variability, Similarity, and Discrimination for Hyperspectral Image Analysis." *IEEE Transactions on Information Theory* 46, no. 5 (August 2000): 1927–32. <https://doi.org/10.1109/18.857802>.

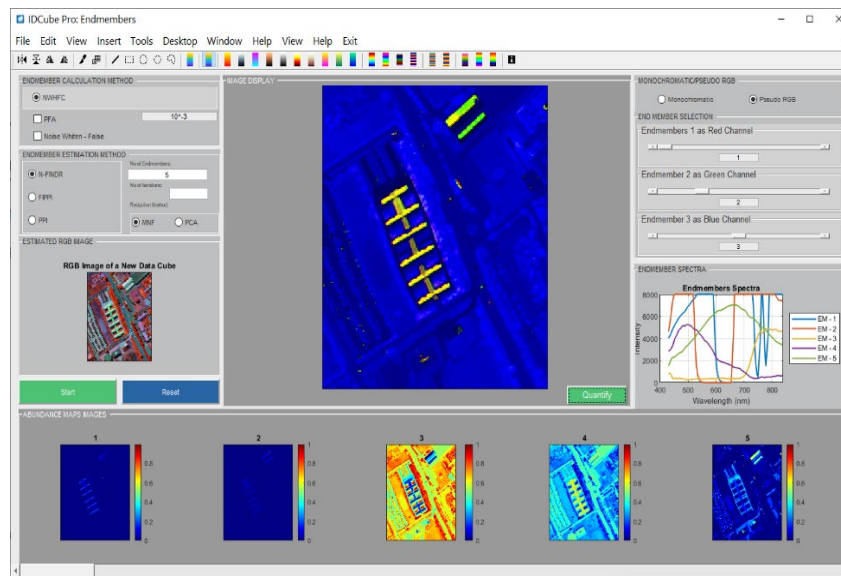
SIDSAM: Chang, Chein-I. "New Hyperspectral Discrimination Measure for Spectral Characterization." *Optical Engineering* 43, no. 8 (August 1, 2004): 1777. <https://doi.org/10.1117/1.1766301>.

Endmembers Extraction Toolbox

NOTE: PAVIA dataset is used as an example.

Features:

- Identifies the number of endmembers from the hyperspectral data.
- Extracts individual endmember spectra and saves them in Excel and the ECOSTRESS format.
- Quantifies the area given by each endmember.



Select **PPI** function to estimate the endmembers by using the PPI approach. The PPI approach projects the pixel spectra to an orthogonal space and identifies extreme pixels in the projected space as endmembers. This is a non-iterative approach, and the results depend on the random unit vectors generated for orthogonal projection. To improve results, you must increase the random unit vectors for projection, which can be computationally expensive.

Use the **FIPPI** function to estimate the endmembers by using the FIPPI approach. The FIPPI approach is an iterative approach, which uses an automatic target generation process to estimate the initial set of unit vectors for orthogonal projection. The algorithm converges faster than the PPI approach and identifies endmembers that are distinct from one another.

Use the **N-FINDR** function to estimate the endmembers by using the N-FINDR method. N-FINDR is an iterative approach that constructs a simplex by using pixel spectra. The approach assumes that the volume of a simplex formed by the endmembers is larger than the volume defined by any other combination of pixels. The set of pixel signatures for which the volume of the simplex is high are the endmembers.

Steps:

1. Select option in **Endmember Calculation Method**. Available options are:
 - a. NWHFC
 - b. PFA
 - c. Noise Whiten -False

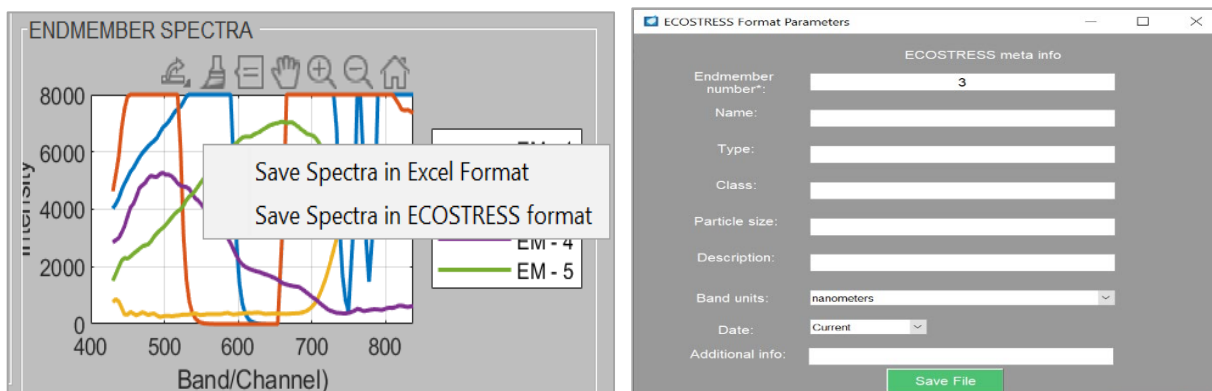
2. Specify the method that calculates the number of endmembers under **Endmember Estimation Method**. Available options are:
 - a. N-FINDR
 - b. Specify the number of iterations. If the field is empty, the default is the *Number of Iterations = 3 x the number of endmembers*. **NOTE:** The computation time of the algorithm increases with the increase in the number of iterations.
 - c. FIPPI
 - d. PPI
 - e. Alternatively, type the number of endmembers you expect to find (shown 5, default is 0). The number must be less or equal to the number of channels. If this box is filled with a number, the method selection is irrelevant.
3. Select the reduction method. If this argument is specified, the function first reduces the spectral dimension of the input data by using the specified method. Then, it computes the endmember signatures from the reduced data. Available options are:
 - a. Principal Component Analysis
 - b. Maximum Noise Fraction (default)
4. After the endmembers spectra are calculated (can be seen in the ENDMEMBER SPECTRA panel), single endmember images are produced in the ABUNDANCE MAP IMAGES panel. At the same time, the best three images are combined in the ESTIMATED RGB IMAGE panel.
5. Select Monochromatic/PseudoRGB options to visualize the image on the IMAGE DISPLAY panel. Available options are:
 - a. Monochromatic
 - b. Pseudo RGB

Use a slider to move between the images (in a monochromatic mode) or combine the images in the pseudo-
RGB mode. Up to three images can be combined.

Click the **Quantify** button to measure the area covered by each of the selected endmember. A new pop-up menu will be opened followed by a new panel (See the Quantify manual).

Tips: You can click on each image to see it in a larger separate window. Each image can be saved.

Each produced endmember spectrum can be saved either in Excel or the ECOSTRESS format. To save the spectra, **right-click** on the ENDMEMBERS SPECTRA panel. In the case of ECOSTRESS, the spectra have to be saved one by one. When **Save Spectra in ECOSTRESS format** is selected, a pop-up dialogue window ECOSTRESS Format Parameters will request additional information, like the Endmember number (mandatory field), name, type, etc.



Additional Information:

The toolbox includes several types of algorithms: a) to find the number of endmembers, b) to identify their spectra, and c) to calculate endmembers' abundance maps.

Noise-whitened Harsanyi–Farrand–Chang (NWHFC) finds the number of endmembers present in a hyperspectral datacube by using the NWHFC method. When 'NoiseWhiten – false' is checked, the algorithm does not perform noise-whitening of the data before extracting the endmembers. In that case, the method is also known as the Harsanyi–Farrand–Chang (HFC) method.

The method also requires the input for the Probability of False Alarm (**PFA**). The default value for PFA is 10^{-3} (default). A smaller value will provide more endmembers.

N-FINDR is an iterative approach for finding the endmembers of a hyperspectral dataset. The method assumes that the volume of a simplex formed by the endmembers (purest pixels) is larger than any other volume defined by any other combination of pixels. Computes principal component bands and reduces the spectral dimensionality of the input data by using MNF or PCA. The number of principal component bands to be extracted is set equal to the number of endmembers to be extracted. The endmembers are extracted from the principal component bands.

Pixel Purity Index (PPI) extracts endmember signatures from hyperspectral datacube by using the pixel purity index algorithm. The method computes the orthogonal projections of hyperspectral data values on a set of randomly generated unit vectors known as the *skewers*. Then, the method computes the PPI count for each data value. PPI count is the number of times a data value results in an extreme point when projected onto these skewers. Those data values with more than the expected number of PPI count comprise the endmembers of the hyperspectral data. PPI is a non-iterative method and the steps involved use MNF or PCA to reduce the dimensionality of the input data. The number of principal component bands to be extracted is set equal to the number of endmembers to be extracted.

Fast Iterative Pixel Purity Index (FIPPI) is an approach that iteratively selects the better candidates for endmembers after each iteration. Unlike the pixel purity index (PPI) technique, the FIPPI method selects the initial set of skewers by using the automatic target generation process (ATGP). As a result, the algorithm converges faster and generates a unique pixel for each endmember. The steps involved in FIPPI approach use MNF or PCA to reduce the dimensionality of the input data.

References:

NWHFC: Chang, C.-I., and Q. Du. "Estimation of Number of Spectrally Distinct Signal Sources in Hyperspectral Imagery." *IEEE Transactions on Geoscience and Remote Sensing* 42, no. 3 (March 2004): 608–19. <https://doi.org/10.1109/TGRS.2003.819189>

N-FINDR: Winter, Michael E. "N-FINDR: An Algorithm for Fast Autonomous Spectral End-Member Determination in Hyperspectral Data." *Proc. SPIE Imaging Spectrometry V* 3753, (October 1999): 266–75. <https://doi.org/10.1117/12.366289>.

PPI: J.W Boardman, F.A. Kruse and R.O. Green, "Mapping target signatures via partial unmixing of AVIRIS data.", Technical Report, California, USA, 1995. <https://ntrs.nasa.gov/citations/19950027316>

FIPPI: Chang, C.-I., and A. Plaza. "A Fast Iterative Algorithm for Implementation of Pixel Purity Index." *IEEE Geoscience and Remote Sensing Letters* 3, no. 1 (January 2006): 63–67. <https://doi.org/10.1109/LGRS.2005.856701>.

Image Indices Toolbox

NOTE: AVIRIS file “Lakes” is used as an example.

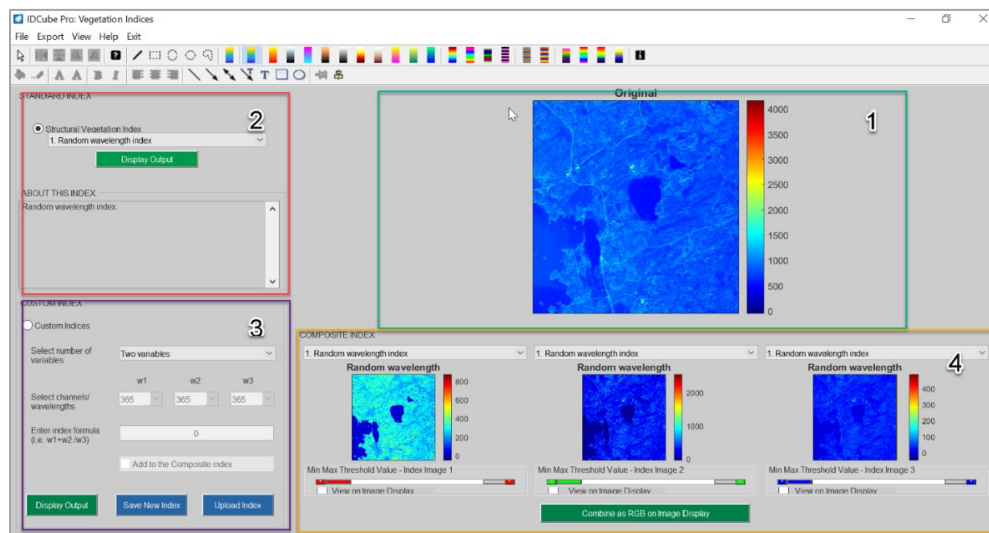
Features:

- Applies established indices to the dataset.
- Saves the new indices.
- Combines established and new indices in a pseudo color image, generating a composite index.

Steps:

1. After opening a file, from the **Main Interface**, select **Toolboxes** → **Image Indices** → **Vegetation Indices** → **AVIRIS**.

A new window toolbox will appear.



The toolbox interface has four panels:

1. **IMAGE DISPLAY** panel shows a 2D image after applying the index. By default, it shows a **Random Wavelength Index**, which is simply a slice of a datacube at a randomly selected band/channel. Other standard indices are given in the following table.
2. **STANDARD INDEX** panel presents a selection of the established standard indices. Selection of the index from the dropdown menu and clicking **Display Output** updates the image on the **Image Display** panel.
3. **CUSTOM INDEX** panel allows you to develop your own index. Currently, IDCube supports two- and three-channel indexes. You can select the available channels from the dropdown menu and visualize the result on the **IMAGE DISPLAY** panel by clicking **Display Output** located on this panel and pressing **Save New Index**. You can add the new index to the list of indexes in the **COMPOSITE INDEX** panel (see below). The panel also allows opening a stored index via the **Upload Index** button.
4. **COMPOSITE INDEX** panel allows you to combine images generated by up to three individual indices into a pseudo-RGB image. This panel has three subpanels. The sliders under the individual subpanels reflect the color of the channel: the left slider – contributes to the red channel, the middle slider – to the green

channel, right slider – to the blue channel. The sliders also help the user to adjust the image before sending it to the Image display. Each slider has two sub-sliders that can be moved.

NOTE: To be combined in the RGB image, each index image in the subpanel is normalized to [0, 1].

| Standard Index | Platforms supported |
|---|-----------------------------|
| 1. Random wavelength index | AVIRIS, AVIRIS-NG, Hyperion |
| 2. Normalized Difference Vegetation Index (NDVI) | AVIRIS, AVIRIS-NG, Hyperion |
| 3. Modified Chlorophyll Absorption in Reflectance Index (MCARI-1) | AVIRIS, AVIRIS-NG, Hyperion |
| 4. Modified Chlorophyll Absorption in Reflectance Index (MCARI-2) | AVIRIS, AVIRIS-NG, Hyperion |
| 5. Normalized Difference Water Index (NDWI) | AVIRIS, AVIRIS-NG, Hyperion |
| 6. Modified Triangular Vegetation Index 1 (MTVI 1) | AVIRIS, AVIRIS-NG, Hyperion |
| 7. Modified Triangular Vegetation Index 2 (MTVI 2) | AVIRIS, AVIRIS-NG, Hyperion |
| 8. Renormalized Difference Vegetation Index (RDVI) | AVIRIS, AVIRIS-NG, Hyperion |
| 9. Leaf Area Index (LAD) | AVIRIS, AVIRIS-NG, Hyperion |
| 10. Modified Simple Ratio (MSR) | AVIRIS, AVIRIS-NG, Hyperion |
| 11. Soil-Adjusted Vegetation Index (SAVI) 2 | AVIRIS, AVIRIS-NG, Hyperion |
| 12. Modified SAVI with self-adjustment factor L (MSAVI) | AVIRIS, AVIRIS-NG, Hyperion |
| 13. Optimized Soil-adjusted Vegetation Index (OSAVI) | AVIRIS, AVIRIS-NG, Hyperion |
| 14. Normalized Difference Nitrogen Index (NDNI) | AVIRIS, AVIRIS-NG, Hyperion |
| 15. Normalized Difference Salinity Index (NDSI) | AVIRIS, AVIRIS-NG, Hyperion |
| 16. Red-edge Inflection Point 1 REIP-1 | AVIRIS, AVIRIS-NG, Hyperion |
| 17. Transformed Chlorophyll Absorption Ratio (TCARI) | AVIRIS, AVIRIS-NG, Hyperion |
| 18. Triangular Vegetation Index (TVI) | AVIRIS, AVIRIS-NG, Hyperion |
| 19. Photochemical Reflectance Index (PRI) | AVIRIS, AVIRIS-NG, Hyperion |
| 20. Cellulose Absorption Index (CAI) | AVIRIS, AVIRIS-NG, Hyperion |
| 21. Cellulose Absorption Index 2 (CAI-2) | AVIRIS, AVIRIS-NG, Hyperion |
| 22. Simple Ratio Water Index (SRWI) | AVIRIS, AVIRIS-NG, Hyperion |
| 23. Plant Water Index (PWI) | AVIRIS, AVIRIS-NG, Hyperion |

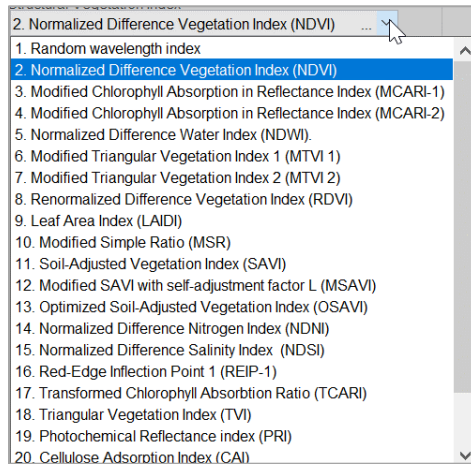
Index Image Display panel

The panel allows you to visualize established and newly developed indices as monochromatic images and composite indices in the RGB format. Each index comes with its own colormap. Some of the colormaps are specifically designed by IDCubePro® team for the corresponding indices. Other colormaps such as preset colormaps from the **Color Toolbar** or the **Right click** menu on the colorbar can be also applied.

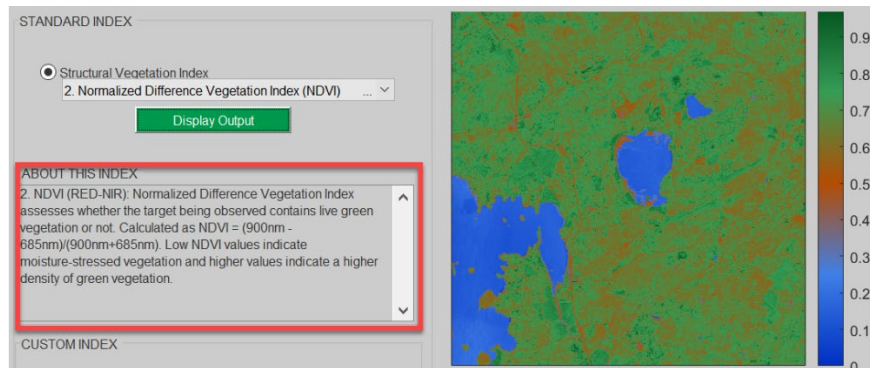
Standard Index panel

Steps:

1. Select an option from the dropdown menu. There are currently 23 indices in our AVIRIS, AVIRIS-NG, and Hyperion index databases. Each index is made of two or three wavelengths. Wavelength selection for the same index differs across platforms because of differences in the hyperspectral hardware.



2. The information about the index will be automatically shown in the ABOUT THE INDEX subpanel. The image corresponding to the selected index will be shown in the IMAGE DISPLAY panel.



3. Click **Display Output** to visualize the index image

Custom Index panel

Steps:

1. Activate the panel by Selecting the **Custom Indices** radio button.
2. Select the number of variables. Current choices:
 - a. Two variables: allows user to enter two bands.
 - b. Three variables: allows user to enter three bands.
3. Type a formula (See **Appendix 1** on notation and selections of available functions).

4. Visualize the result on the INDEX IMAGE DISPLAY panel by clicking **Display Output** located on this panel.
5. Save the index by clicking the **Save New Index** button.

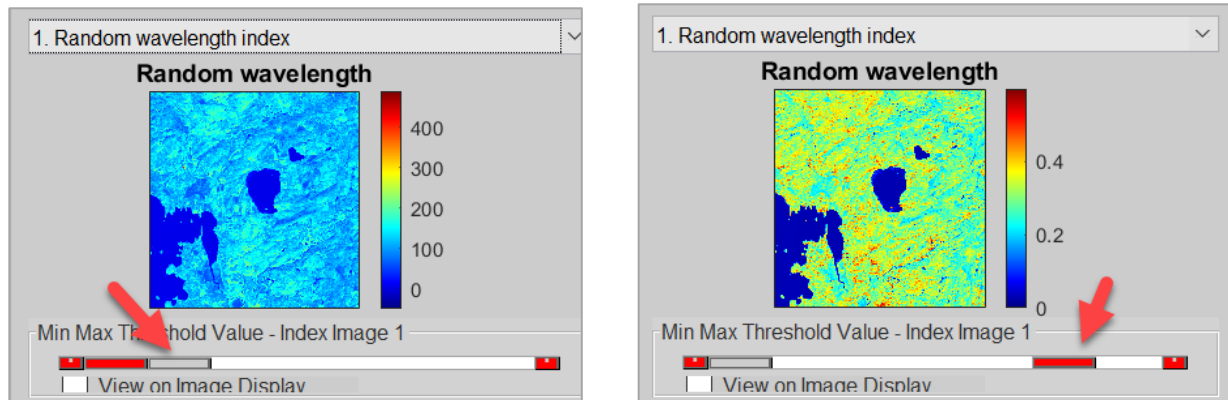
(Optional). You can add a new index to the list of indices in the COMPOSITE INDEX panel by checking **Add to the Composite Index** box. A new index called **custom1** will appear at the bottom of the list of indices in the COMPOSITE INDEX panel.

6. You can also open a previously stored index via the **Upload Index** button.

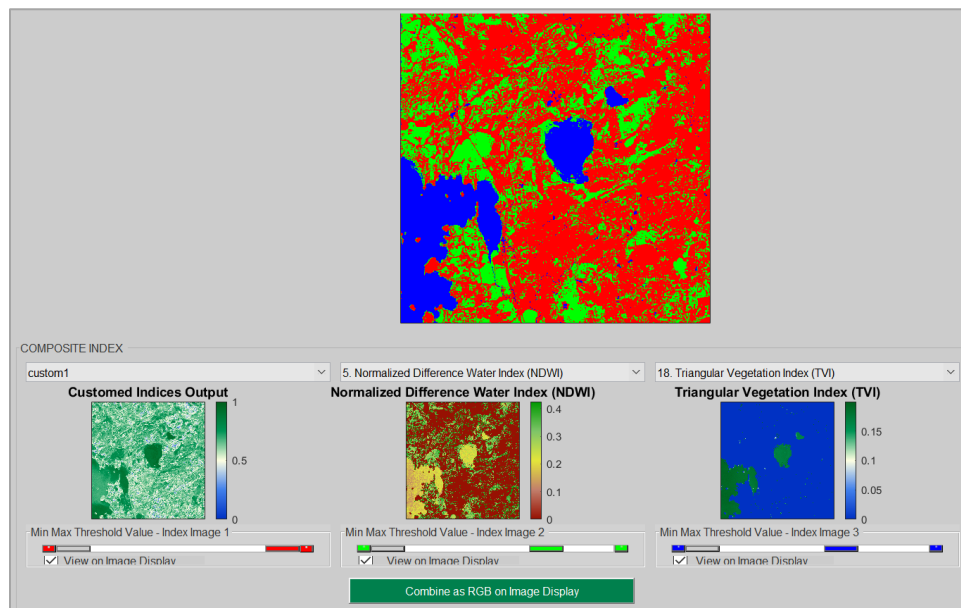
Composite Index panel

Steps:

1. There are three subpanels. Select an index from the dropdown menu on each of the subpanels. The index images will be immediately shown as monochromatic images. Pixel intensities on the image are normalized between 0 and 1 values.
2. Use sliders to adjust the visual appearance of the image. Each slider box has two small sliders. To move the small slider, click on it to activate (changes the color from grey to color) and then use the left and right boxes to move the slider. Repeat the procedure to the second slider.



