

ARCTIS

(ARChaeological Toolbox for Imaging
Spectroscopy)

Documentation

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Introduction

Hyperspectral data sets offer new possibilities for archaeological research as they record spectral signatures in many (often > 100) contiguous and small spectral bands, whereas traditional multi-spectral sensors and cameras undersample the true signature. Imaging spectroscopy offers therefore a wealth of information not available in classical data sets. The additional features – in particular related to the shape of the spectral signatures (e.g. “red edge”) as well as to absorption related features (e.g. “band depths”) – need to be extracted from the data set using specific algorithms.

With this new data source, however, at least two broad problems need to be solved (assuming that the image geometry can be correctly handled). The first problem relates to the huge amount of information available not directly accessible to the human eye. This makes special data mining and visualization approaches necessary. The second problem relates to data quality. Indeed, as the upwelling electromagnetic radiation is recorded in small bands that are only about ten nanometers wide, the signal received by the sensor is quite low compared to sensor noise and possible atmospheric perturbations. Thus, compared to traditional broad band sensors, the signal-to-noise ratio (SNR) is an important issue in imaging spectroscopy. In the same way, the often very small IFOV - necessary for achieving a high spatial resolution - further limits the useful signal stemming from the ground. For these reasons, filter techniques are necessary.

ARCTIS, a user-friendly MATLAB-based graphical user interface (GUI) was developed in a cooperation between University of Vienna and BOKU Vienna to help the image analyst (not necessarily a specialist in remote sensing or in imaging spectroscopy) getting the most information out of the recorded 3D data cube. The aim was to visualize the data so to highlight possibly occurring crop or soil marks. For example, the user can apply a variety of different contrast stretching methods and display any band combination as an RGB image. Powerful filters based on the Whittaker smoother were implemented currently not available within commercial image processing software. The filter can be tuned to smooth the data along the spectral axis or in space. Data gaps are easily handled. The user can visualize the sequence of individual bands in an animated way using adjustable FPS rates. Principal component analysis is possible using either data from the whole image or from a region of interest as calculation base. Shape information such as the red edge inflection point is derived from spectrally smoothed and oversampled signatures thus giving new insights into crop vigor/crop marks. Additionally, various standard and optimized hyperspectral vegetation indices were implemented. Areas can be highlighted having a similar spectral signature compared to a user-selected pixel or region of interest. The user can further test the usefulness of a large set of edge detection algorithms. If desired, it is also possible to combine data for example from magnetic resonance imaging and imaging spectroscopy.

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About this documentation

In this documentation, hyperlinks to internet resources (mostly hyperlinks to the MATLAB documentation) are underlined and blue, whereas references to bookmarks in this document are displayed in red. Words written in ***bold and italic*** refer to Buttons/Texts/Captions/etc. in ARCTIS.

This manual was written to explain the usage of ARCTIS in a practical way. The mathematical and scientific background of the underlying methods is specified within the indicated References.

We gratefully acknowledge those people having made available their MATLAB® codes so that we could integrate the proposed functionalities into ARCTIS: P. Eilers for the MATLAB®-based implementation of the Whittaker smoother, D. Garcia for the 2-dimensional smoothing and gap-filling algorithm, and B. Shoelsen for his zoom2cursor function which inspired the Stretch2Cursor and Zoom2Cursor functionality of ARCTIS.

We also would like to thank F. Totir, J. Tuszynski and I. Howat for making their ENVI read/write scripts available on the MATLAB® File Exchange platform. Their works helped to overcome difficulties in handling ENVI files.

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We request that you actively acknowledge our work by quoting following publications:

1. Atzberger C., Wess M., Doneus M., Verhoeven G., 2014. ARCTIS—A MATLAB® Toolbox for Archaeological Imaging Spectroscopy. Remote Sens. 2014, 6, 8617-8638; doi:10.3390/rs6098617
2. Doneus M., Verhoeven G., Atzberger C., Wess M., Ruš M., 2014. New ways to extract archaeological information from hyperspectral pixels, Journal of Archaeological Science (2014), doi: 10.1016/j.jas.2014.08.023.

Basic characteristics of ARCTIS

ARCTIS Concept

ARCTIS was basically developed to help the image analyst getting the most information out of hyperspectral (3D data) images. It is a tool to display hyperspectral data in many different ways to retrieve as many pieces of information as possible out of the input data. To achieve this goal, ARCTIS is able performing a variety of image processing functions. Nevertheless, the image analyst has to keep in mind that ARCTIS is basically a viewing and displaying tool.

To provide the user with the greatest possible freedom, ARCTIS can display an infinite number of images at the same time in separate draggable, resizable windows. Each click on the **View!** button opens a new window containing the [Active Image](#) displayed with the current [contrast parameters](#). This concept allows the user to compare or analyze any number of images in a project. All opened windows can be closed with a single click on the “X”-button.