3. Repeat the steps on all three subpanels.
4. Check **View on Image Display** to combine the index images together and visualize them on the INDEX IMAGE DISPLAY panel by pressing **Combine as RGB on the Image Display** button. You can continue adjusting the subpanels with sliders. After every adjustment, click **Combine as RGB** to visualize on the INDEX IMAGE DISPLAY panel.



References:

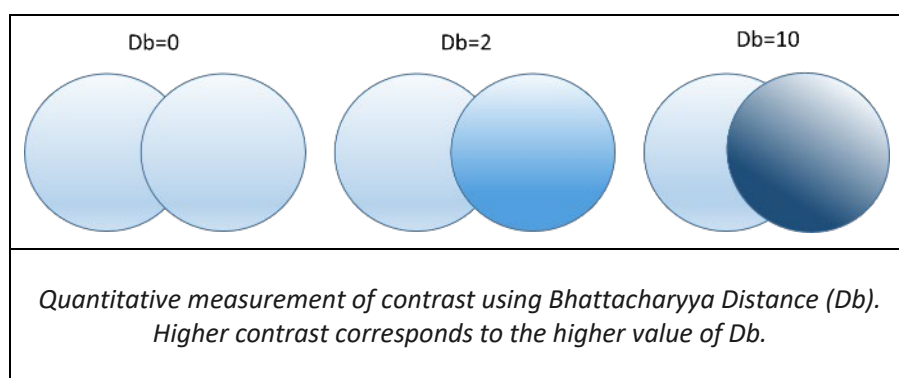
The design of the sliders was based on the work by Danielle Ripsman, (2022). superSlider <https://www.mathworks.com/matlabcentral/fileexchange/43285-superslider>, *MATLAB Central File Exchange*. Retrieved May 11, 2022.

Contrast Maximization Toolbox

NOTE: The toolbox works best when the original image in the **Main Interface** is monochromatic. If you see issues, please close this toolbox, return to the **Main Interface** and select **Single Channel** radio button.

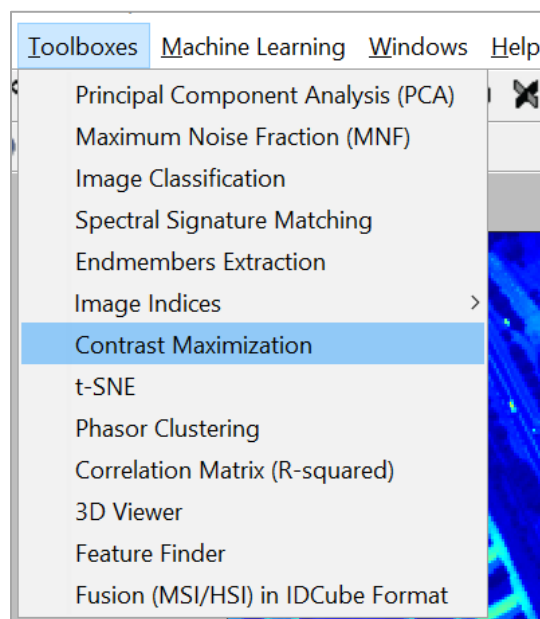
Features:

1. Finds the channel/wavelength for the best contrast between two selected regions of interest (ROIs).
2. Finds the channel/wavelength for the best contrast and the corresponding bandwidths between two selected regions of interest (ROIs).
3. Identify whether there is a difference between two ROIs and quantify the difference using Bhattacharyya distance (Db). Higher Db corresponds to better contrast between two ROIs
4. Identifies new indexes.

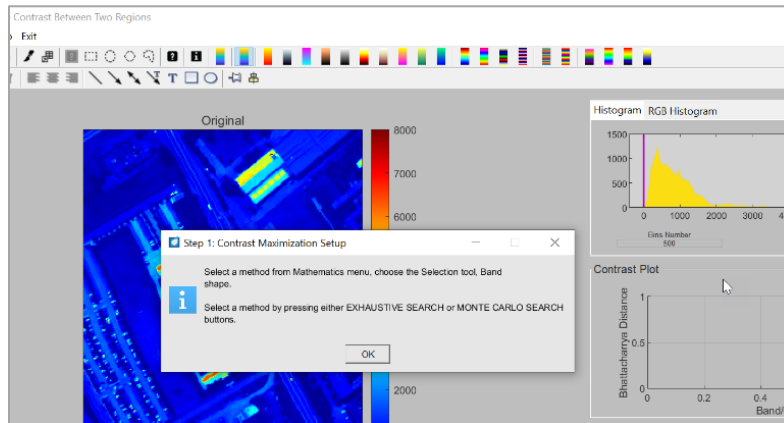


Steps:

1. Load the file and select **Toolboxes** → **Contrast Maximization**



A toolbox window with instructions will pop up.



2. Select **Mathematics**. Available options are:

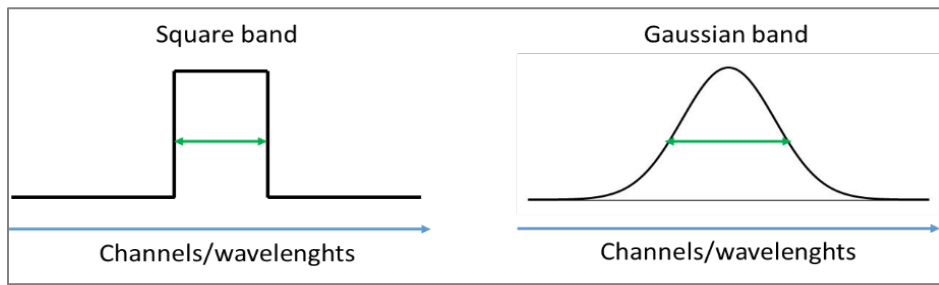
| Description | Mathematical Expression or function |
|--------------------------------------|-------------------------------------|
| Single channel: | $w1$ |
| Summation (two channels) | $w1 + w2$ |
| Simple Ratio (two channels) | $w1./w2$ |
| Normalized Ratio (two channels) | $(w1-w2)/(w1+w2)$ |
| Weber Ratio (two channels) | $(w1-w2)/w2$ |
| Log10(Ratio) (two channels) | $Log10(w1./w2)$ |
| Multiplication (two channels) | $w1 \times w2$ |
| Log10(multiplication) (two channels) | $Log10(w1 + w2)$ |
| Logical AND (two channels) | $w1 \text{ AND } w2$ |
| Logical OR (two channels) | $w1 \text{ OR } w2$ |
| Logical XOR (two channels) | $w1 \text{ XOR } w2$ |
| Image complement (Single band only) | $imcomplement(w1)$ |
| First derivative (Single band only) | $gradient(w1)$ |
| Second derivative (Single band only) | $gradient(gradient(w1))$ |

3. Select the **Selection Tool**. Available options are:

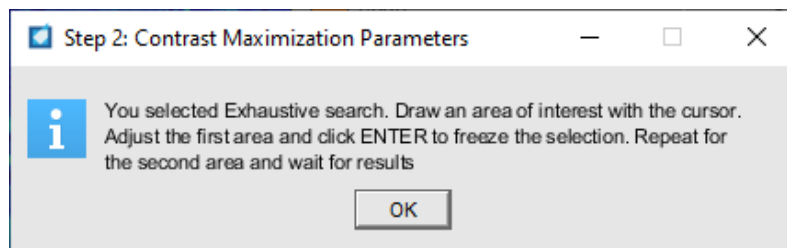
- Ellipse
- Polygon
- Freehand
- Rectangular

4. Select the **Band Shape**. Available options are:

- Rectangular Band Shape
- Gaussian Band Shape



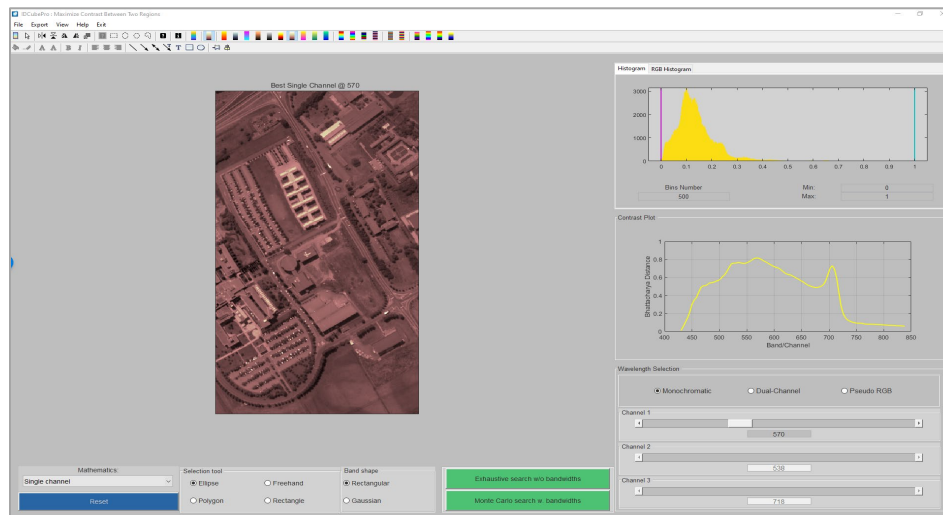
5. Select the method for finding the best channel(s) for contrast. Available options are:
 - a. **Exhaustive Search** without the bandwidths
 - b. **Monte Carlo Search** with the bandwidths



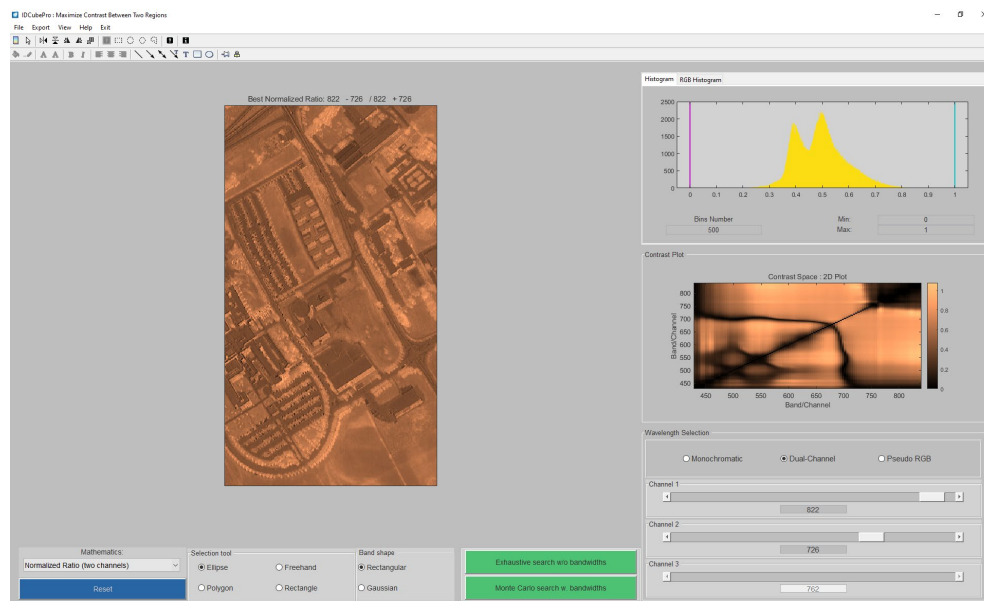
6. Draw the first region of interest with the cursor and adjust. Click ENTER to fix the selection and draw a second area. Adjust the second area and click ENTER to fix the selection. The calculations will start immediately.



If the single channel is selected the resulting screen will provide a Contrast Plot showing the contrast between the areas vs wavelength, and the image panel will show the image with the highest (best) contrast.



If the two channels from the **Mathematics** panel is selected, then instead of a Contrast Plot, a 2D Contrast Space will be shown. The best combination of the wavelengths will be given as a title



If the Monte Carlo is selected, then a new dialog asks to put the minimum and maximum bandwidths as well as the number of samples. (**NOTE:** The number of samples depends on the size of the image. A higher number will make the calculation slower.)

Input

Enter minimum bandwidth:

1

Enter maximum bandwidth:

50

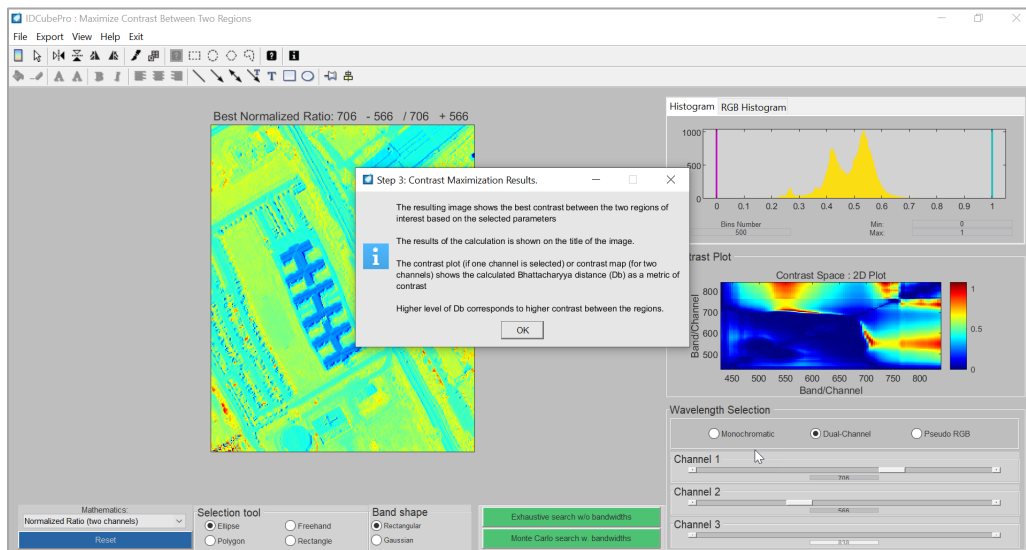
Enter number of parameter samples:

2000

OK

Cancel

The results are displayed as a new image and a contrast map. The title of the image gives the wavelengths. Toolbox display once processing has been completed. Note the title of the image gives the specific max contrast values.



Additional Information:

The algorithm implies relatively homogenous intensities within the region of interest. Adjust the size of the ROI accordingly.

References:

T Du, DK Mishra, L Shmuylovich, A Yu, H Hurbon, ST Wang, MY Berezin. Hyperspectral imaging and characterization of allergic contact dermatitis in the short-wave infrared, *Journal of Biophotonics* 13 (9), e202000040, 2020

DM Kim, H Zhang, H Zhou, T Du, Q Wu, TC Mockler, MY Berezin. Highly sensitive image-derived indices of water-stressed plants using hyperspectral imaging in SWIR and histogram analysis *Scientific Reports* 5 (1), 1-11, 2015

t-SNE Clustering Toolbox

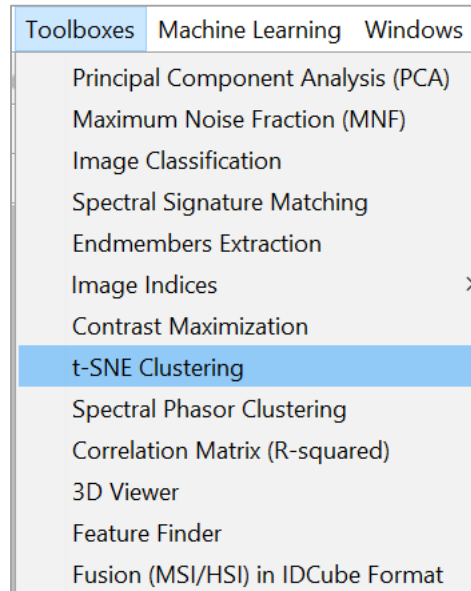
NOTE: The Toolbox supports parallel computing to accelerate computation. Plastic is used as an example. Large files might take a long time to compute. A typical time for a 50Mb file (Pavia, 340 x 610 x 103) takes about 10 minutes on an average desktop computer.

Features:

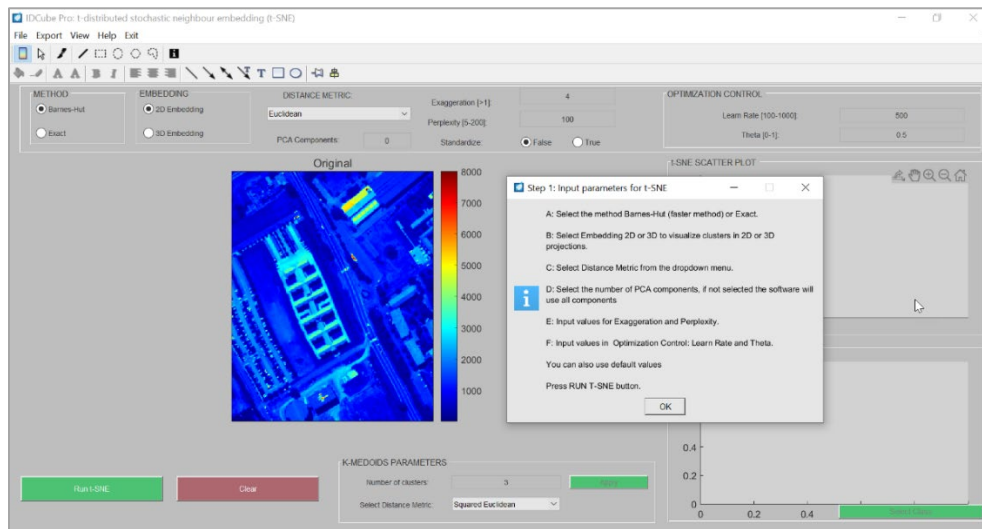
- Builds a 2D or 3D scatter map from the entire datacube.
- Enables a user to separate clusters via the k-means and visualize their position on an image.
- Enables a user to visualize up to 10 clusters.
- Calculates the area covered by each cluster (in pixels).

Steps:

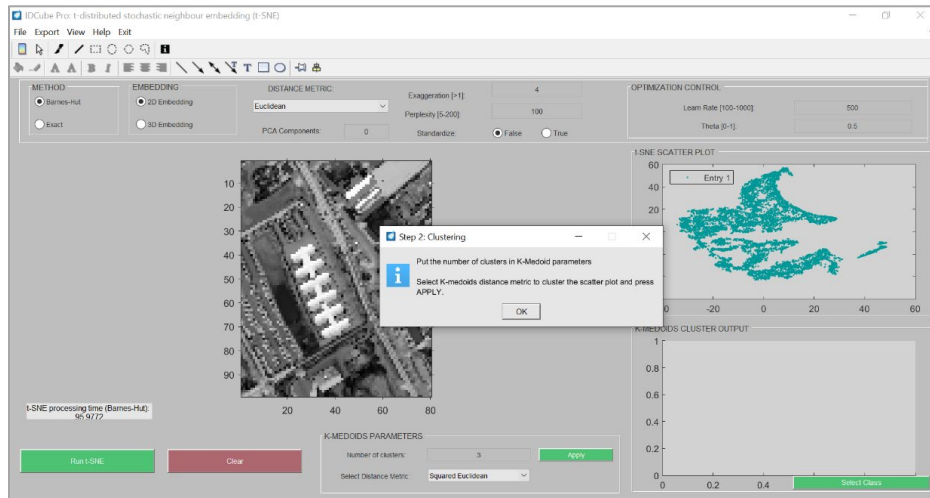
3. Open a file.
4. Select **Toolboxes** → **t-SNE Clustering**



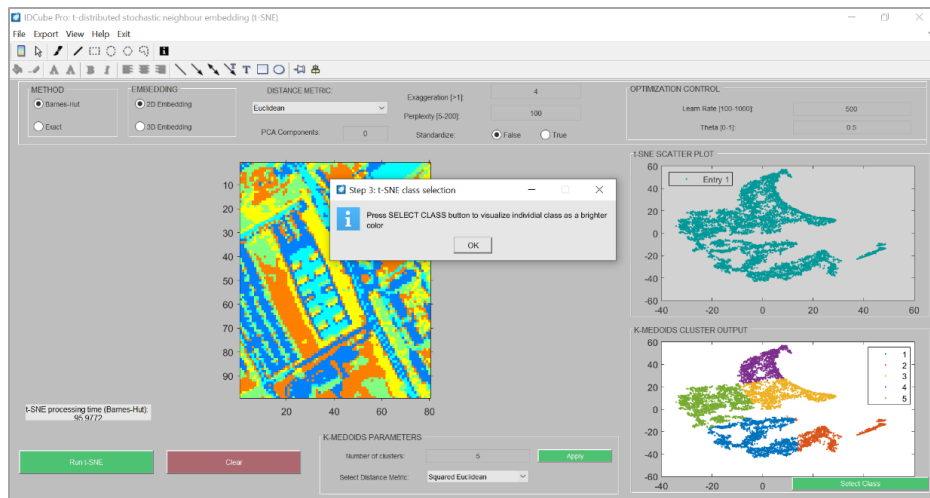
Calculations for t-SNE are computationally demanding. For that, the datacube size is minimized by using the pre-binning step in both spectral (bin=3) and spatial bin (3x3) dimensions. The preprocessing calculation starts immediately.



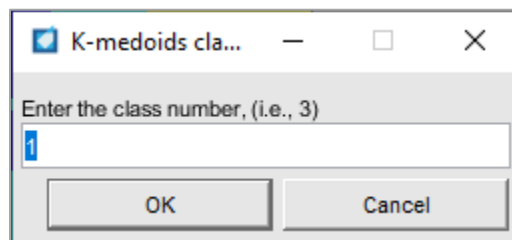
5. Select a method: available options are:
 - a. **Barnes-Hut** variation of t-SNE is used to speed the t-SNE algorithm and to cut down on its memory usage. The Barnes-Hut algorithm groups nearby points together to lower the complexity and memory usage of the t-SNE optimization step. The Barnes-Hut algorithm is an approximate optimizer, not an exact optimizer. There is a nonnegative tuning parameter **Theta** that affects a tradeoff between speed and accuracy. Larger values of **Theta** give faster but less accurate optimization results. The algorithm is relatively insensitive to **Theta** values in the range (0.2 - 0.8).
 - b. **Exact** method.
6. Select a type of embedding to specify the type of scatter plot that you will receive. Available options are:
 - a. 2D (default)
 - b. 3D
7. Under **Distance Metric** from the top, chose the parameters for the calculations (see Additional Information for further explanation):
 - a. Distance metric
 - b. PCA components
 - c. Exaggeration parameter
 - d. Perplexity parameter
 - e. Standardize
 - f. Under Optimization Control
8. Click the green **Run t-SNE** button. The t-SNE scatter plot will be generated on the right upper panel.
9. Select the **Number of clusters** and the **Distance Metric**. The results of clustering will be seen in the CLUSTER OUTPUT panel on the right lower panel.



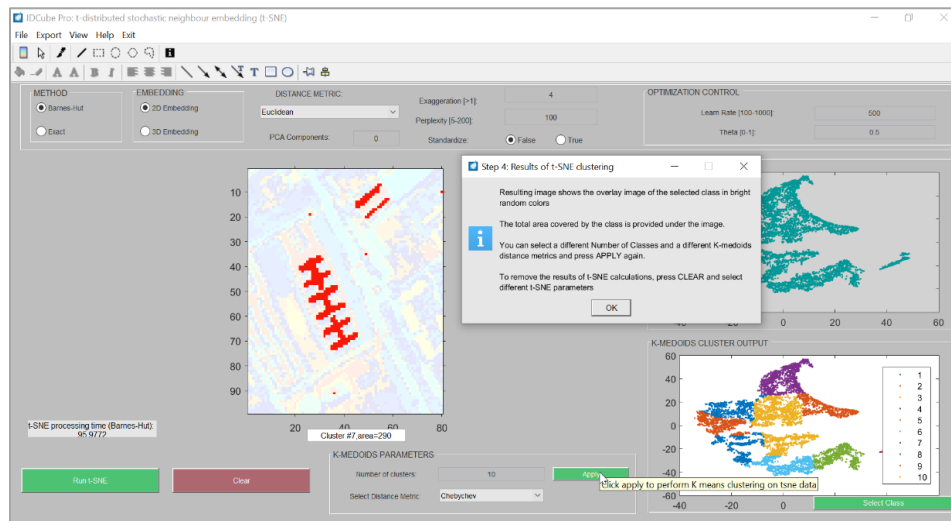
Click the green **Select Class** button to compare which cluster is relevant to various areas in the datacube.



A pop-up will appear asking for which class/cluster the user would like to view.

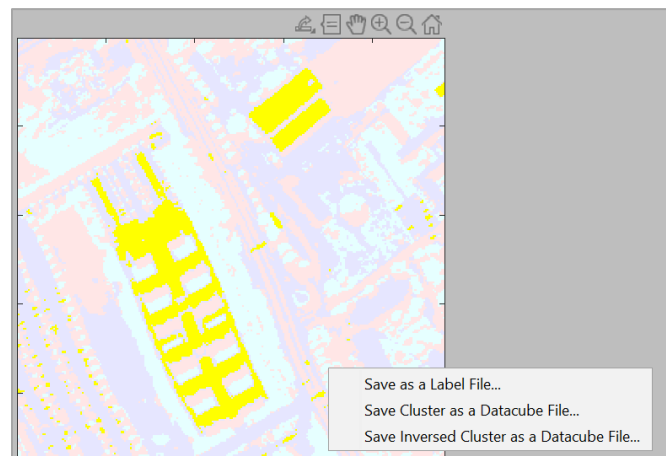


The area covered by the selected cluster (in a bright color with the area measured in pixels) will appear at the bottom of the image.



10. Save the segmented image as a **Label file** for the **Machine Learning** toolbox. After selecting the class, make a **right click** on the segmented image to activate **Save as a Label File** tab. Click the tab and specify the file name. The *.png* and *.mat* files will be generated.

You can also save only the data that belongs to the cluster area as a new datacube by selecting **Save Cluster as a Datacube file**. In this case others the pixel values of the object will be preserved as original, while the other pixels will be assigned as 0 (zeroes) across the entire datacube. By selecting **Save Inversed Cluster as a Datacube File**, the saving will be inverted. The pixels from the area occupied by the cluster will be assigned to zero, while the other values across the object will remain.



Additional Information:

There are two t-SNE algorithms, specified as **Exact** or **Barnes-Hut**.

The **Exact** algorithm optimizes the Kullback-Leibler divergence of distributions between the original space and the embedded space.

The **Barnes-Hut** algorithm performs an approximate optimization faster and uses less memory when the number of data rows is large.

For both algorithms, t-SNE uses squared pairwise distances to calculate the Gaussian kernel in the joint distribution of X.

Exaggeration: Size of natural clusters in data, scalar value 1 or greater, 4 (default). Size of natural clusters in data, specified as a scalar value 1 or greater. A large exaggeration makes t-SNE learn larger joint probabilities of Y and creates relatively more space between clusters in Y. t-SNE uses exaggeration in the first 99 optimization iterations. If the value of Kullback-Leibler divergence increases in the early stage of the optimization, try reducing the exaggeration.

Number PCA Components: PCA dimension reduction nonnegative integer, 0 (default). PCA dimension reduction, specified as a nonnegative integer. Before t-SNE embeds the high-dimensional data, it first reduces the dimensionality of the data to **Number PCA Components** using the PCA function. When **Number PCA Components** is 0, t-SNE does not use PCA.

Perplexity: Effective number of local neighbors of each point positive scalar, 30 (default). Effective number of local neighbors of each point, specified as a positive scalar. Larger **Perplexity** causes t-SNE to use more points as nearest neighbors. Use a larger value of **Perplexity** for a large dataset. Typical **Perplexity** values are from 5 to 50. In the **Barnes-Hut** algorithm, t-SNE uses $\min(3 \times \text{Perplexity}, N-1)$ as the number of nearest neighbors.

The 'Perplexity' value cannot be greater than the number of rows of X.

Standardize: Normalize input data, false (default) / true. Normalize input data, specified as false or true. When true, t-SNE centers and scales X by dividing the columns by their standard deviations. When features in X are on different scales, set '**Standardize**' to **true**. Do this because the learning process is based on nearest neighbors, so features with large scales can override the contribution of features with small scales.

Learn Rate: Learning rate for the optimization process, 500 (default), positive scalar. Typically, set values from 100 through 1000. When **Learn Rate** is too small, t-SNE can converge to a poor local minimum. When **Learn Rate** is too large, the optimization can initially have the **Kullback-Leibler** divergence increase rather than decrease.

Theta: Barnes-Hut tradeoff parameter, 0.5 (default), scalar from 0 through 1. Barnes-Hut tradeoff parameter, specified as a scalar from 0 through 1. Higher values give a faster but less accurate optimization. Applies only when Algorithm is **Barnes-Hut**.

Distance Metrics

A distance metric is a function that defines a distance between two observations. Distance metrics can be specified by one of the following. Definitions of the distance metrics are given in the Table:

| Value | Description |
|------------------|--|
| euclidean | Euclidean distance. |
| squaredeuclidean | Squared Euclidean distance. (This option is provided for efficiency only. It does not satisfy the triangle inequality.) |
| seuclidean | Standardized Euclidean distance. Each coordinate difference between observations is scaled by dividing by the corresponding element of the standard deviation, |
| mahalanobis | Mahalanobis distance using the sample covariance of X, $C = \text{cov}(X, \text{'omitrows'})$. |
| cityblock | City block distance. |
| minkowski | Minkowski distance. The default exponent is 2. |
| chebychev | Chebychev distance (maximum coordinate difference). |
| cosine | One minus the cosine of the included angle between points (treated as vectors). |
| correlation | One minus the sample correlation between points (treated as sequences of values). |
| hamming | Hamming distance, which is the percentage of coordinates that differ. |

| Value | Description |
|----------|---|
| jaccard | One minus the Jaccard coefficient, which is the percentage of nonzero coordinates that differ. |
| spearman | One minus the sample Spearman's rank correlation between observations (treated as sequences of values). |

***k*-Medoids Clustering:** *k*-Medoids clustering is a partitioning method commonly used in domains that require robustness to outlier data, arbitrary distance metrics, or ones for which the mean or median does not have a clear definition. It is similar to *k*-Means, and the goal of both methods is to divide a set of measurements or observations into *k* subsets or clusters so that the subsets minimize the sum of distances between a measurement and the center of the measurement's cluster. In the *k*-Means algorithm, the center of the subset is the mean of measurements in the subset, often called a centroid. In the *k*-Medoids algorithm, the center of the subset is a member of the subset, called a medoid.

k-Medoid is more robust to noise and outliers as compared to *k*-Means because it minimizes a sum of pairwise dissimilarities instead of a sum of squared Euclidean distances. The *k*-Medoids algorithm returns Medoids, which are the actual data points in the data set. This allows you to use the algorithm in situations where the mean of the data does not exist within the data set. This is the main difference between *k*-Medoids and *k*-Means where the centroids returned by *k*-Means may not be within the data set. Hence *k*-Medoids are useful for clustering categorical data where a mean is impossible to define or interpret.

Performance of t-SNE:

Performance depends on data sizes and algorithms. t-SNE can take a good deal of time to process data. If you have *N* data points in *D* dimensions that you want to map to *Y* dimensions, then

- **Exact t-SNE** takes of order $D \times N^2$ operations.
- **Barnes-Hut t-SNE** takes of order $D \times N \log(N) \times \exp(\text{dimension}(Y))$ operations.

For Pavia, *N* is greater than 1000 or so and has the embedding dimension *Y* is 2 or 3 hence the Barnes-Hut algorithm can be faster than the exact algorithm.

References:

van der Maaten, Laurens, and Geoffrey Hinton. "Visualizing Data using t-SNE." *J. Machine Learning Research* 9, 2008, pp. 2579–2605.

van der Maaten, Laurens. Barnes-Hut-SNE. arXiv:1301.3342 [cs.LG], 2013.

Jacobs, Robert A. "Increased rates of convergence through learning rate adaptation." *Neural Networks* 1.4, 1988, pp. 295–307.

***k*-Medoids:**

Kaufman, L., and Rousseeuw, P. J. (2009). Finding Groups in Data: An Introduction to Cluster Analysis. Hoboken, New Jersey: John Wiley & Sons, Inc.

Park, H-S, and Jun, C-H. (2009). A simple and fast algorithm for *k*-Medoids clustering. *Expert Systems with Applications*. 36, 3336-3341.

Spectral Phasor Clustering Toolbox

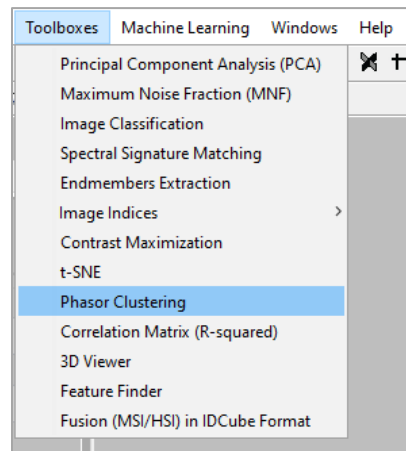
NOTE: This Toolbox supports parallel computing to accelerate computation. PAVIA dataset is used as a sample.

Features:

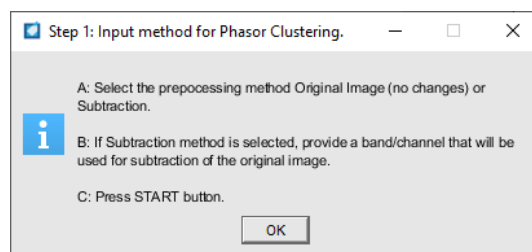
- Builds a density map from the entire datacube.
- Enables a user to select a cluster and visualize their position on a black and white image.
- Enables user to visualize up to three clusters.
- Calculates the area covered by each cluster (in pixels).
- Enables searching of the region of interest on a cluster.

Steps:

1. After loading a file, select **Toolboxes** → **Phasor Clustering**.



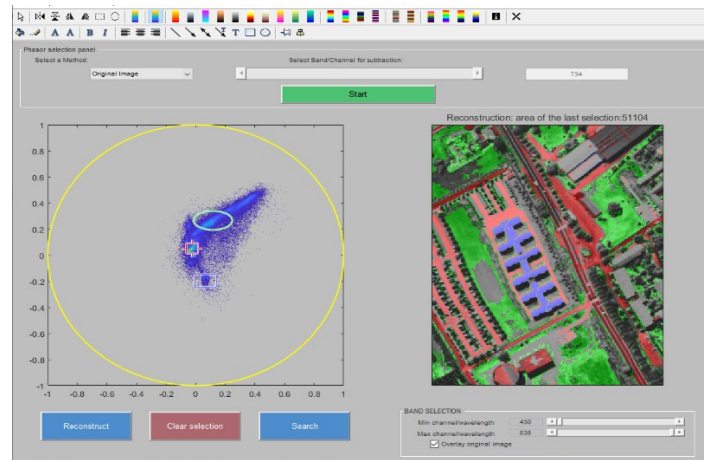
A set of pop-ups will guide you through the process.



2. Select a Method. Available options are:
 - a. Original image.
 - b. Subtraction (help to spread the scatter plot). For this option, select a wavelength using either a slider or type a band/channel/wavelength.
3. Click a **Start** button to generate a scatter plot (PHASOR SCATTER panel) and a gray image (RECONSTRUCTION panel).

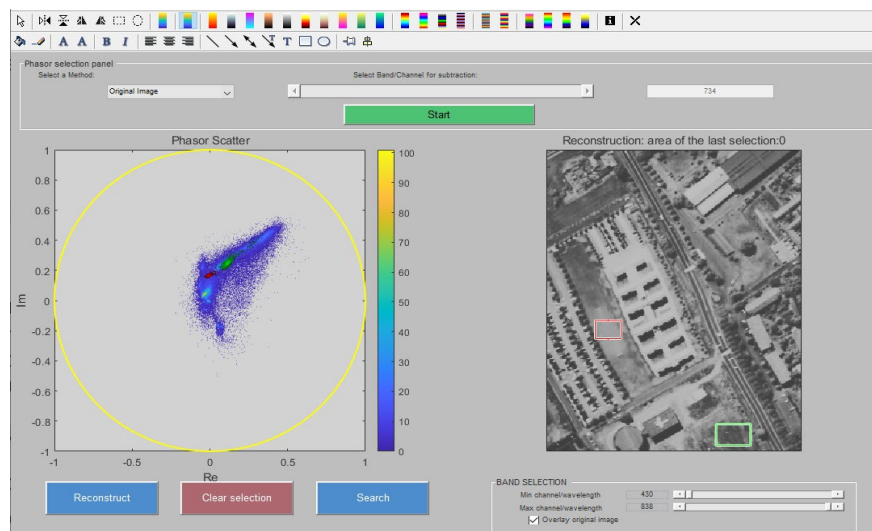
A: Visualize portions of the cluster on the RECONSTRUCTION panel by clicking the blue **Reconstruct** button. Click **Reconstruct** and select the first region of interest using either a rectangular or an ellipsoid

selection tool. This will produce the areas on the cluster as matching colors on the grayscale image. Click Check/Uncheck the “**Overlay original image**” to show/unshow the original image as a background.



B: Visualize selected areas from the RECONSTRUCTION panel on the PHASOR SCATTER panel using the **Search** button.

4. Press the **Search** button and select the area of interest to see the location of the corresponding cluster (as red, green, or blue dots). You can repeat this selection up to three times.
5. Use **Band Selection** to visualize the image within a specific wavelength range.



6. Save the segmented image as a **Label file** for the **Machine Learning** toolbox. After reconstructing, make a **right click** on the reconstructed image (right panel) to activate **Save as a Label File...** tab. Click the tab and specify the file name. The *.png* and *.mat* files will be generated. **NOTE:** we suggest using a single reconstruction for saving as a label file.

**Additional Information:**

The toolbox uses the Fourier Transform function that computes and plots the transformed spectrum from each pixel as a scatter plot.

Correlation Matrix (R-squared)

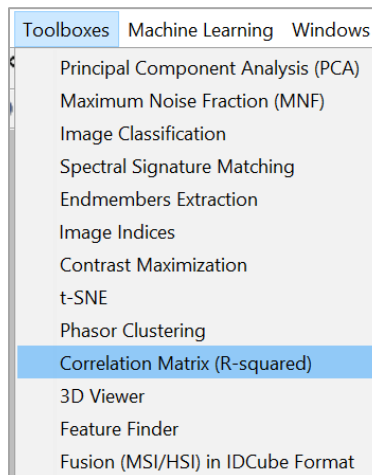
NOTE: Plastic and Coin dataset is used as an example.

Features:

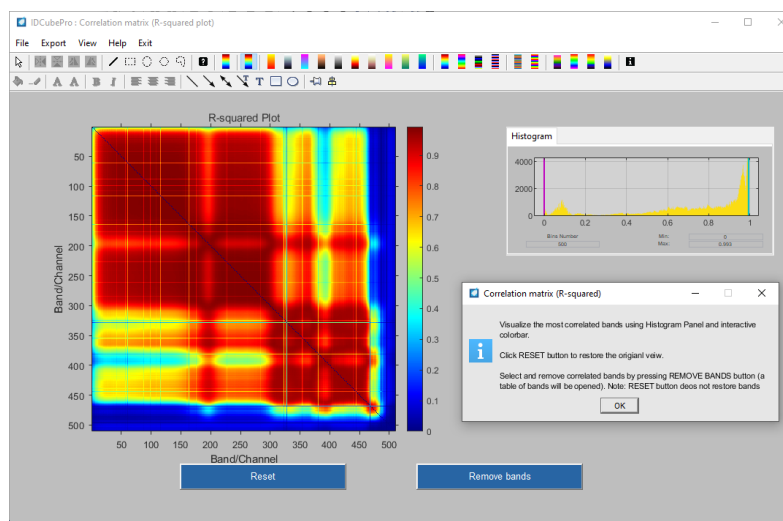
- Builds a correlation matrix to visualize the cross correlation between bands.
- The matrix identifies groups of highly correlated bands in the dataset for potential compression of data.
- The toolbox allows manual deletion of the redundant bands.

Steps:

1. Open a file.
2. Select **Toolboxes** → **Correlation Matrix (R-squared)**.

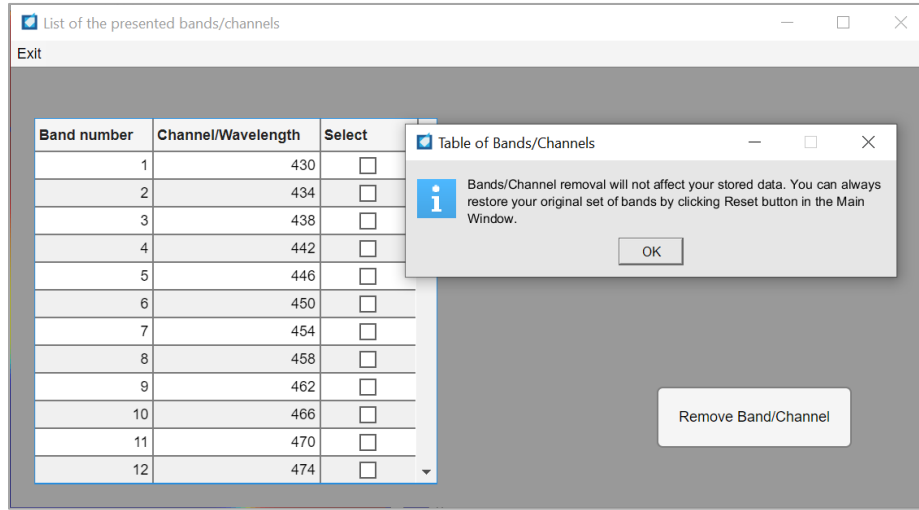


The calculation will start immediately and produce a correlation matrix with the histogram.



Remove Highly Correlated Bands (Optional):

1. Press **Remove Bands** to launch a Table with all bands in the dataset.
2. Select the bands with the highest values of correlation (i.e., 75-90) and click **Remove**.
The removal of the bands is global and will affect the original data.
3. To see a new correlation matrix, you will need to run the Correlation Matrix toolbox again. Within the toolbox, the numbering of bands will reflect the deletion.



Additional Information:

The toolbox uses a square of a function that computes a Pearson correlation matrix.

Pearson's linear correlation coefficient is the most used linear correlation coefficient. For a band X_a in X and a band Y_b in matrix Y , having means

$$\bar{X}_a = \sum_{i=1}^n (X_{a,i})/n, \text{ and } \bar{Y}_b = \sum_{j=1}^n (Y_{b,j})/n,$$

where n is the length of each spectrum.

Pearson's linear correlation coefficient $\rho(a,b)$ is defined as:

$$\rho(a,b) = \frac{\sum_{i=1}^n (X_{a,i} - \bar{X}_a)(Y_{b,i} - \bar{Y}_b)}{\left\{ \sum_{i=1}^n (X_{a,i} - \bar{X}_a)^2 \sum_{j=1}^n (Y_{b,j} - \bar{Y}_b)^2 \right\}^{1/2}},$$

Values of the correlation coefficient can range from -1 to $+1$. A value of -1 indicates a perfect negative correlation, while a value of $+1$ indicates a perfect positive correlation. A value of 0 indicates no correlation between the columns. IDCube uses a square of the correlation coefficients. In this case, the correlation coefficient can range from 0 to $+1$. A value of $+1$ indicates a perfect positive or negative correlation between the bands, suggesting the redundancy of the bands. A value of 0 indicates no correlation between the bands.

References:

Gibbons, J.D. *Nonparametric Statistical Inference*. 2nd ed. M. Dekker, 1985.

Hollander, M., and D.A. Wolfe. *Nonparametric Statistical Methods*. Wiley, 1973.

3D Viewer

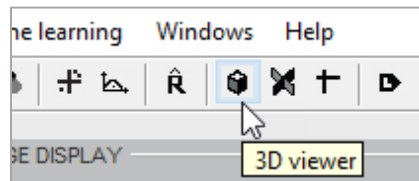
NOTE: Plastic and Coin dataset is used as an example.

Features:

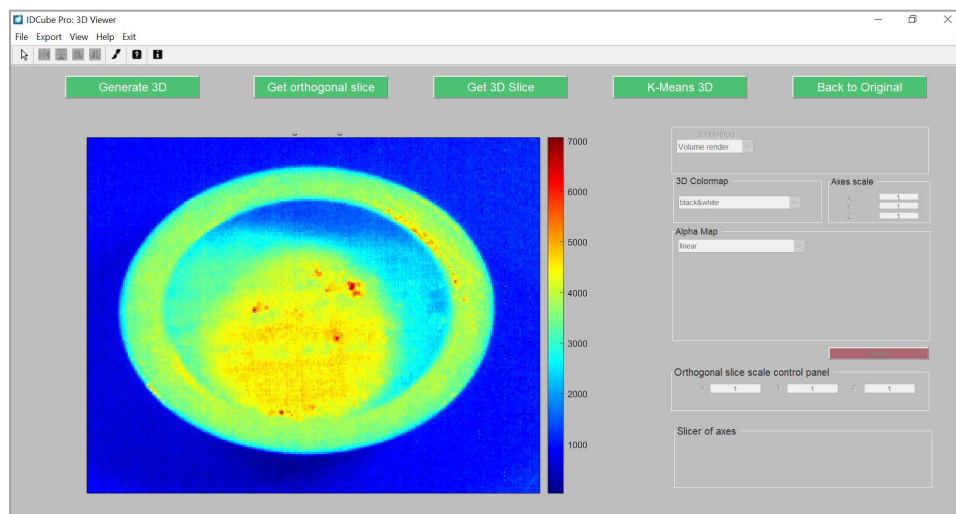
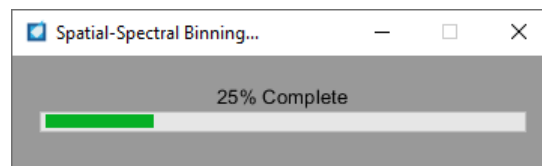
1. Builds and rotates 3D images where X, and Y are spatial coordinates and Z – is the spectral coordinate.
2. Changes the dimensions for better representation of the datacube.
3. Performs Isosurface and Alpha mapping.
4. Performs orthogonal slicing.
5. Performs 3D slicing.