File Structure

In ARCTIS, images are organized in separate projects. Each project is meant to cover a certain geographic area and is meant to contain images of the same resolution and size.

ARCTIS projects consist of a project file (extension “.cpm”) where information about the project and - most important - the path to the images is stored, and any number of image files (extension “.mat” – MATLAB File). By default, images are stored in a subdirectory having the same name as the project file, but during [project creation](#), you can select/create any directory you want for the images.

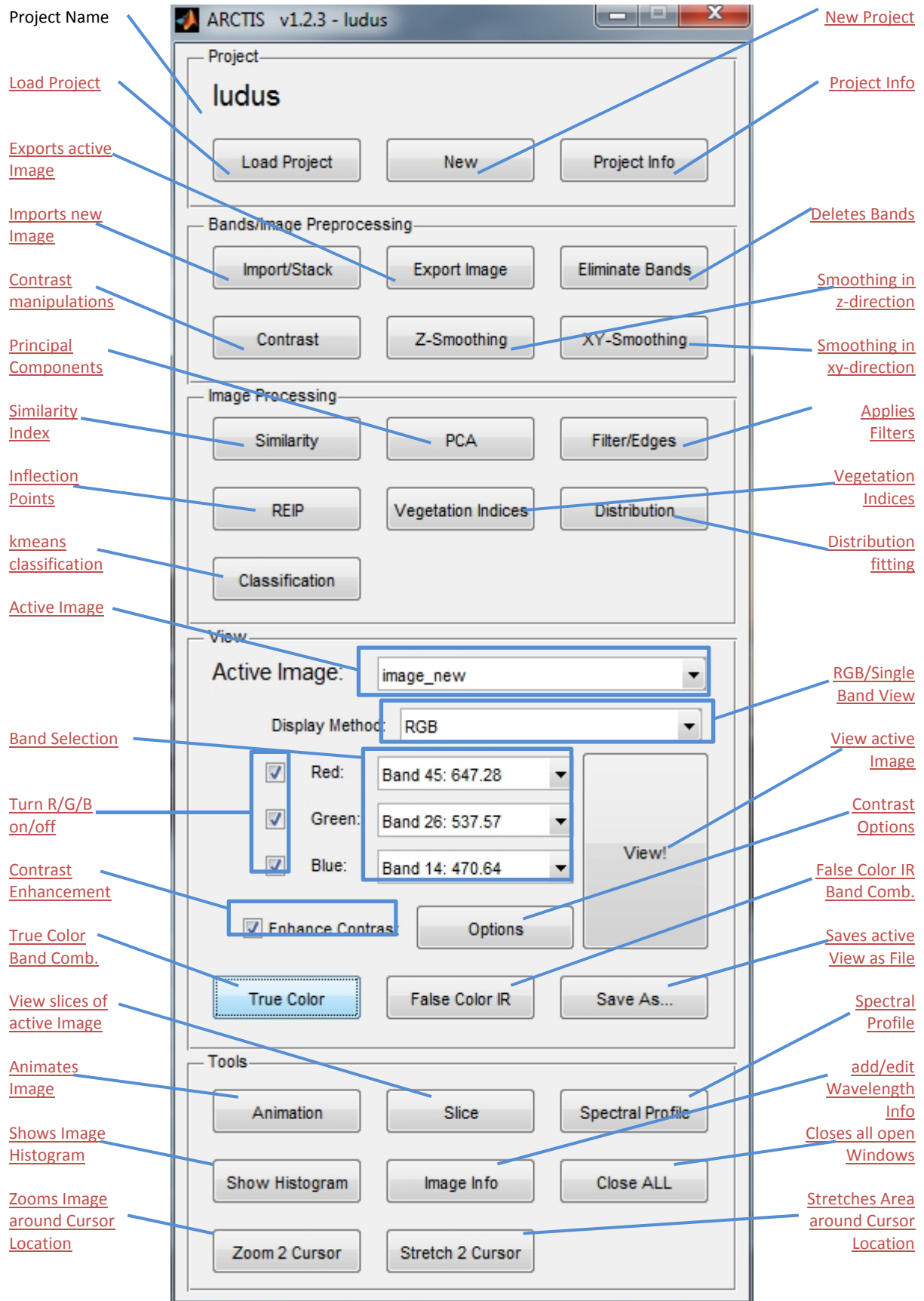
ARCTIS distinguishes images from different projects using an image prefix assigned by the user, which should be unique for each project. Image files are named after the following pattern: “[image prefix]_[image name].mat”. If you create new images during your use of ARCTIS, you only need to specify the [image name], ARCTIS will add the [image prefix] automatically.