Steps:

1. Select the **3D Viewer** toolbox or a shortcut icon button from the **Main Interface** to start 3D Viewer.

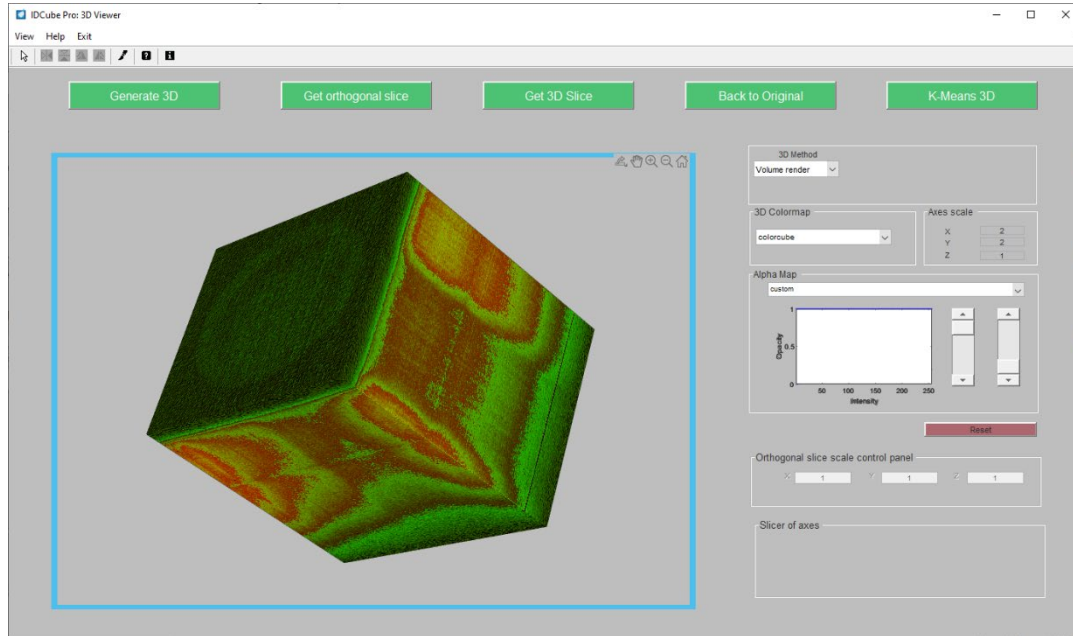


For effective visualization of files, the toolbox performs spatial and spectral binning ($n=3$) before 3D visualization.

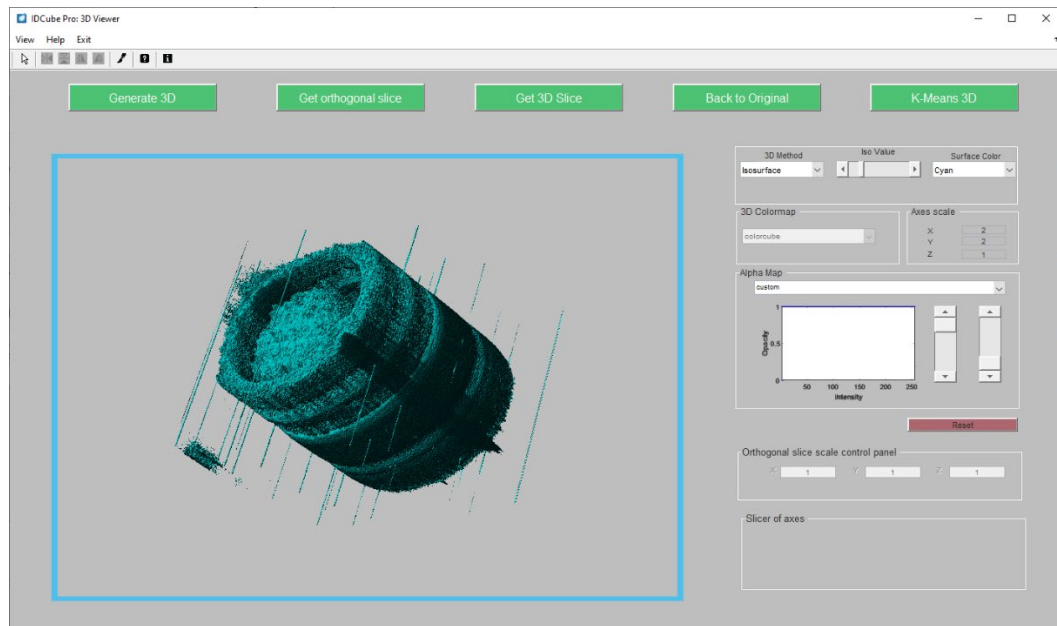


3D View

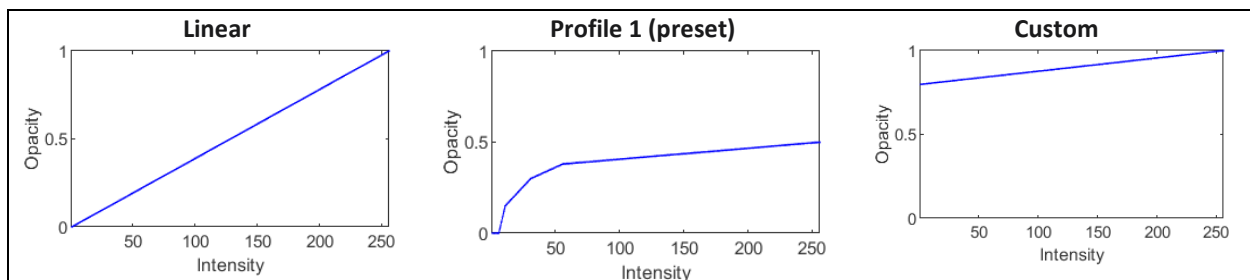
1. Click **Generate 3D** button. This command will activate a 3D INTERACTIVE panel on the right.



2. Mouse control is activated:
 - a. Rotate 3D View by clicking, holding, and moving the left button of the mouse.
 - b. Zoom 3D View by clicking, holding, and moving the right button of the mouse.
 - c. Zoom can also be activated by the scroll wheel.
3. 3D INTERACTIVE panel enables the following options:
 - a. Volume type.
 - i. *Volume render* (default). Shows all data with or without the alpha values. Alpha values provide transparency to the object.
 - ii. *Isosurface*. The isosurface function computes and draws a surface by connecting points of a constant value within a volume of space. Activates the following options (**NOTE:** Other functions will not work when Isosurface is selected).
 - iii. *Isovalue*. This value defines the surface properties where each point has the same value (the slider shows the range from 0 to 1).
 - iv. *Surface Color*. Shows the color of the isosurface (see below).



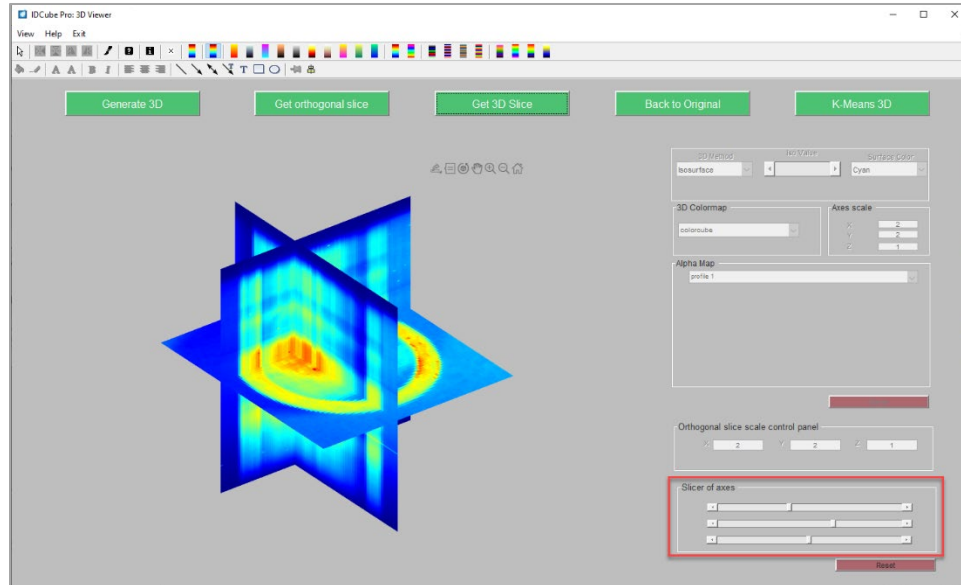
- b. *Alpha map*: alpha value sets the face transparency for objects. Alpha Map uses a vector of values ranging from 0 to 1. This alpha map displays the lowest alpha data values as completely transparent and the highest alpha data values as opaque. There are preset sets of vectors:
 - i. Linear.
 - ii. Profile 1- 9
 - iii. Custom. The user selects the alpha value and the intensity value. When this function is selected, two sliders corresponding to the alpha value and the intensity values are activated. Only a linear profile is currently implemented.
 - iv. (an example of a Linear and Profile 1 is shown below).
- c. *Dimension Control*. Is used to multiply the size of the object in X, Y, and Z directions to visually increase/decrease the dimensions for better visualization. No changes are introduced to the actual values in the dataset.



- d. Select a **3D Colormap** under Generate 3D. Available colormaps are black&white, autumn, bone, cool, copper, gray, hot, pink, spring, summer, winter, jet, hsv, colorcube, flag, lines, prism, CT-bone, white, and contrast.

3D Slice View

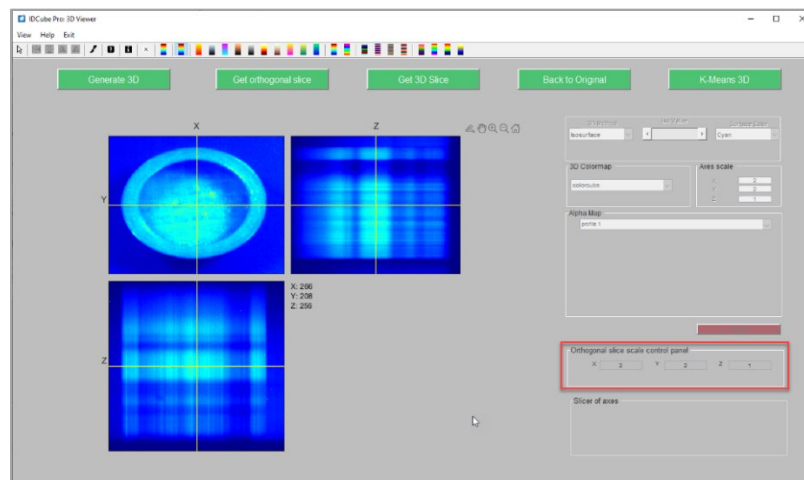
Click **Get 3D Slice** button. This command will activate a SLICER OF AXES panel on the right. The panel has three slicers corresponding to the X, Y, and Z axes.



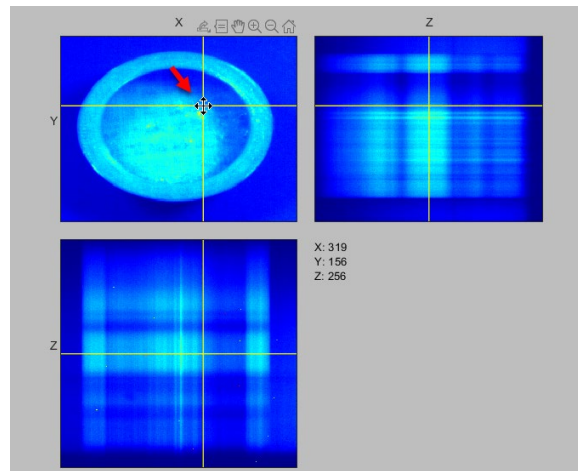
Click **Reset** to return to the default view.

Orthogonal Slice View

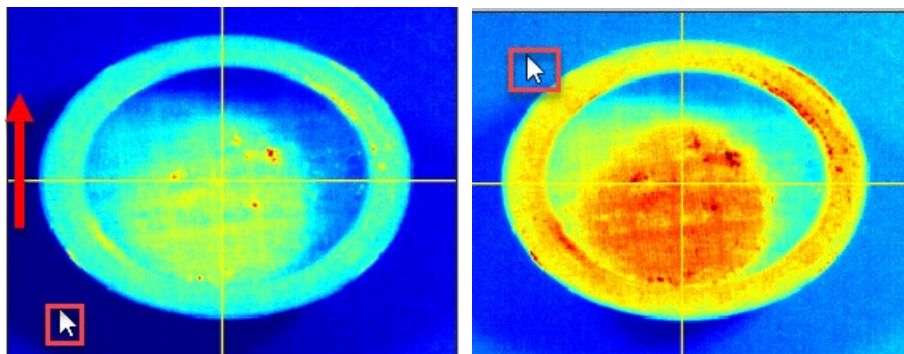
Click **the Get Orthogonal slice** button. This command will activate an ORTHOGONAL SLICE SCALE CONTROL panel on the right. Enter the values to adjust the dimension (the value is used to multiply the dimension with default values equal to 1). It will only affect visualization.



Grab the intersection of the two lines and move it across the image to see different slices.



To change the intensity of the image, left-click on the image and drag the cursor up or down.

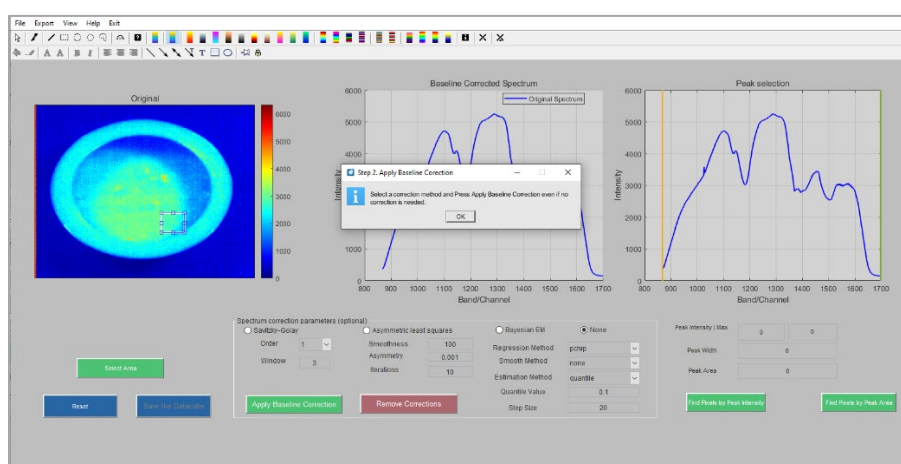


Feature Finder

NOTE: Plastic and Coin dataset is used as an example.

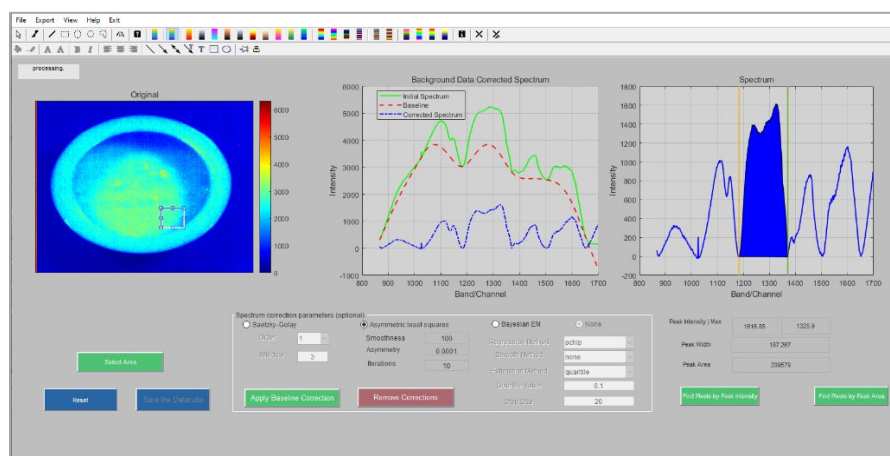
Features:

- Calculates and removes the background from the spectra.
- Calculates the peak intensity, position, peak width, and area under the peak (positive and negative).
- Visualizes the peak in the dataset.
- Generates the new dataset for the peak of interest and saves it in the original directory.
- The toolbox supports parallel computing to accelerate computation.



Steps:

1. Select the area of interest.
2. Correct the spectrum for background using None, Asymmetric Least Squares Smoothing, Savitzky-Golay, or Bayesian EM methods



3. Move the boundaries to select a spectrum and calculate spectral parameters: such as **Peak Intensity**, **Peak Maximum**, **Peak Width**, and **Peak Area**.

- Press the **Find Pixels buttons** to visualize the pixels that have the peak features. This can be done by two different methods specified below.

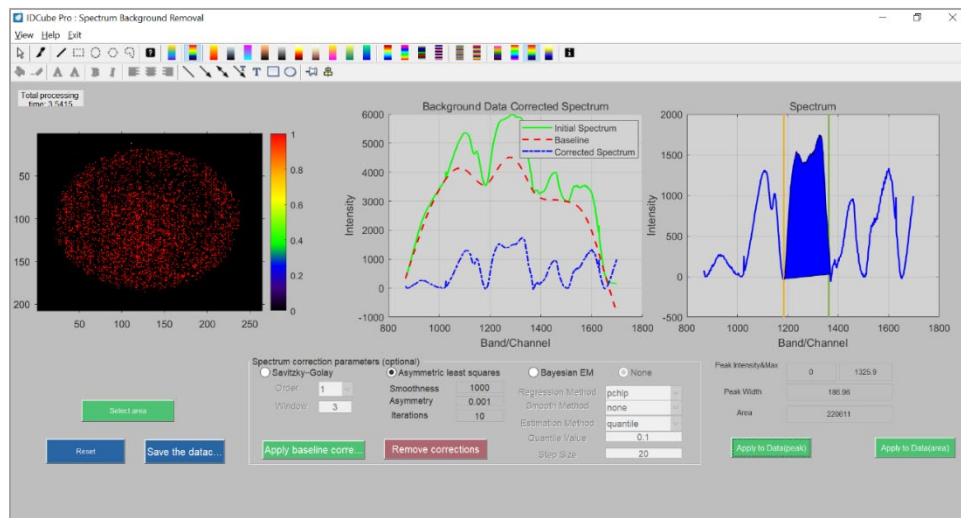
Method 1: Find Peaks by Peak Intensity. Change the values of the peak to any positive value less or equal to the identified peak intensity. Enter zero, if you would like to see the pixels in the image corresponding to the entire peak. Press **Apply to Data (Peak)**.

Peak Intensity | Max: 1616.85 1325.9

Peak Width: 187.267

Peak Area: 209579

Find Pixels by Peak Intensity Find Pixels by Peak Area



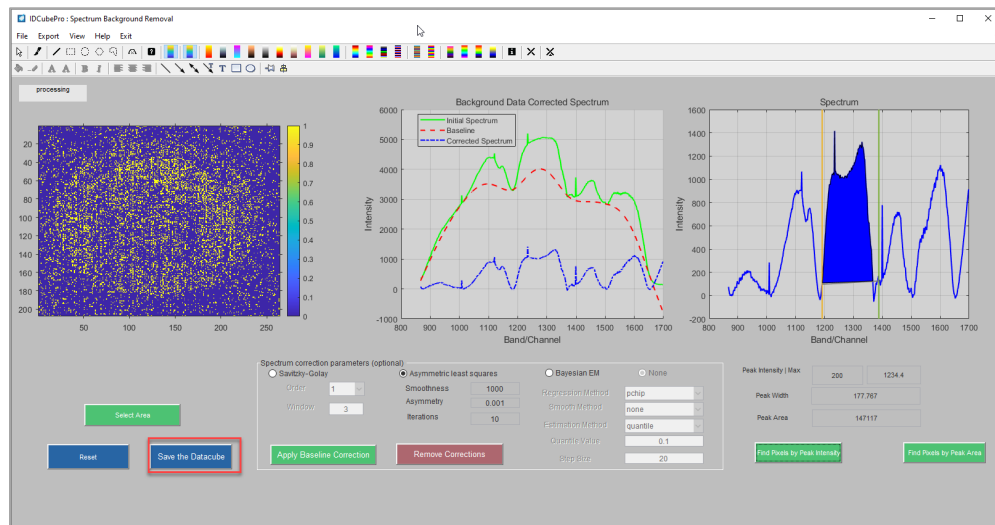
Method 2: Find Peaks by Peak Area. Leave the value intact. Press **Find Pixels by Peak Area**.

Peak Intensity&Max: 0 1325.9

Peak Width: 186.96

Area: 220611

Apply to Data(peak) Apply to Data(area)



You can save the new datacube with the corresponding changes in the image by pressing **Save the Datacube** as a new dataset to the directory.

Additional Information:

Savitzky-Golay filter: The filter applies a type of sliding window to the data.

ORDER: is an order of the polynomial.

WINDOW: is the number of data points in the window at any one time.

For example, Window = 11, and Order = 3 fit a polynomial of order 3 to 11 data points at a time and the i th data point will be approximated by the polynomial evaluated at the point corresponding to i .

Asymmetric Least Squares Smoothing: This method uses a smoother with an asymmetric weighting of deviations to get a baseline estimator. In doing such, this processor quickly ascertains and corrects a baseline while retaining the signal peak information.

SMOOTHNESS: defines how smooth the baseline should be (default 100).

ASYMMETRY: defines how "low" the baseline should be. The range is from 0 to 1. Lower peaks require asymmetry approaching 0, while high peaks require asymmetry value approaching 1.

ITERATIONS: defines the number of iterations to reach the converge (default 20). The calculation time is proportional to the number of iterations.

Bayesian EM filter: The filter adjusts the variable background (baseline) of a signal with peaks by following three steps: 1) estimates the background within multiple shifted windows of width 200 separation units (s.u.) along the x-axis, 2) regresses the varying baseline to the window points using a spline approximation, and 3) adjusts the background of the input signal.

WINDOWSIZE: sets the width for the shifting window. The default is 200 s.u., which means a background point is estimated for windows of 200 s.u. in width.

STEPSIZE: sets the steps for the shifting window. The default is 200 s.u., which means a background point is estimated for windows at every 200 s.u.

REGRESSION METHOD sets the method used to regress the window estimated points to a soft curve. The default is 'pchip'; i.e., shape-preserving piecewise cubic interpolation. Other options are 'linear' and 'spline' interpolation.

ESTIMATION METHOD sets the method used to find the likely background value at every window. Default is 'quantile', in which the quantile value is set to 10. An alternative method is 'em', which assumes a doubly stochastic model.

SMOOTH METHOD sets the method used to smooth the curve of estimated points, useful to eliminate the effect of possible outliers. Options are 'none' (default), 'lowess' (Linear Fit), 'loess' (Quadratic Fit), or 'rloess' and 'rloess' (Robust Linear and Quadratic Fit).

QUANTILE VALUE changes the default quantile value. The default is 0.10.

NOTE: The baseline subtraction mode does not preserve the height of the tallest peak in the signal when subtracting the baseline.

References:

Lucio Andrade and Elias Manolakos, "Signal Background Estimation and Baseline Correction Algorithms for Accurate DNA Sequencing" *Journal of VLSI, special issue on Bioinformatics* 35:3 pp 229-243 (2003)

Fusion (MSI/HSI, pansharpening)

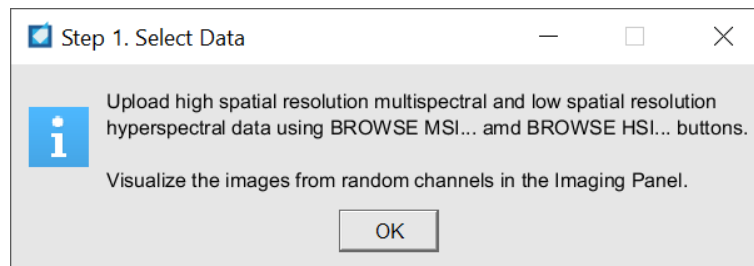
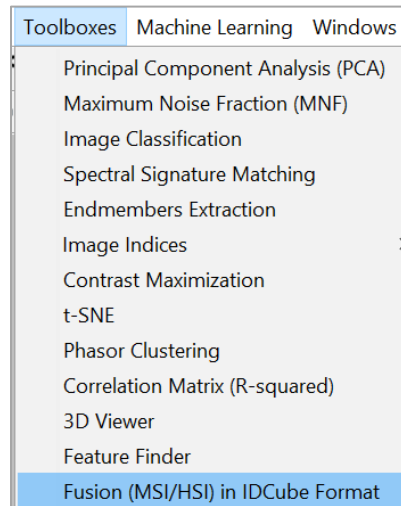
NOTE: Hyperspec-VNIR Chikusei dataset is used as an example.

Features:

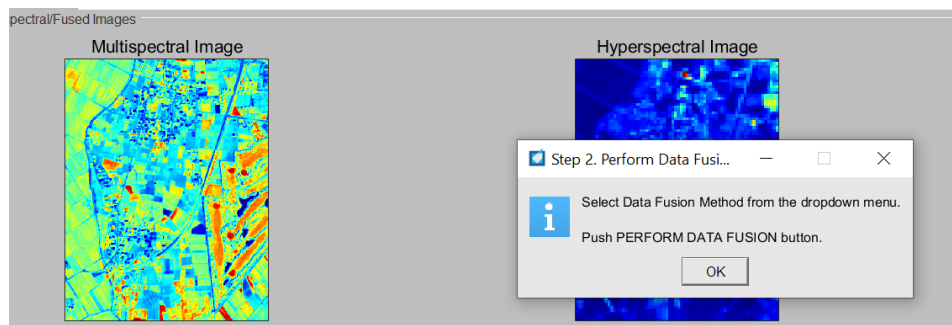
- Combines low-resolution hyperspectral dataset and high-resolution multispectral dataset to generate a high-resolution hyperspectral dataset.
- *Future release* Evaluates the quality of fusion.

Steps:

1. Open **Toolboxes** → **Fusion (MSI/HSI)** in IDCube format. A new window will pop up.

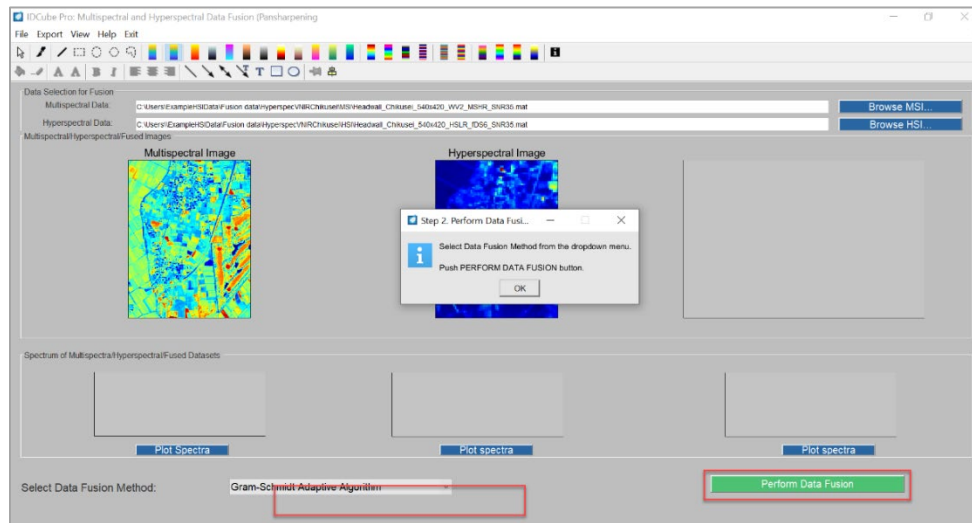


2. Click **Browse...** and locate the multispectral and hyperspectral datasets.

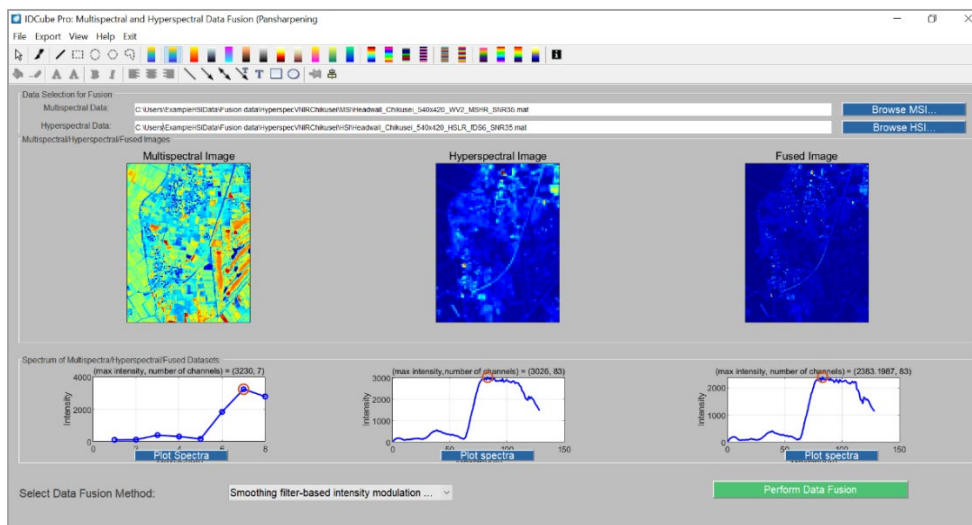


3. Select an algorithm from the **ALGORITHM SELECTION** panel. Currently available options are:

- Gram-Schmidt Adaptive algorithm.
- Smoothing filter-based intensity modulation with hypersharpening.
- Generalized Laplacian pyramid with hypersharpening.



Click the green **Perform Data Fusion** button. Click the **Plot Spectra** buttons and touch the images to visualize the spectra. Click on the top of the image to expand the image.



To save the fused dataset, **right-click** on the fused image and select **Save as New Datacube**.

References:

This toolbox includes three algorithms for fusing hyperspectral and multispectral data to obtain high-resolution hyperspectral data. The toolbox is based on the following references:

Review of fusion methods: N. Yokoya, C. Grohnfeldt, and J. Chanussot, "Hyperspectral and multispectral data fusion: a comparative review of the recent literature," *IEEE Geoscience and Remote Sensing Magazine*, vol. 5, no. 2, pp. 29-56, June 2017.

GSA (Gram-Schmidt adaptive): N. Yokoya, C. Grohnfeldt, and J. Chanussot, "Hyperspectral and multispectral data fusion: a comparative review of the recent literature," *IEEE Geoscience and Remote Sensing Magazine*, vol. 5, no. 2, pp. 29-56, June 2017.

SFIM-HS (Smoothing filtered-based intensity modulation with hypersharpening): J. G. Liu (2000) Smoothing Filter-based Intensity Modulation: A spectral preserve image fusion technique for improving spatial details, *International Journal of Remote Sensing*, 21:18, 3461-3472, DOI: 10.1080/014311600750037499

GLP-HS (Generalized Laplacian pyramid with hypersharpening): Selva, M.; Aiazzi, B.; Butera, F.; Chiarantini, L.; Baronti, S. Hyper-sharpening: A first approach on SIM-GA data. *IEEE J. Sel. Top. Appl. Earth Obs. Remote. Sens.* 2015, 8, 3008–3024.

Hyperspec-VNIR Chikusei data converted to the IDCube format is available from our website. Visit <https://www.idcubes.com/examples> to download.

7.9. Machine Learning Tab

The functions under the **Machine Learning Tab** include labeling and masking toolboxes that are necessary for the training of datasets. The functions also include supervised and non-supervised machine learning techniques.

| Tabs | Function | Additional info |
|------------------|--|-----------------|
| Machine Learning | Creates Label(s) | Pop-up toolbox |
| | Creates Mask(s) | Pop-up toolbox |
| | Binary Tool | Pop-up toolbox |
| | <i>k</i> -Means Classifier (two methods) | Dialogue window |
| | Machine Learning | Pop-up toolbox |
| | Deep Learning* | Pop-up toolbox |

* not currently available for IDCubePro® users

Create Label(s)

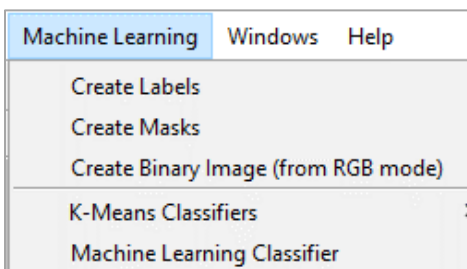
NOTE: Rose Leaves dataset is used as an example.

Features:

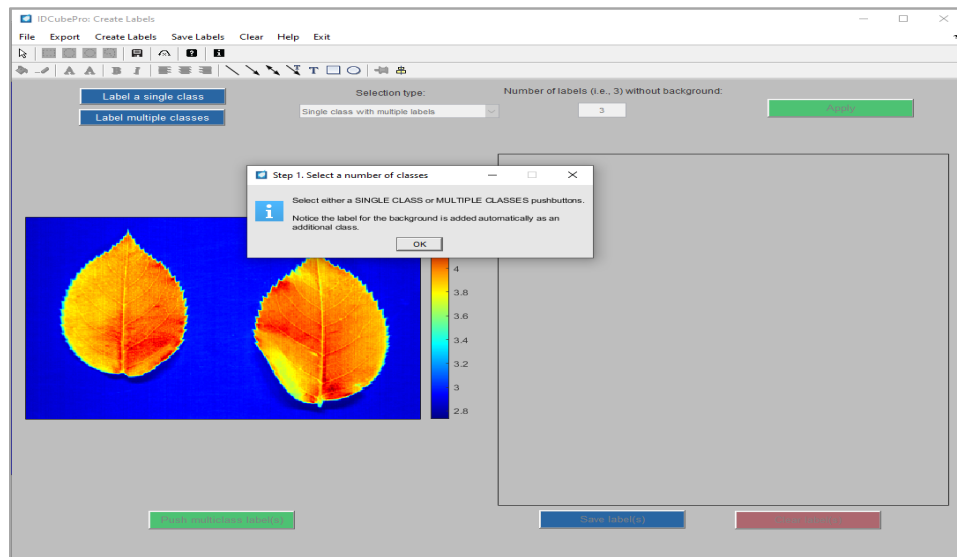
- Enables user to label a single class with multiple labels.
- Enables user to label multiple classes with a single label for each class.
- The labels can be saved to use for the machine and deep learning applications implemented in IDCube.

Steps:

1. Select **Create Labels** from **Machine Learning Tab**.



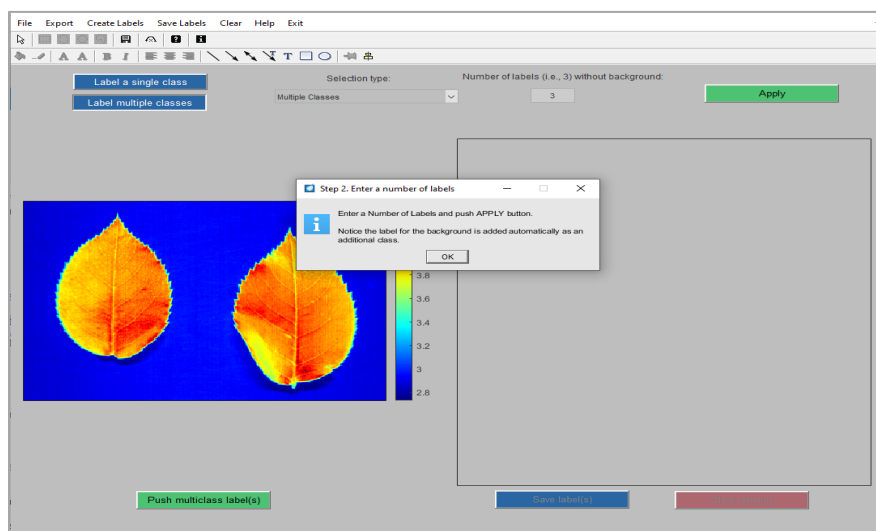
The image from the **IMAGE DISPLAY** panel (from the **Main Interface**) will automatically be shown.



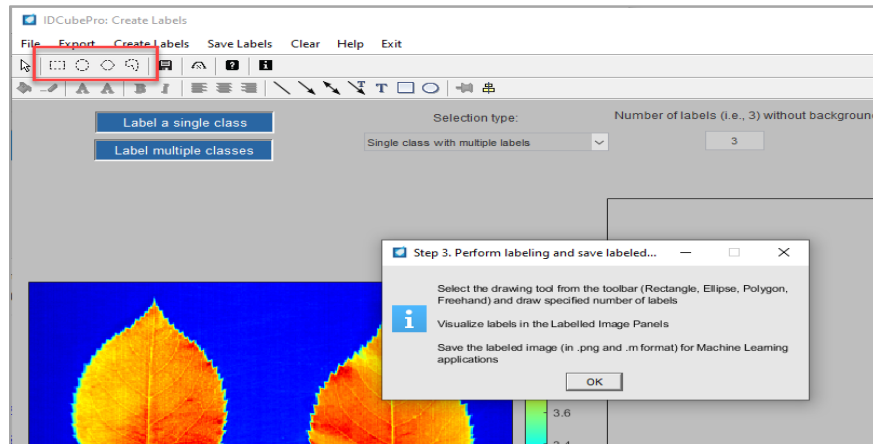
2. The **Label** maker toolbox offers two options:
 - a. Label a single class (in addition, a background class is generated automatically, thus a total of two classes are generated)
 - b. Label multiple classes (in addition, a background class is generated automatically, thus $N+1$ classes are generated).

Label a single class

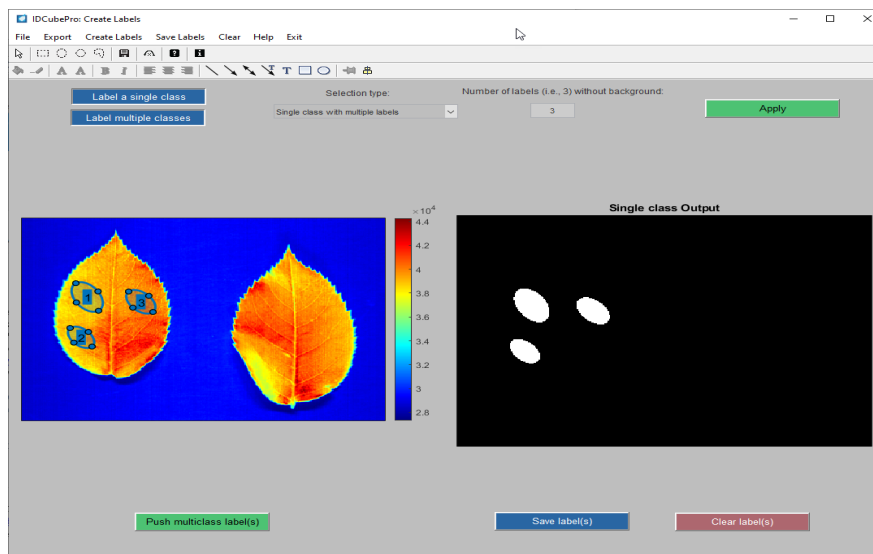
1. Click **Label a Single Class** pushbutton. The choice will be confirmed by the dropdown menu from the **Selection Type**. A **Number of Labels** window will be activated.
2. Enter a number of labels you plan to have and click **Apply**. The background label will also be generated automatically.



3. A pop-up will ask you to select the drawing tool. Click **OK** and select a tool (i.e., rectangle).



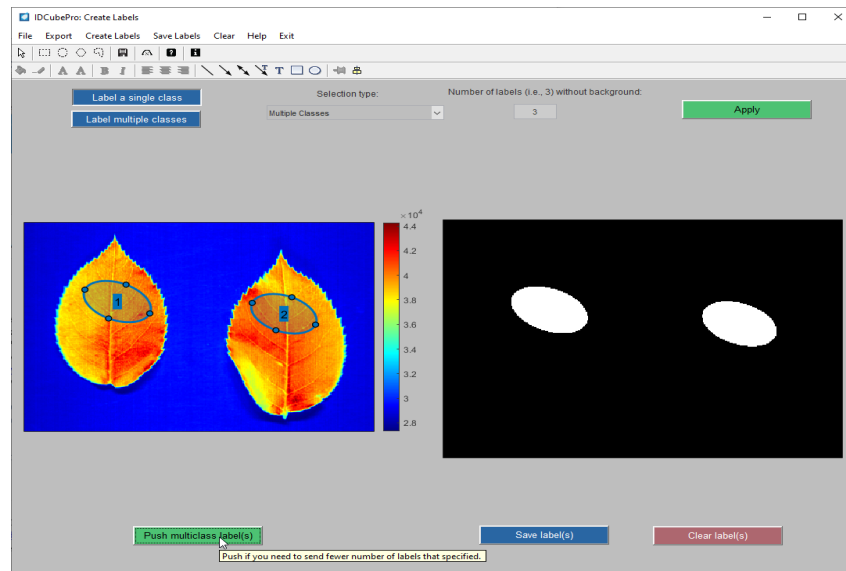
4. Draw the number of areas that belong to the same class. The labels will be numbered such as shown below and automatically shown in the LABELS panel after the number of labels reaches the specified number (i.e., 3).



5. Click **Save Label(s)** and select the directory. The default directory is the location of the original dataset. **NOTE:** two files will be generated a *png* file and a *m* (or *mat*) file. *Both files* are necessary for machine and deep learning applications.

Label Multiple Classes

The steps are similar. In addition, you can use the **Push Multiclass Label(s)** function to visualize the selected labels on the left panel at any time as long as the number of drawn labels is less than specified in the **Number of Labels** field.



Click **Save Label(s)** and select the directory. The default directory is the location of the original dataset. **NOTE:** two files will be generated a *png* file and a *m* (or *mat*) file. *Both files* are necessary for machine and deep learning applications.

Create Mask(s)

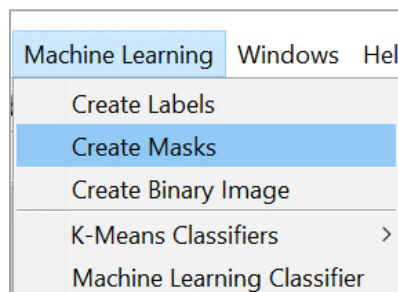
NOTE: PAVIA dataset is used as an example

Features:

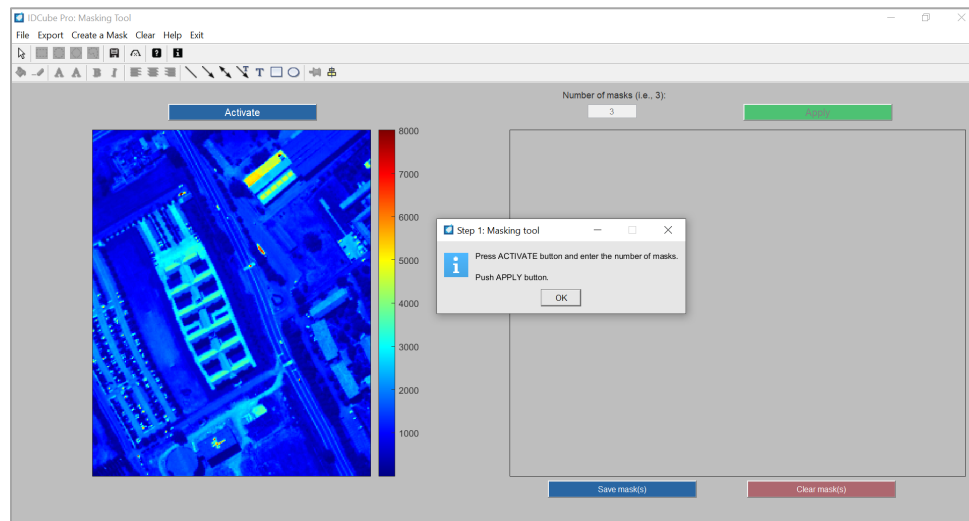
- Enables user to select masks with multiple labels.
- The masked image can be saved to use for machine and deep learning applications implemented in IDCube.

Steps:

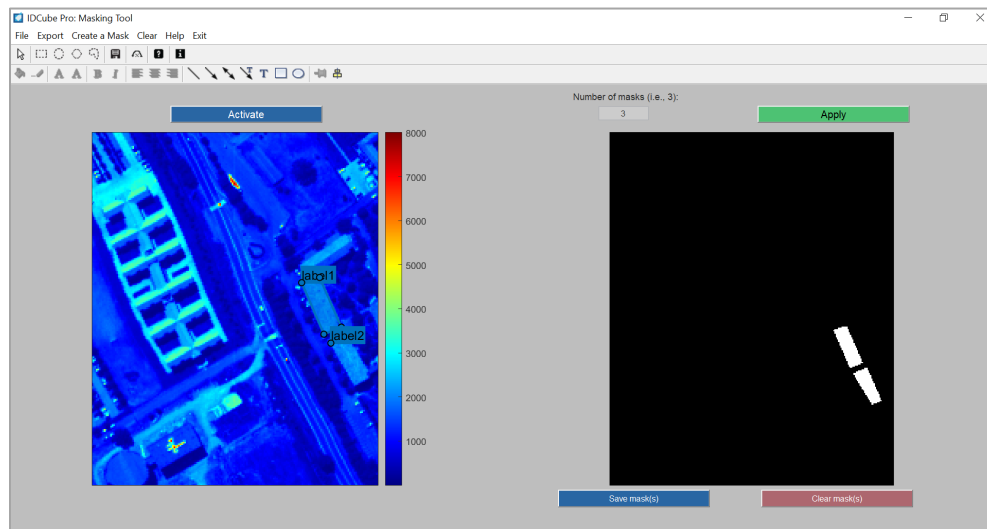
1. Open file in IDCube format.
2. Select **Machine Learning** → **Create Mask**.



3. From the new pop-up window **Masking Tool**, push the **Activate** button, enter the **number of masks** (default is 3) and press **Apply**.



4. Choose a drawing tool from the toolbar and select the area on the left image. You can zoom in if desired. The selected areas will be automatically converted into pixels with values equal to ONES with the rest of the image (background) to ZEROS. The colors for the masked objects are random and selected by IDCubePro®. In this example, a Freehand tool has been selected.



5. Press the **Save mask(s)** button. The user will be asked to provide the name of the file. Two files will be generated: *png* (color image) and *m* (in the format $m \times n \times 3$). These files can be used for machine and deep learning applications in IDCubePro®.
6. Press the **Clear mask(s)** button to start a new task.

NOTE: Future versions of the software will enable the user to adjust the selected area.

Binary Tool

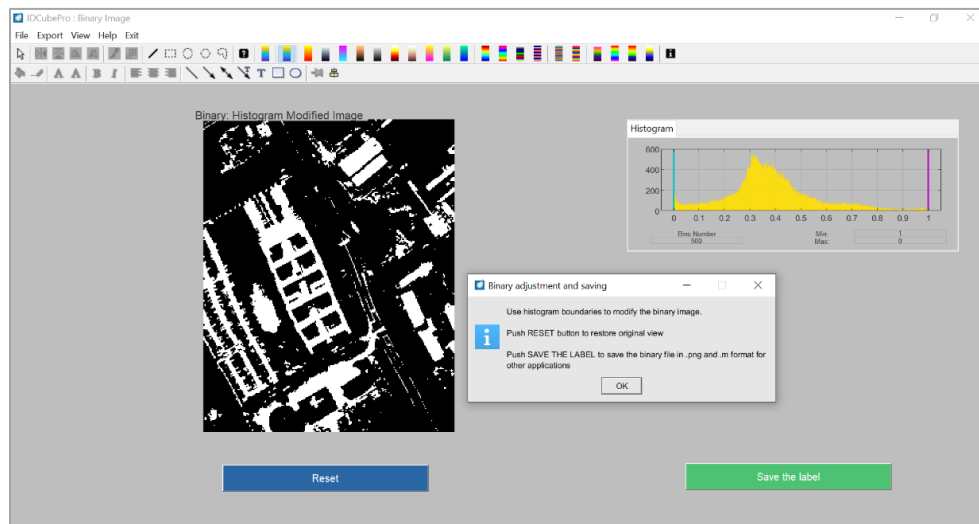
NOTE: PAVIA dataset is used as an example.

Features:

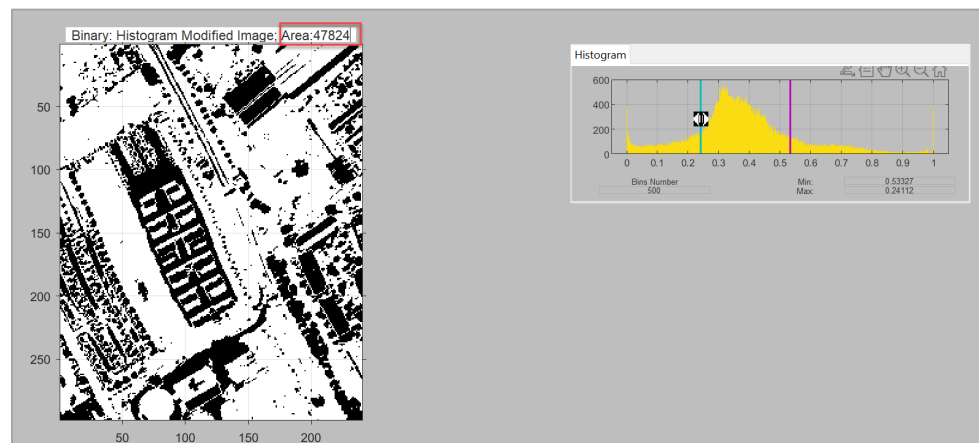
- Performs classification of the dataset using a binary method. Each pixel above a certain threshold is assigned to a value of '1' (white color) while each pixel less than a threshold level has a value of "0" (black color).
- Calculates the area above the threshold (see below).
- That classified image can be saved as a labeled file for machine learning.

Steps:

1. Select **Machine Learning** → **Binary Image**. The calculation will start immediately and produce the binary matrix with the histogram.



2. Move the boundaries on the HISTOGRAM panel to set new thresholds.



3. Press **Save the Label** to generate a *png* file in your specified directory and (automatically) *mat* file. These files will be needed for the Machine Learning applications.

| Name | Status | Date modified | Type | Size |
|--------|--------|-------------------|-------------|------|
| Label4 | ✓ R | 5/13/2022 7:01 PM | MATLAB Data | 3 KB |
| Label4 | ✓ R | 5/13/2022 7:01 PM | PNG File | 9 KB |
| Label4 | ✓ R | 5/13/2022 7:01 PM | PNG File | 9 KB |

k-Means Classifier

NOTE: PAVIA dataset is used as an example.

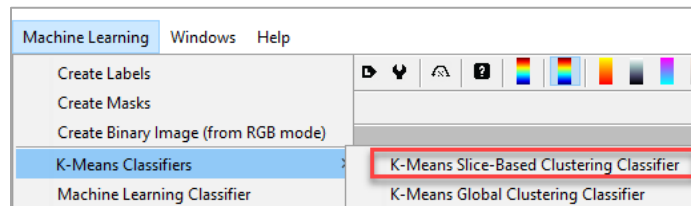
Features: Performs classification of 3D datasets using *k*-Means clustering-based volume segmentation algorithms. Two types of the *k*-Means classifier are available:

- Slice-based clustering *k*-Means classifier (frame-to-frame classifier)
- Global clustering *k*-Means classifier (entire datacube).

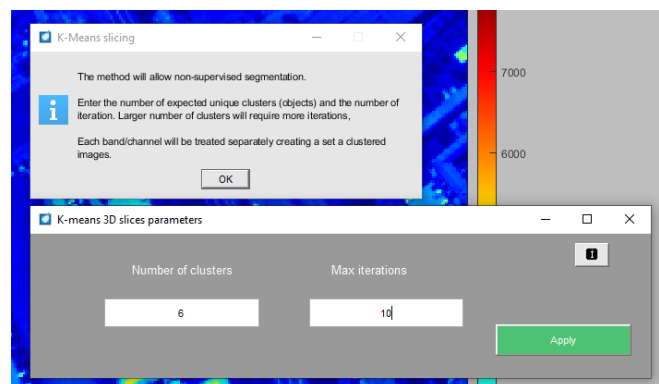
Slice-based frame-to-frame classifier

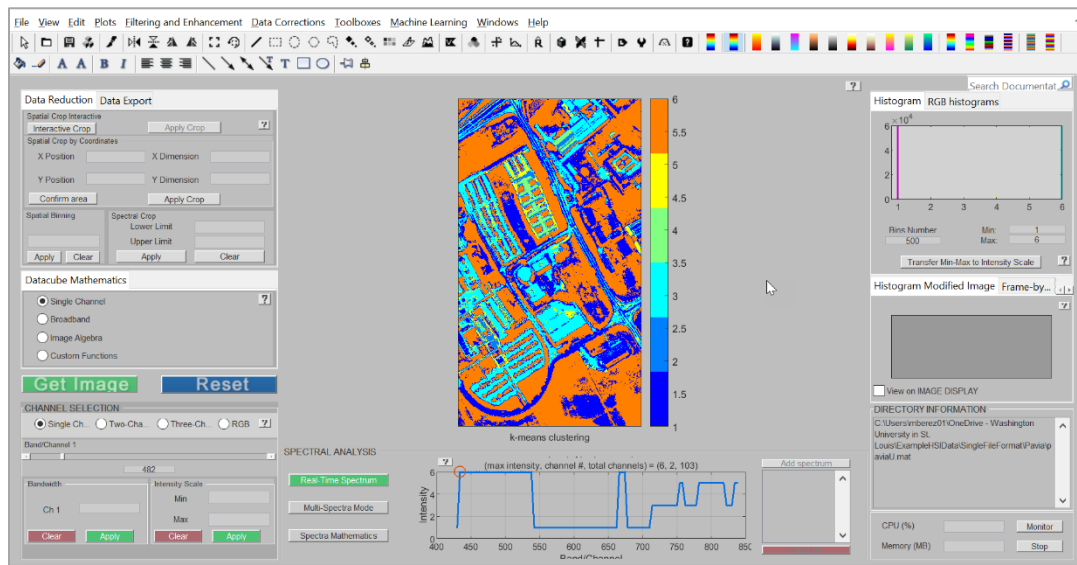
Steps:

1. Open the dataset in the IDCube format.
2. Click the **Machine Learning** tab on the menu bar, select **k-Means Classifiers**, and select **k-Means Slice-Based Clustering Classifier**.



3. The new dialogue window ***k*-Means parameters** will open. Enter the number of expected clusters (classes). The default number is 2. Enter the number of iterations (usually <100).
4. Each color in the updated image corresponds to a different class (1 out of 10 in this example). Pixels with the color corresponding to label 1 on the colorbar belong to the first cluster, label 2 belongs to the second cluster, and so on for each of the *k* clusters.



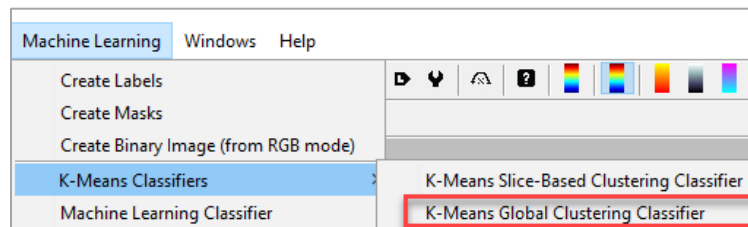


5. Use **Band/Channel** sliders and other functions to further optimize the image.

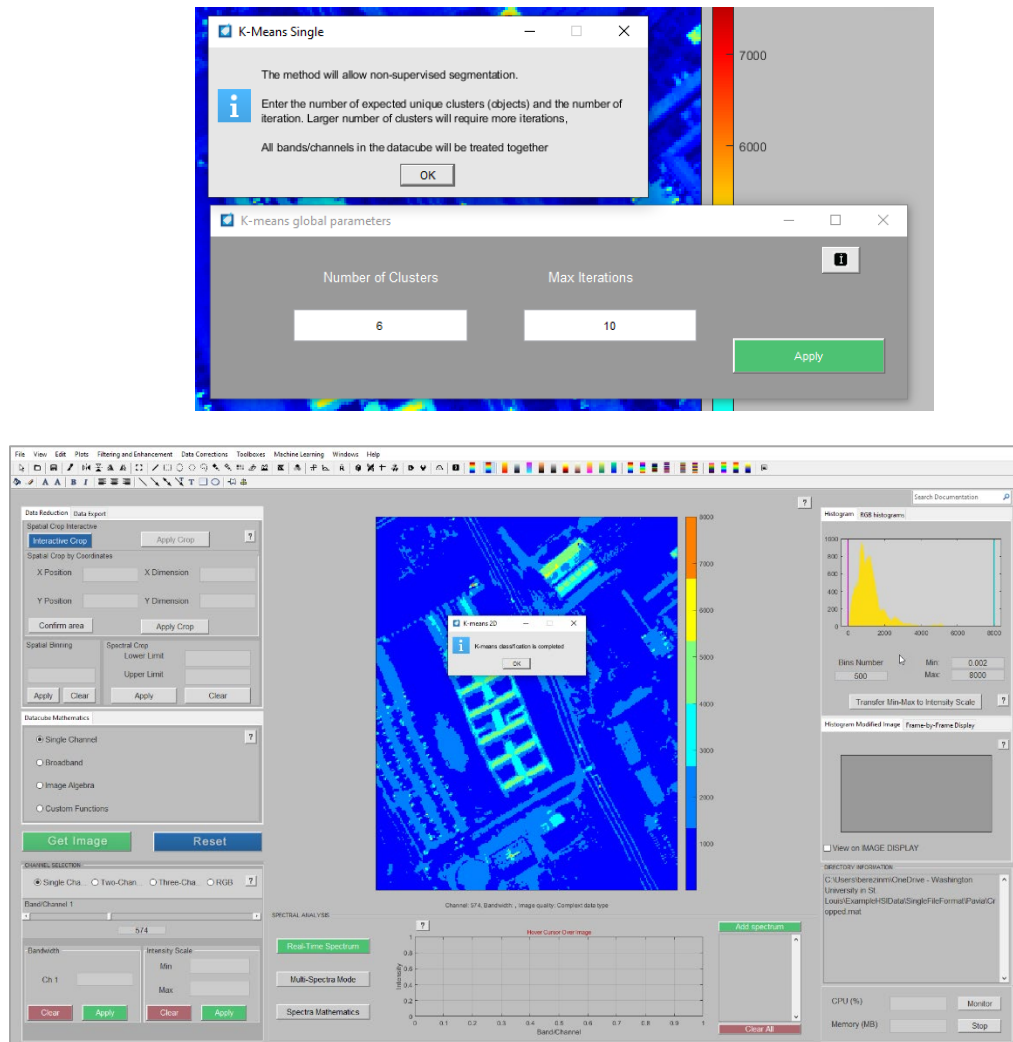
NOTE: The number of labels on the colorbar is identified automatically and could be equal to or less than the number of input clusters.

k-Means Global Clustering Classifier

1. Open the dataset in the IDCube format.
2. Click the **Machine Learning** tab on the menu bar, and select **k-Means Classifiers** and **k-Means Global Clustering Classifier**.



3. The new dialogue window **k-Means parameters** will open. Enter the number of expected clusters (classes). The default number is 2. Enter the number of iterations (usually <100).
4. Each color in the updated image corresponds to a different class (1 out of 6 in this example). Pixels with the color corresponding to label 1 on the colorbar belong to the first cluster, label 2 belongs to the second cluster, and so on for each of the *k* clusters.



Since this algorithm is global across all bands/channels, the changes in the **Band/Channel** slider positions will not affect the image.

NOTE: The number of labels on the colorbar is identified automatically and could be equal to or less than the number of input clusters.

Additional Information:

k -Means clustering is an unsupervised machine learning algorithm. It is the fastest and most efficient algorithm to categorize data points into groups even when very little information is available about data. IDCube employs a k -Means++ algorithm that chooses the initial values (or "seeds") for the k -Means clustering algorithm. The procedure initializes the cluster centers before proceeding with the standard k -Means optimization iterations.

References:

Arthur, David, and Sergei Vassilvitskii. "K-Means++: The Advantages of Careful Seeding." In *Proceedings of the Eighteenth Annual ACM-SIAM Symposium on Discrete Algorithms*, 1027–35. SODA '07. USA: Society for Industrial and Applied Mathematics, 2007.

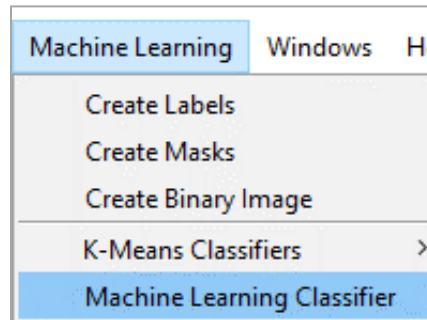
Machine Learning Classifier

NOTE: Rose Leaves dataset is used as an example.

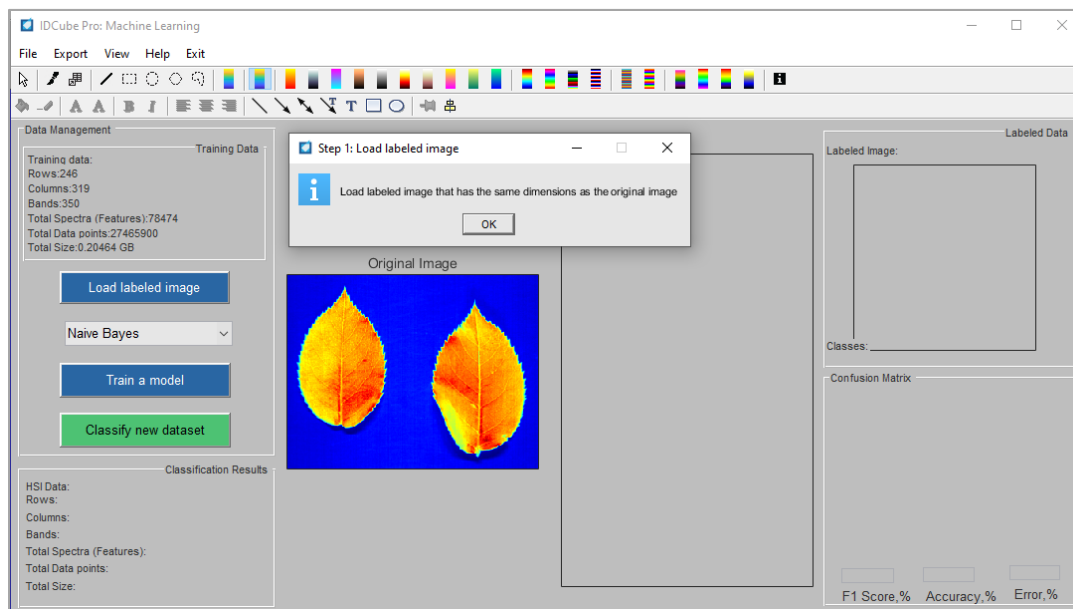
Features: Performs limited classification of 3D datasets using machine learning algorithms. Training is conducted using a single file. The validation process is currently not supported. Confusion matrixes are only built for the training procedures.

Steps:

1. Open an IDCube file from the **Main Interface**.
2. Click the **Machine Learning** tab and select **Machine Learning Classifier** from the menu.



A new **Machine Learning** window will open. The window will present the image in the same mode as the main interface (such as RGB as shown below). The window will also provide information about the dataset (left upper corner).



The toolbox enables the user to use two types of labeling files. Available options are:

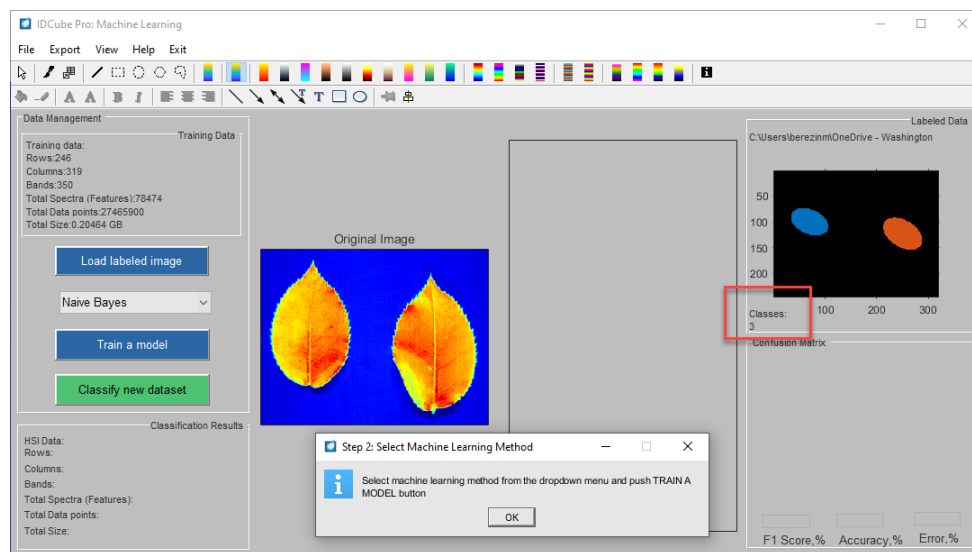
- Single class labels. This option enables using multiple labels of the same class.
- Multiple class labels. This option enables using multiple classes with one label per class.

The algorithm also counts unlabeled parts of the images as background classes for both of these options, that the total number of classes for a single class label is equal to two: labeled + background.

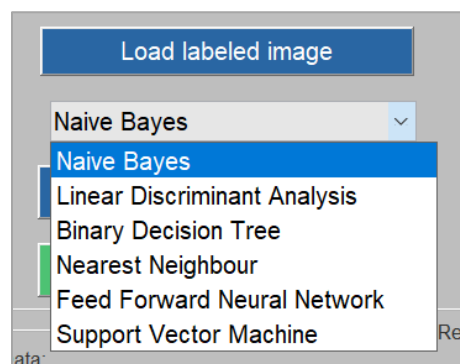
NOTE: IDCube treats the background data as a separate additional class. The labels of this class are identified automatically.

In this example, we will use a file with two selected classes using one label for each class.

3. Click **Load Label Data** and select a file previously saved from labeling. The file should have a *.m* (or *.mat*) extension and is automatically generated along with the *.png* file by using the **Create Label** tool. The labeled file with two labeled areas corresponding to different leaves will appear in the right corner. The number of classes (=3) corresponds to two labeled classes (in blue and red) and a background (black).



4. Select a method from the dropdown menu.

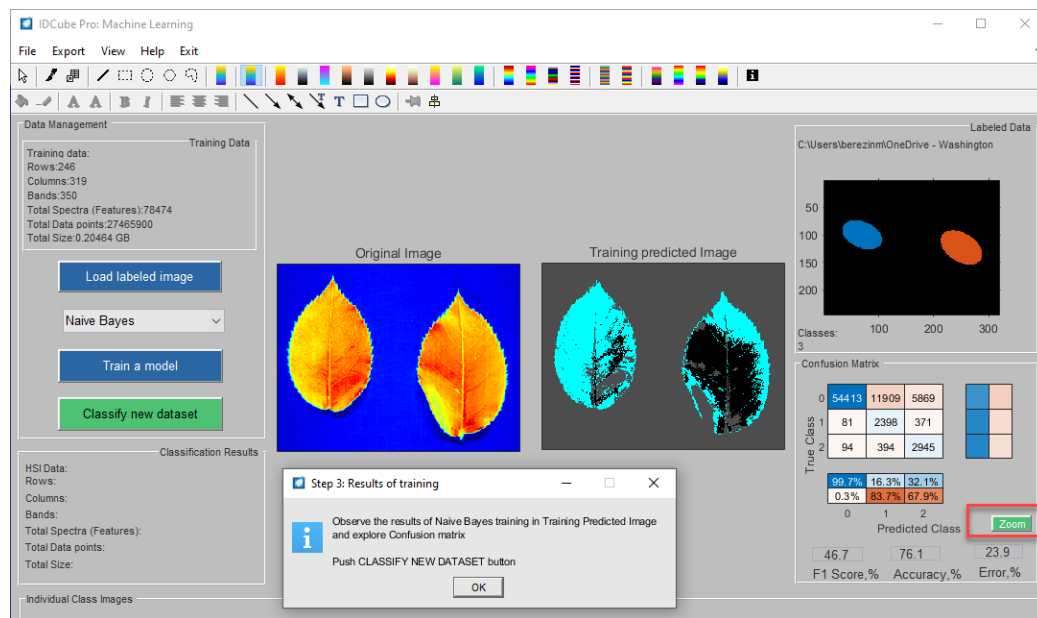


Currently available options are:

| Machine Learning Method | Training speed* | Prediction speed | Memory usage |
|------------------------------|----------------------|------------------|-----------------|
| Naïve Bayes | Very Fast (1.2 sec) | Fast | Small |
| Linear Discriminant Analysis | Very Fast (3.38 sec) | Fast | Small |
| Binary Decision Tree | Fast (6.56 sec) | Fast | Small |
| Nearest Neighbor | Slow (700 sec) | Slow | Large |
| Feed Forward Neural Network | Fast (11 sec) | Moderate | Medium to Large |
| Support Vector Machine | Slow (3300 sec) | Very slow | Medium |

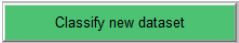
*) actual time is for the shown file on a desktop 64 GB RAM, Intel(R) Xeon(R) E-2286G CPU @ 4.00GHz 4.01 GHz

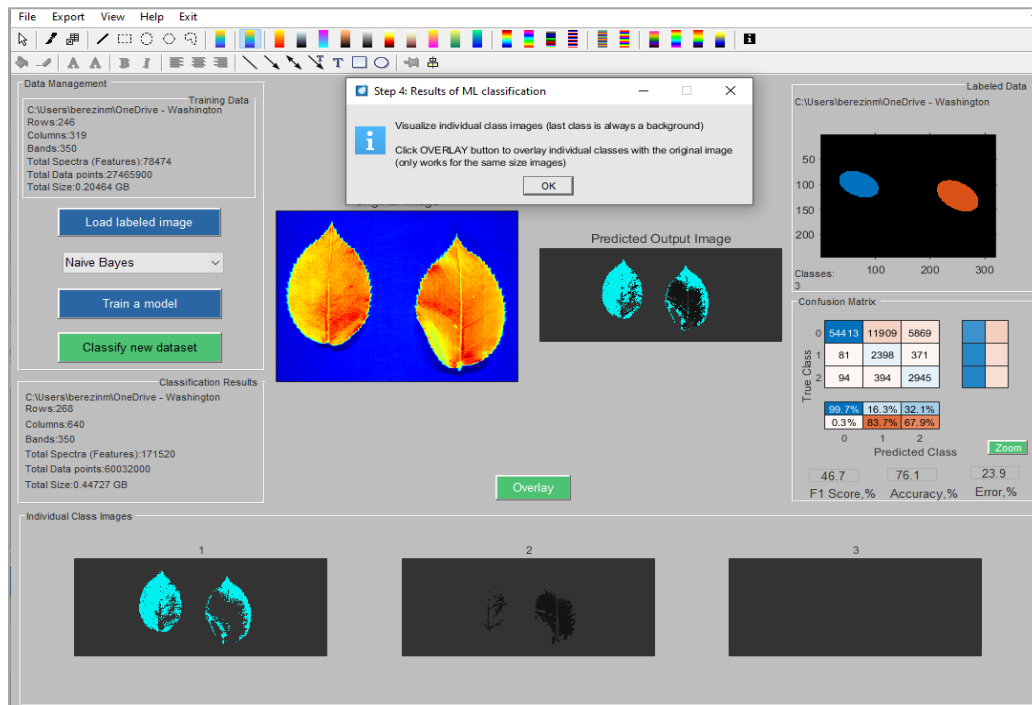
- An example is given with the Naïve Bayes method. After selecting this method, press the **Train a model** button. The training prediction model will appear as an image. The classified leaves seem to reproduce the actual shapes. The accuracy of the training is 76.1%, and the F1 score is moderate (46.7%).



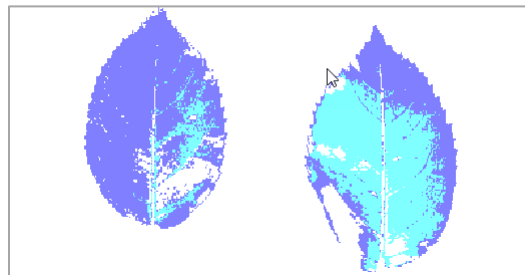
The produced **Confusion Matrix** can be opened in a separate window by clicking the green **Zoom** button. Class 0 is the background. Classes 1 and 2 are the leaves.

The score might be improved by making the **right click** on the **Training Predicted Image**.

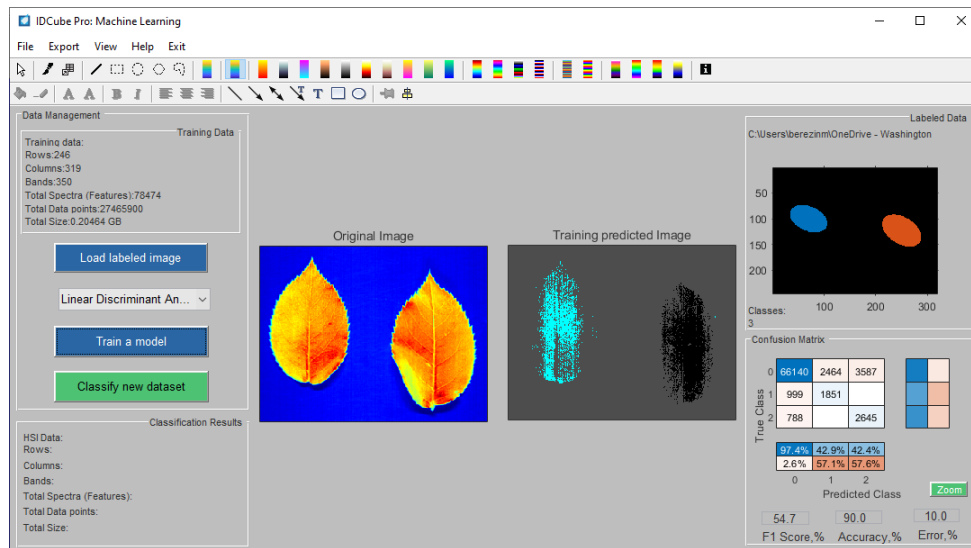
- After the training is complete, press **Classify new dataset** button  and open, for example, the original (not cropped) *Rose_Leaves* file.



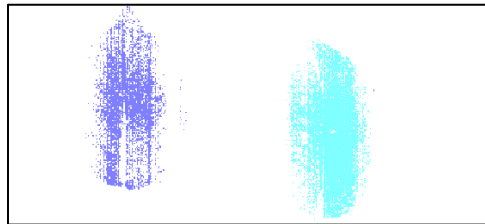
- The results from this example where three individual classes are identified: the labeled classes (class 1, light green, class 2, black), and the background (class 3). (**NOTE:** The background class is identified automatically).
- Press the **Overlay** button to put all classes together. Although having the same dimension of the training set and the new datasets are not critical, having the same dimension enables overlay function by pressing the corresponding button. The overlay image below shows all three classes: white – background, purple (mostly left leaf), and light blue (mostly right leaf).



Using **Machine Learning** with **Linear Discriminant Analysis**.



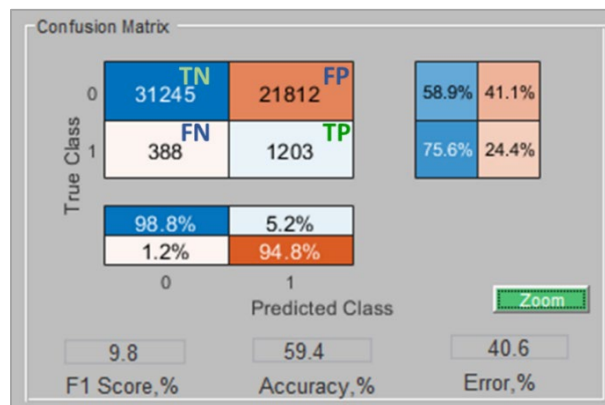
Press the **Overlay** button to combine classes together in one image. The overlay image below shows all three classes: white – background, purple (mostly left leaf), and light blue (mostly right leaf).



Additional information

Confusion Matrix for Binary Classification

Confusion matrix is often used as an evaluation criterion for the machine learning model. It gives simple and efficient performance measures for the selected model. The most common performance metrics calculated from the confusion matrix are shown below and to the left of the confusion matrix and specified below. For simplicity, we can only consider a case, when the binary classification problem has only two classes positive and a negative (background) class.



True Negative (TN): refers to the number of predictions where the classifier correctly predicts the negative class as negative.

False Positive (FP): refers to the number of predictions where the classifier incorrectly predicts the negative class as positive.

False Negative (FN): refers to the number of predictions where the classifier incorrectly predicts the positive class as negative.

True Positive (TP): refers to the number of predictions where the classifier correctly predicts the positive class as positive.

Accuracy: provides the overall accuracy of the model, meaning the fraction of the total samples that were correctly classified by the classifier. To calculate accuracy, use the following formula:

$$Accuracy = (TP+TN)/(TP+TN+FP+FN) \times 100, \%$$

Error (Classification Error or Misclassification): tells what fraction of predictions were incorrect.

$$Error = (FP+FN)/(TP+TN+FP+FN) \times 100, \% \text{ or } (100-Accuracy, \%)$$

Precision: Defines what fraction of predictions as a positive class were actually positive. Calculated using the following formula:

$$Precision = TP/(TP+FP) \times 100, \%$$

Recall: Defines what fraction of all positive samples were correctly predicted as positive by the classifier. It is also known as True Positive Rate (TPR), Sensitivity, Probability of Detection. Calculated using the following formula:

$$Recall = TP/(TP+FN) \times 100, \%$$

Specificity: Defines what fraction of all negative samples are correctly predicted as negative by the classifier. It is also known as True Negative Rate (TNR). Calculated using the following formula:

$$Specificity = TN/(TN+FP) \times 100, \%$$

F1-score: It combines precision and recall into a single measure. Mathematically it's the harmonic mean of precision and recall. It can be calculated as follows:

$$F1score = 2 \times \frac{Precision \times Recall}{Precision + Recall} = \frac{2TP}{2TP + FP + FN}, \%$$

A perfect model has a precision of 100%, recall of 100%, and the F1-score of 100%. The metrics of the model can be improved by trying different methods.

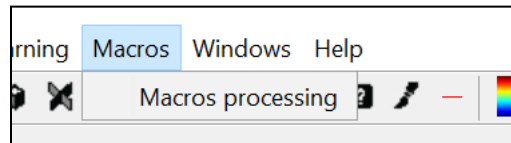
7.10. Macros Editor Tab

Macros Editor

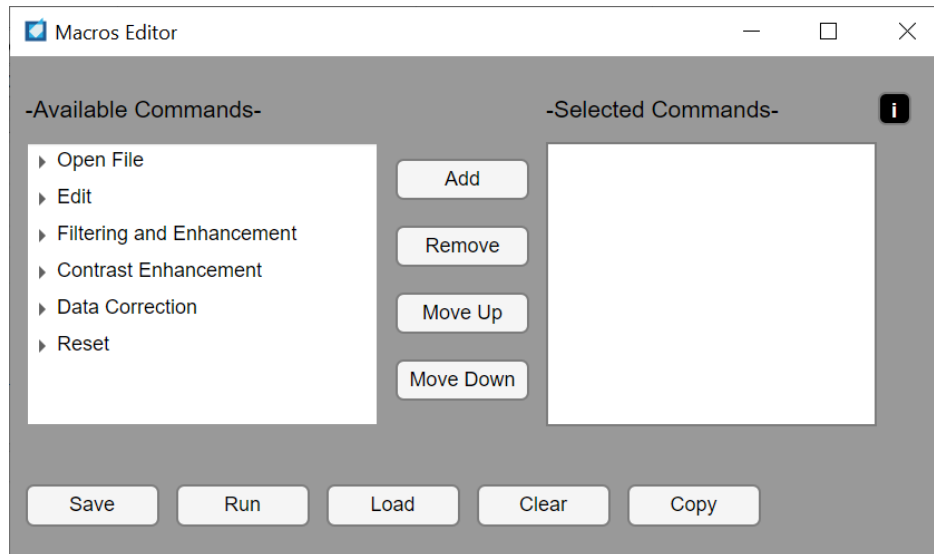
NOTE: Plastic and Coin dataset (cropped) is used as an example.

Features: The Macros Editor is an interactive graphical user interface (GUI) designed to help you create and execute custom sequences of commands for automatic data processing.

Step 1. Open a hyperspectral file and click **Macros** → **Macros Processing**.



A new pop-up window **Macros Editor** will appear.



Layout

Upon launching the **Macros Editor**, you will find the main window divided into two sections:

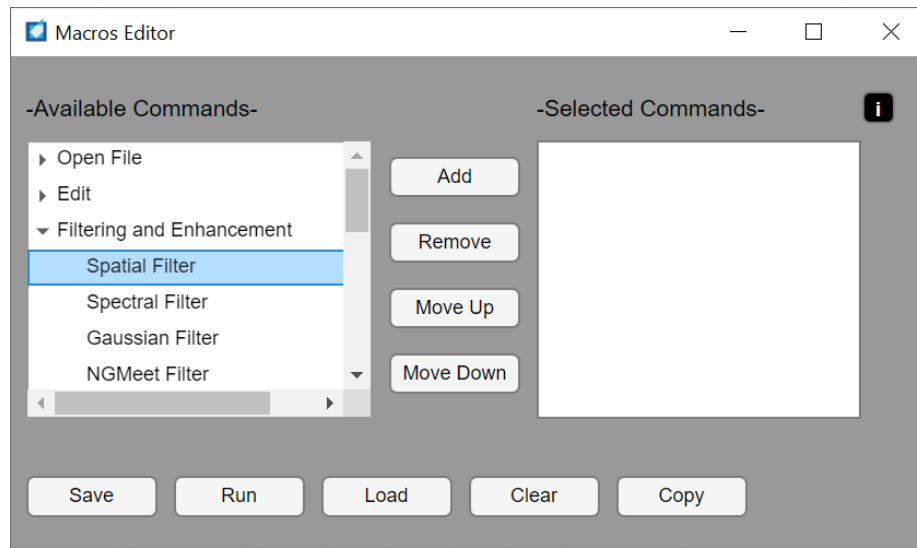
- The left side displays **Available Commands** grouped by categories in a tree structure.
- The right side displays the **Selected Commands** that will be executed in order.

At the bottom, you will find several buttons for controlling and managing your command sequences.

Using the Macros Editor

Step 2. Selecting Commands

Navigate the command tree on the left by expanding the nodes to reveal the available commands. Click on a command to select it. For example, click **Filtering and Enhancement** and select **Spatial Filter**.

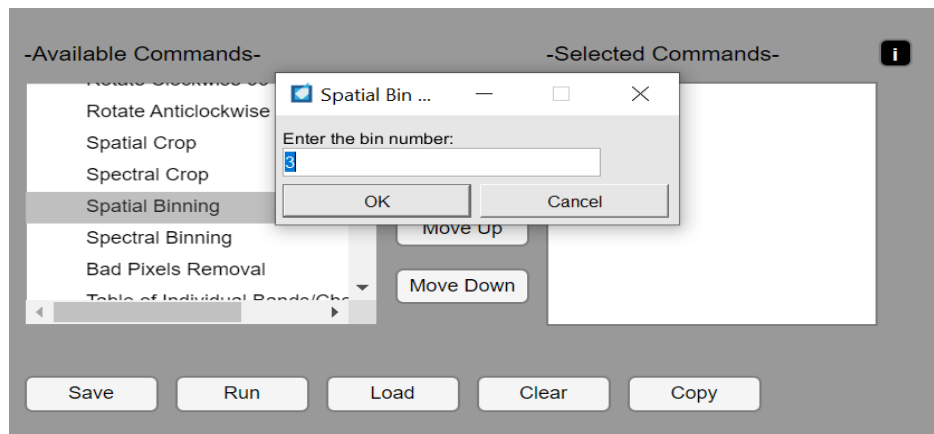


Step 2. Adding Commands to Sequence

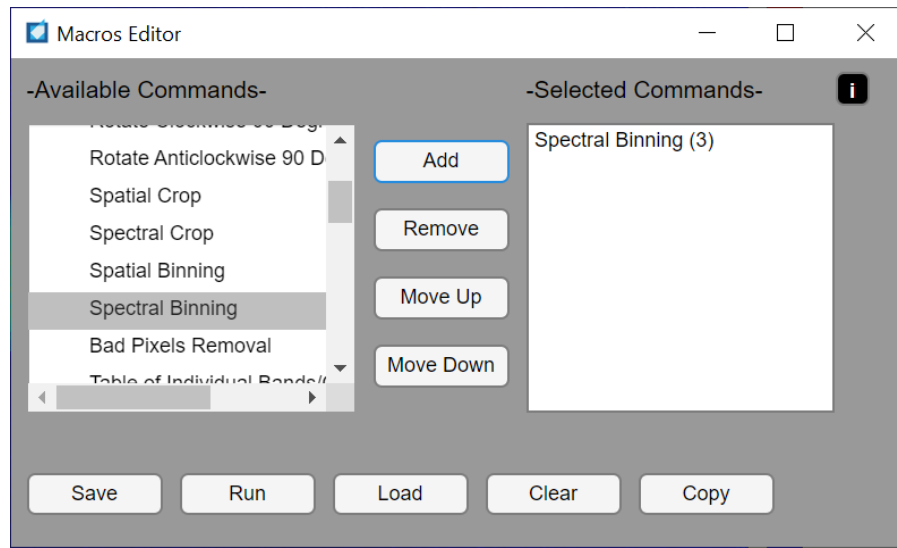
Once you have selected a command, click the **Add** button located in the middle of the GUI to add it to your sequence. The selected command will appear in the **Selected Commands** list on the right side of the GUI.

There are three types of commands:

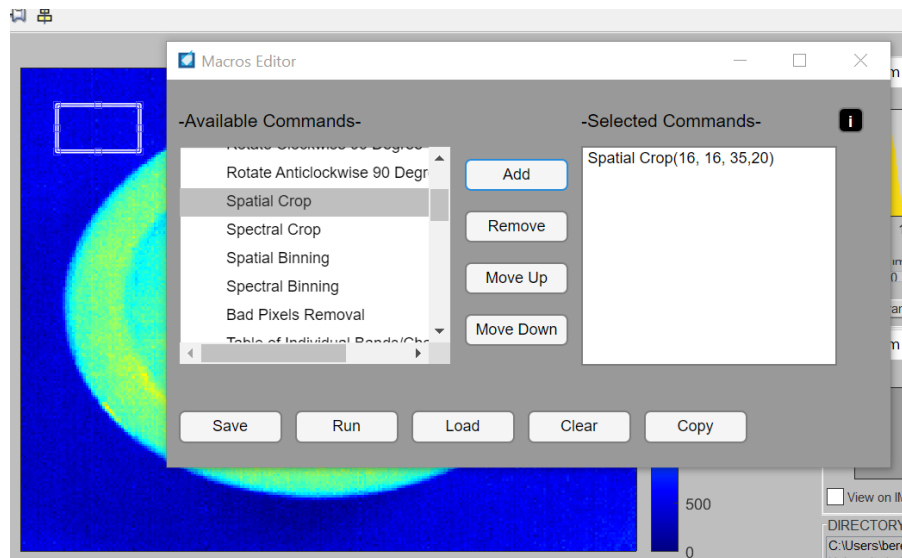
1. Command that directly appear in the Selected Commands without any additional input from the user (i.e., flip horizontally)
2. Command that requires an input from the user in the form of dialog box. For example when **Spatial binning** is selected, pressing the button **Add** will prompt the box asking to enter the bin number.



After the input entered, the command will appear with the entered number in parenthesis.



3. Command that requires an interactive input, such as **Spatial Crop** that will ask the user to draw an interactive region of interest on the **Main Interface Image Display Panel**. **After the region of interest is drawn, the command will appear with the entered area coordinates in parenthesis**



You can create any sequence of commands to tailor the processing to your specific needs.

Removing Commands from Sequence

To remove a command from your sequence, select it in the **Selected Commands** list and then click the **Remove** button. The command will be removed from your sequence but will remain available in the tree of commands on the left.

Moving Commands Up and Down

To move the command up or down the sequence list, select the command from the Selected Commands list and press **Move Up** or **Move Down** buttons.

Saving and Loading Sequences

You can save your current sequence of commands for later use by clicking the **Save** button. Conversely, you can load a previously saved sequence by clicking the **Load** button.

Clearing the Sequence

To clear all commands from your current sequence, click the **Clear** button.

Running the Sequence

To execute your sequence of commands, click the **Run** button. All commands will be run in the order they appear in the **Selected Commands** list. After each step a message box stating that the command is complete will appear.

Copying the Sequence

To copy the list of your sequence of commands, click the **Copy** button and paste into as text format.

Getting Help

The **i** button in the upper right corner of the GUI will provide additional information about the Macros Editor and how to use it.

Command Categories

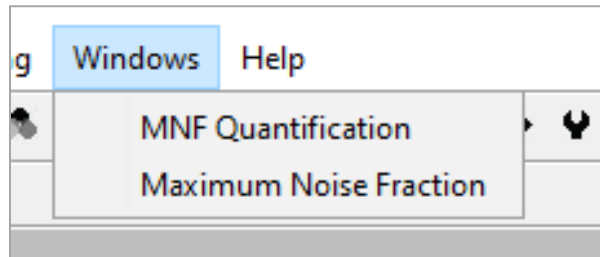
The **Macros Editor** organizes available commands into the same categories as the **Main Interface**:

- **Open File:** Commands for opening files in the IDCube format.
- **Edit:** Commands for editing data, such as flipping, rotating, cropping, etc.
- **Filtering and Enhancement:** Commands for applying different filters and data enhancement techniques.
- **Contrast Enhancement:** Commands for enhancing the contrast of your data.
- **Data Correction:** Commands for correcting your data.
- **Reset:** Commands for resetting the state of your data.

The current version of IDCubePro, the **Macros Editor** offers almost forty functions. More commands will be added in the future releases.

7.11. Windows Tab

Shows all open windows except the **Main Interface**. Enables the user to bring the window on top of the software. Automatically populates.



7.12. Help Tab

| Tabs | Function | Additional info |
|------|-----------------------------------|----------------------|
| Help | About IDCubePro® and Terms of Use | Pop-up document |
| | Tutorials | Online videos |
| | Report Bug | Online form |
| | Error Log | Generated document |
| | About HSpeQ | Online (idcubes.com) |
| | Contact Us | Online form |

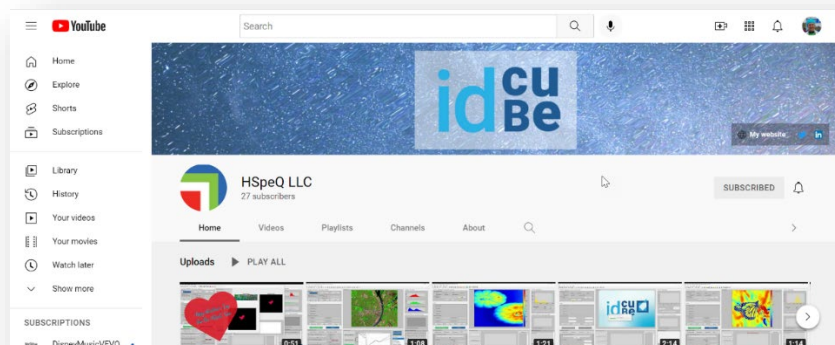
About IDCubePro® and Terms of Use

IDCubePro®, by HSpeQ LLC, St. Louis, MO, 63110, USA; Initial release September 2022.

Cite: IDCube Pro, Hyperspectral Imaging Software, HSpeQ LLC.

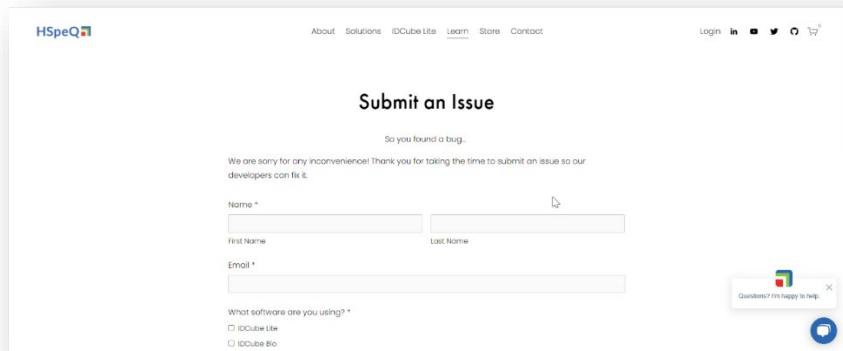
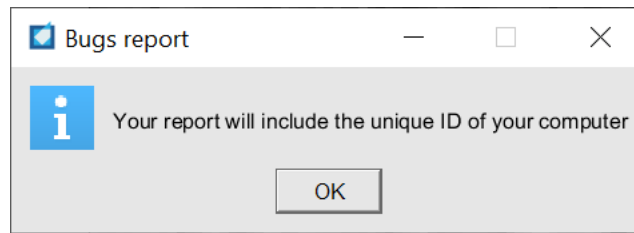
Tutorials

Video tutorials to the software are located at the HSpeQ website <https://www.idcubes.com/tutorials> or our YouTube Channel https://www.youtube.com/channel/UCgkuxZAkOSIDho2V9tvE5_g



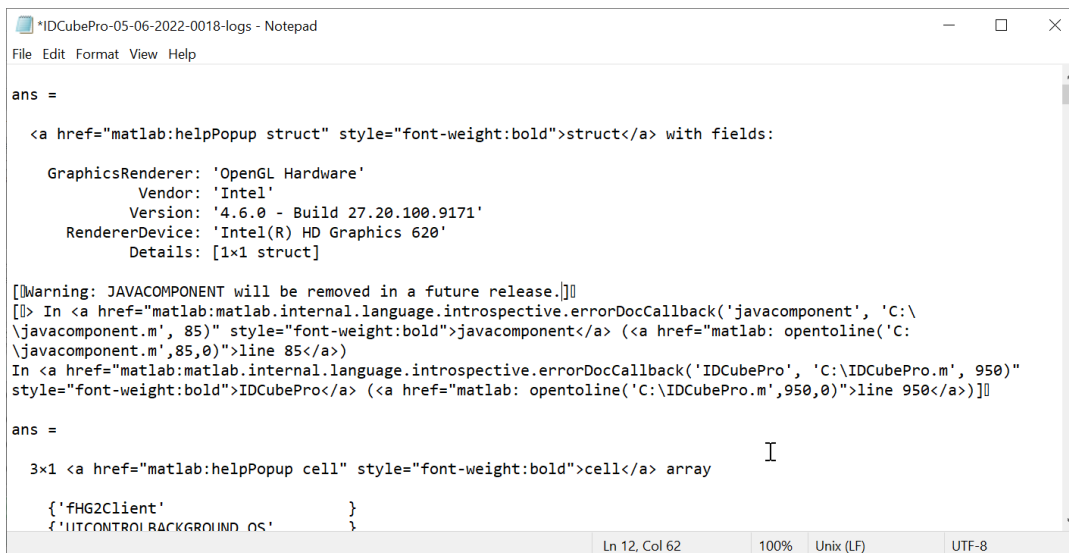
Report Bug

You can report your problem online. Please be aware that your report generates the unique ID of your computer and sends us an **Error Report Log** (see the following section). We need this information to check for the source of the problem and find a solution.



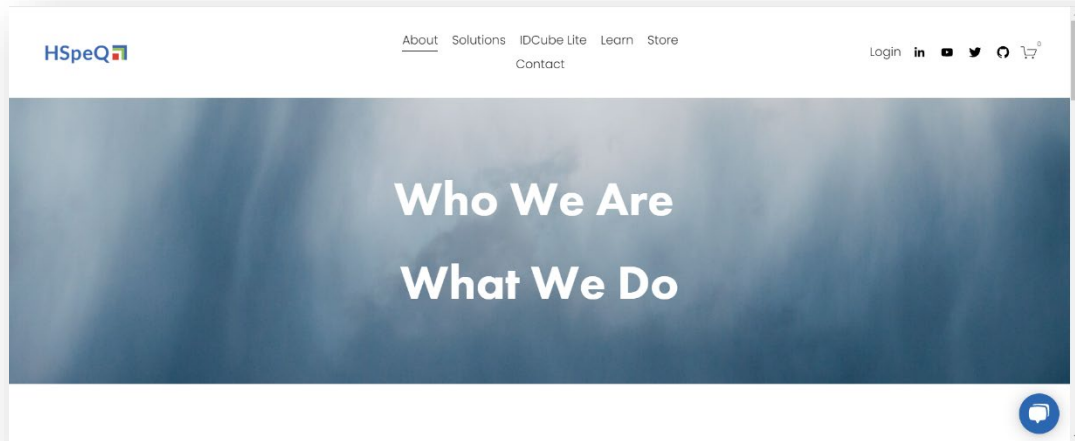
Error Report Log

IDCubePro® automatically generates a report log and stores it on your computer.



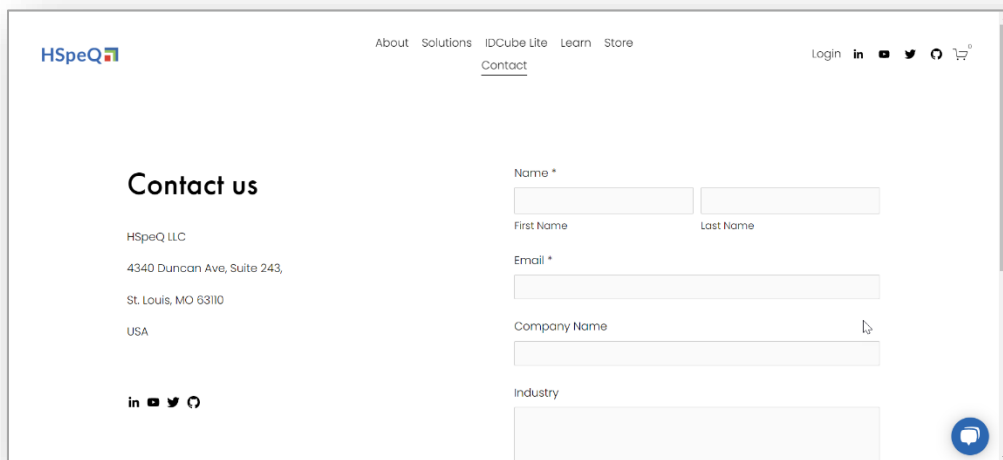
About HSpeQ

We invite you to visit our website at <https://www.idcubes.com>, where you can access information about us, find educational materials and get access to new downloads. By clicking on the picture below, you will be connected to the page.



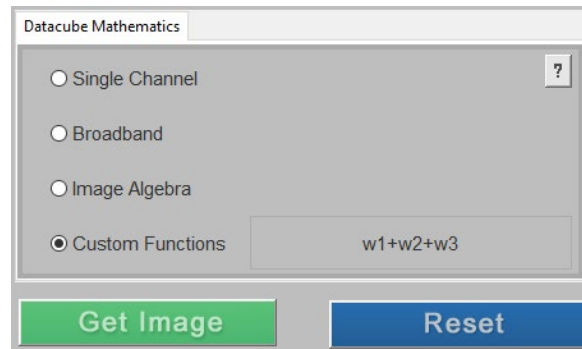
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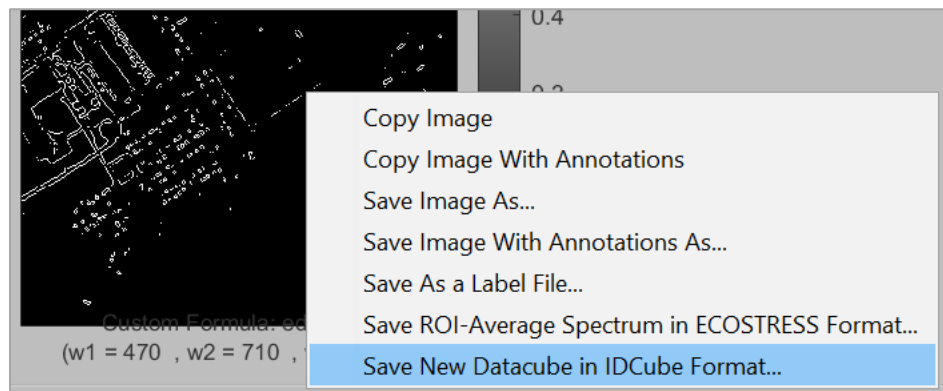


Appendix 1: Expressions That Can Be Used in IDCube

Select the **Custom Function** radio button. This will automatically activate an interactive field where the user can enter an equation. After entering an equation, click **Get Image**.



To save the entire datacube make **Right Click** on the image and click **Save New Datacube in IDCube Format**. If more than one wavelength is used in the custom function, only $w1$ will be used as a variable.



Format and notation

Type an equation using the following format:

Examples:

$$w1 + w2$$

$$\sin(w1 + w2)$$

$$\sin(w1 ./ w2)$$

$$\sin(w1 .* w2) \text{ (use dots for divisions and multiplications)}$$

Only up to three selected channels are supported. Use $w1$, $w2$, or $w3$ and their combinations. Combine any of the functions with other functions:

Examples:

$$\log(\sin(\sqrt{w1 .* w2}))$$

$$\text{fftshift}(\text{erf}(\cos(w1)))$$

NOTE: some of the functions and operations are linked to the explanation materials available from <https://www.mathworks.com/>.

Arithmetic Operators

| Function | Description | Mathematical Expression Example |
|----------|-----------------------------|---------------------------------|
| + | Addition | $w1 + w3$ |
| - | Subtraction | $w1 - w3$ |
| .* | Element-wise multiplication | $w1 .* w3$ |
| ./ | Element-wise right division | $w1 ./ w3$ |
| .\ | Element-wise left division | $w1 .\ w3$ |

Trigonometric Functions

| Function | Description | Mathematical Expression Example |
|----------|--|---------------------------------|
| sin | Sine of the input | $\sin(w1)$ |
| cos | Cosine of the input | $\cos(w1)$ |
| tan | Tangent of the input | $\tan(w1)$ |
| asin | Inverse sine of the input | $\sin^{-1}(w1)$ |
| acos | Inverse cosine of the input | $\cos^{-1}(w1)$ |
| atan | Inverse tangent of the input | $\tan^{-1}(w1)$ |
| atan2 | Four-quadrant inverse tangent of the input | $\text{atan2}(w1)$ |
| sinh | Hyperbolic sine of the input | $\sinh(w1)$ |
| cosh | Hyperbolic cosine of the input | $\cosh(w1)$ |
| tanh | Hyperbolic tangent of the input | $\tanh(w1)$ |
| asinh | Inverse hyperbolic sine of the input | $\sinh^{-1}(w1)$ |
| acosh | Inverse hyperbolic cosine of the input | $\cosh^{-1}(w1)$ |
| atanh | Inverse hyperbolic tangent of the input | $\tanh^{-1}(w1)$ |

Log and Exponential Functions

| Function | Description | Mathematical Expression Example |
|----------|---|---------------------------------|
| exp | Exponential | $\exp(w1)$ |
| expm1 | Compute $\exp(x)-1$ accurately for small values of x | $\expm1(w1)$ |
| log | Natural logarithm | $\log(w1)$ |
| log10 | Common logarithm (base 10) | $\log_{10}(w1)$ |
| log1p | Compute $\log(1+x)$ accurately for small values of x | $\log_{1p}(w1)$ |
| log2 | Base 2 logarithm and floating-point number dissection | $\log_2(w1)$ |
| nextpow2 | Exponent of next higher power of 2 | $\text{nextpow2}(w1)$ |
| pow2 | Base 2 power and scale floating-point numbers | $\text{pow2}(w1)$ |
| reallog | Natural logarithm for nonnegative real arrays | $\text{reallog}(w1)$ |

| Function | Description | Mathematical Expression Example |
|----------|------------------------------------|---------------------------------|
| realpow | Array power for real-only output | $\text{realpow}(w1)$ |
| realsqrt | Square root for nonnegative values | $\text{realsqrt}(w1)$ |
| sqrt | Square root | $\text{sqrt}(w1)$ |

Hyperbolic Functions

| Function | Description | Mathematical Expression Example |
|----------|--|---------------------------------|
| sinh | Symbolic hyperbolic sine function | $\sinh(w1)$ |
| cosh | Symbolic hyperbolic cosine function | $\cosh(w1)$ |
| tanh | Symbolic hyperbolic tangent function | $\tanh(w1)$ |
| coth | Symbolic hyperbolic cotangent function | $\coth(w1)$ |
| sech | Symbolic hyperbolic secant function | $\text{sech}(w1)$ |
| csch | Symbolic hyperbolic cosecant function | $\text{csch}(w1)$ |

Inverse Hyperbolic Functions

| Function | Description | Mathematical Expression Example |
|----------|--|---------------------------------|
| asinh | Symbolic inverse hyperbolic sine function | $\text{asinh}(w1)$ |
| acosh | Symbolic inverse hyperbolic cosine function | $\text{acosh}(w1)$ |
| atanh | Symbolic inverse hyperbolic tangent function | $\text{atanh}(w1)$ |
| acoth | Symbolic inverse hyperbolic cotangent function | $\text{acoth}(w1)$ |
| asech | Symbolic inverse hyperbolic secant function | $\text{asech}(w1)$ |
| acsch | Symbolic inverse hyperbolic cosecant function | $\text{acsch}(w1)$ |

Error Functions

| Function | Description | Mathematical Expression Example |
|----------|------------------------------|---------------------------------|
| erf | Error function | $\text{erf}(w1)$ |
| erfc | Complementary error function | $\text{erfc}(w1)$ |

Fast Fourier Transform (FFT) Functions

| Function | Description | Mathematical Expression Example |
|-----------|---|---------------------------------|
| fft | Computes the discrete Fourier transform (DFT) of $w1$ using a fast Fourier transform (FFT) algorithm | $\text{fft}(w1)$ |
| fft2 | 2-D fast Fourier transform, which is equivalent to computing $\text{fft}(\text{fft}(X))$ | $\text{fft2}(w1)$ |
| fftshift | Rearranges a Fourier transform X by shifting the zero-frequency component to the center of the array. | $\text{fftshift}(w1)$ |
| ifftshift | Rearranges a fftshift back to the original transform output, undoing the result of fftshift | $\text{ifftshift}(w1)$ |

Graphic, Image Processing, and Filtering functions

| Function | Description | Mathematical Expression Example |
|--------------------------------|---|--|
| Edge | Find edges in a 2-D grayscale image, Sobel is the default | <code>edge(w1)</code> |
| "Sobel" | Finds edges at those points where the gradient of the image <i>I</i> is maximum, using the Sobel approximation to the derivative. | <code>edge(w1, 'Sobel')</code> |
| "Prewitt" | Finds edges at those points where the gradient is maximum, using the Prewitt approximation to the derivative. | <code>edge(w1, 'Prewitt')</code> |
| "Roberts" | Finds edges at those points where the gradient is maximum, using the Roberts approximation to the derivative. | <code>edge(w1, 'Roberts')</code> |
| "log" | Finds edges by looking for zero-crossings after filtering with a Laplacian of Gaussian (LoG) filter. | <code>edge(w1, 'log')</code> |
| "zerocross" | Finds edges by looking for zero-crossings after filtering with a filter that you specify, <i>h</i> | <code>edge(w1, 'zerocross', h)</code> |
| "Canny" | Finds edges by looking for local maxima of the gradient of <i>I</i> . The edge function calculates the gradient using the derivative of a Gaussian filter. This method uses two thresholds to detect strong and weak edges, including weak edges in the output if they are connected to strong edges. By using two thresholds, the Canny method is less likely than the other methods to be fooled by noise, and more likely to detect true weak edges. | <code>edge(w1, 'Canny')</code> |
| "approxccanny" | Finds edges using an approximate version of the Canny edge detection algorithm that provides faster execution time at the expense of less precise detection. Floating point images are expected to be normalized to the range [0, 1]. | <code>edge(w1, 'approxccanny')</code> |
| entropyfilt | returns the image, where each output pixel contains the entropy value of the 9-by-9 neighborhood around the corresponding pixel in the input image | <code>entropyfilt(w1)</code> |
| rangefilt | returns an image, where each output pixel contains the range value (maximum value – minimum value) of the 3-by-3 neighborhood around the corresponding pixel in the input image. | <code>rangefilt(w1)</code> |
| bwconvhull(BW) | Computes the convex hull of the desired objects in BW (black and white, binary mask) and returns, a binary convex hull image. Desired pixel connectivity <i>conn</i> = 4 or 8 | <code>bwconvhull(BW,'objects',conn)</code> |
| bwconvhull(BW) | Computes the convex hull of the all objects in BW (black and white, binary mask) and returns, a binary convex hull image. Desired pixel connectivity <i>conn</i> = 4 or 8 | <code>bwconvhull(BW,'union',conn)</code> |
| im2bw | Converts the grayscale image to binary image BW, by replacing all pixels in the input image with luminance greater than <i>level</i> with the value 1 (white) and replacing all other pixels with the value 0 (black). | <code>im2bw(w1,level)</code> |
| imbinarize | Creates a binary image from 2-D or 3-D grayscale image by replacing all values above a globally determined threshold with 1s and setting all other values to 0s. By default, <i>imbinarize</i> uses Otsu's method, | <code>imbinarize(w1)</code> |

| Function | Description | Mathematical Expression Example |
|----------------------------|--|---------------------------------|
| imgradient | Find gradient magnitude of 2-D image | <code>imgradient(w1)</code> |
| imilatfilt | Applies an edge-preserving Gaussian bilateral filter to the grayscale or RGB image with smoothing <i>N</i> . | <code>imilatfilt(w1, N)</code> |

| Function | Description | Mathematical Expression Example |
|-----------|---|---------------------------------|
| padarray | Pads image with an amount of padding in each dimension specified by N | padarray(w1, [N N], 'both') |
| 'both' | Pads before the first element and after the last array element along each dimension. | padarray(w1, [N N], 'both') |
| 'post' | Pad after the last array element along each dimension. | padarray(w1, [N N], 'post') |
| 'pre' | Pad before the first array element along each dimension. | padarray(w1, [N N], 'pre') |
| watershed | Transform the image treating it as a surface where light pixels represent high elevations and dark pixels represent low elevations | watershed(w1) |
| imclose | imclose(w1,SE) performs morphological closing on the grayscale or binary image w1, using the structuring element SE (example SE = strel('disk',10)) | imclose(w1, strel('disk',10)) |

Other Special Functions

| Function | Description | Mathematical Expression Example |
|----------|--|---------------------------------|
| gamma | Gamma function | gamma(w1) |
| gammaln | Logarithmic gamma function | gammaln(w1) |
| ellipke | Complete elliptic integrals of first and second kind | ellipke(w1) |
| expint | Exponential integral | expint(w1) |
| airy | Airy function | airy(w1) |
| psi | Digamma function | psi(w1) |
| lambertw | Lambert W function | lambertw(w1) |
| zeta | Riemann zeta function | zeta(w1) |

Appendix 2. System Requirements for Graphics (PC)

Recommended System Requirements

For the best results with graphics, your system must have:

- At least 1 GB of GPU memory and 16GB of RAM memory for the files less than 500MB. For larger files at least 32GB RAM memory is recommended.
- Graphics hardware that supports a hardware-accelerated implementation of OpenGL 2.1 or later. Most graphics hardware released since 2006 has OpenGL 2.1 or later. If you have an earlier version

of OpenGL, most graphics features still work, but some advanced graphics features are unavailable. For the best performance, OpenGL 4.0 or later is recommended.

- The latest versions of graphics drivers are available from your computer manufacturer or graphics hardware vendor.

IDCubePro® is a DPI-aware application that takes advantage of your full system resolution. Our graphics look sharp and properly scaled on all systems, including Windows and Macintosh systems.

Upgrade Your Graphics Drivers

Graphics hardware vendors frequently provide updated graphics drivers that improve hardware performance. To help ensure that your graphics hardware works with IDCubePro®, upgrade your graphics drivers to the latest versions available.

IDCubePro® can encounter low-level issues when creating graphics on your system. For example, plots will become corrupted, or your graphics hardware might run out of memory. You can encounter these issues while creating and working with 2D or 3D charts. These issues are often due to older graphics hardware or outdated graphics drivers. To resolve them, try the options described here.

- On Windows® systems, check for driver updates on the website of your manufacturer. If no updates are provided, then check the website of your graphics hardware vendors, such as [AMD](#), [NVIDIA](#), or [Intel](#).
- On Macintosh systems, the graphics drivers are part of the operating system. Use the latest updates provided.
- On Linux systems, use proprietary vendor drivers instead of open-source replacements.

Finding a Renderer Implementation for Your System

NOTE: this function might not be applicable for all computers.

IDCubePro® displays graphics using a *hardware-accelerated*, *basic hardware-accelerated*, or *software implementation* of the graphics renderer. To determine which implementation IDCubePro® is using, press **Help** → **Error Log** report. This structure also provides the name of the graphics renderer. For example, if IDCubePro® is using hardware-accelerated OpenGL, the field returns 'OpenGL Hardware'. If it is using software OpenGL, the field returns 'OpenGL Software'. Your **Error Log** report will have this information.

Hardware-accelerated graphics:

```
GraphicsRenderer: 'OpenGL Hardware'
Vendor: 'Intel'
Version: '4.6.0 - Build 27.20.100.9171'
RendererDevice: 'Intel(R) HD Graphics 620'
Details: [1×1 struct]
```

Software implementation of the graphics:

```
GraphicsRenderer: 'OpenGL Software'
Vendor: 'Microsoft Corporation'
```

Version: '1.1.0'

RendererDevice: 'GDI Generic'

Details: [1×1 struct]

By default, IDCube tries to use a hardware-accelerated implementation if your graphics hardware supports it. In some cases, IDCubePro® automatically switches to a software implementation:

- If your system does not have the necessary graphics hardware.
- If you are using a graphics driver with known issues, an older graphics driver, or graphics virtualization. Update your graphics drivers to the latest versions available.
- If a previous IDCubePro® session crashed due to a graphics issue. If the previous session was using software OpenGL and crashed, then subsequent sessions use a more stable version of software OpenGL that has fewer capabilities.

Future upgrades will enable a user to specify an OpenGL implementation.

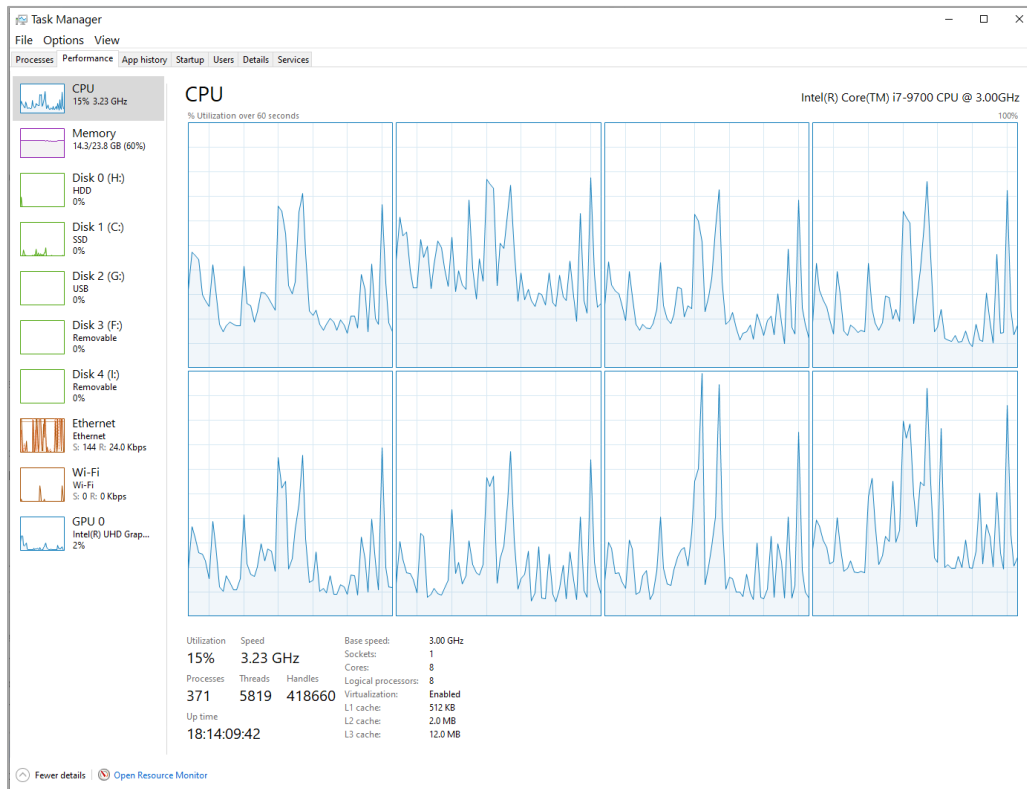
Fix Out-of-Memory Issues

Graphics hardware with limited graphics memory can cause poor performance or lead to out-of-memory issues. Improve performance and work around memory issues with these changes:

- Use smaller figure windows.
- Close other toolboxes.
- Bin your images if possible.

Parallel Processing

To deliver the best performance, some of the functions and toolboxes of IDCubePro® (i.e., **t-SNE**, **Feature Finder**, **Machine Learning** use parallel processing. To visualize the performance and see the number of cores on your PC click **ctrl+alt+del** to activate **Task Manager**, select **Performance** tab and change the view to display all cores if you like. **Right-click** inside the CPU graph, choose **Change graph to** and select **Logical processors**. The picture below shows the activity in every core (total 8 cores).



Contact Technical Support

If you cannot resolve the issues, please contact HSpEQ technical support at <https://www.idcubes.com/contact-us> and provide the **Error Log** report.

| |
|---|
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