GUI Structure

The GUI is divided in five sections as demonstrated in the screenshot below. The first section contains functions for [loading](#), [creating](#) and [maintaining](#) a project. It also displays the name of the currently loaded project.

The second section provides image pre-processing functions like [importing/exporting](#) an image, the [deletion of user-specified bands](#), functions for [contrast adjustment](#) or [2 or 3-dimensional smoothing](#). **Note:** Smoothing of data – even if it takes a rather long time – is highly recommended as it increases the quality of all subsequent analyses.

In the third section you find the main image processing functions: [Similarity index calculation](#), [principal component analysis](#), [filter and edge detection functions](#), [inflection point calculation](#), [vegetation index calculation](#), [distribution fitting](#) and a simple [classification algorithm](#). All these functions produce new images with unique names which are stored in the image path of the current project.

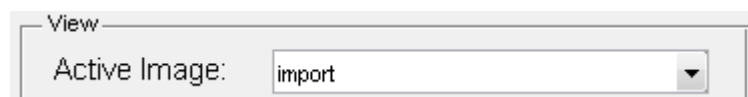


The fourth section provides the display controls and allows you to view your images. It contains the [drop-down menu for selecting the active image](#), you can switch between [single band and RGB display mode](#), select which [bands to display](#), decide whether or not you want to [enhance the contrast](#) of your image before viewing it (and the way how to manipulate the contrast), you can [select predefined bands](#) and you can [save the your current view](#) as a JPG or JPG2000 file. The functions in this section do **NOT** change the data of your image; they just display the image using the selected parameters.

The last section contains several tools which might help you during your image analysis: You can display an [animated sequence](#) of your 3D data cube, view your data in [slices](#), display [spectral profiles](#) at selected points, show [image histograms](#), add/edit [wavelength information](#), [close all open ARCTIS windows](#) and use the [Zoom2Cursor](#) and [Stretch2Cursor](#) functions to highlight areas around the cursor automatically while you move it within the image frame.

The Active Image concept

In ARCTIS, you have always an image which is the so-called “Active Image”. You select this image using the **Active Image** dropdown menu in the **View** section:



For example, if you click the **View!** button, the active image is displayed. This applies to all other functions, too. That means if you run any image processing function, ARCTIS will automatically select your current Active Image as default input image.

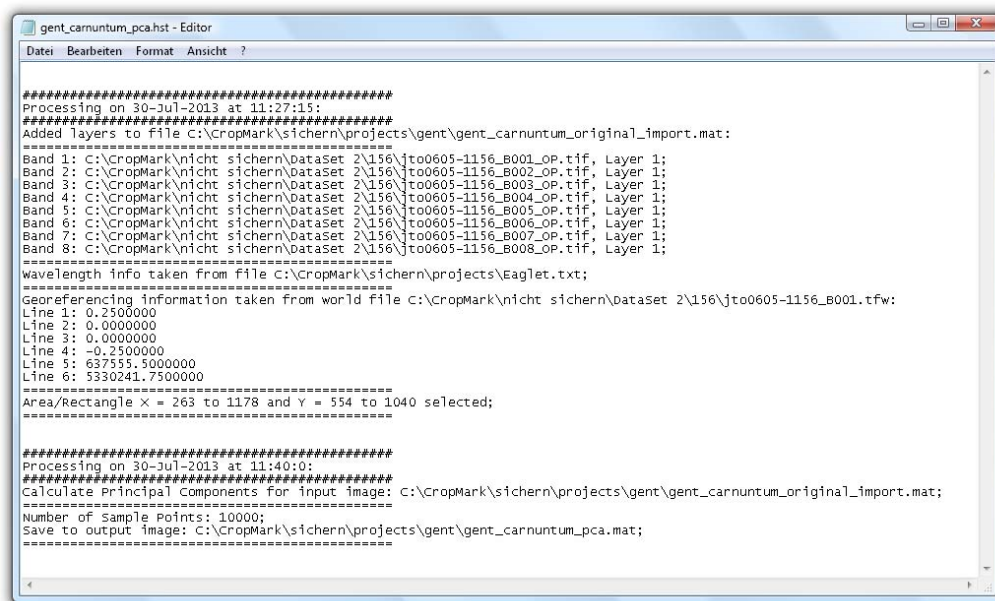
If you load a project, ARCTIS looks for images in the image folder specified in the project file. It then checks if the image files found start with the correct file name prefix. All image files in the image path starting with the prefix are then listed in the active image popup menu and you can select them to make them the current active image.

Images which are not listed in your **Active Image** dropdown menu need to be imported using the [Import](#) function.

History Files

ARCTIS offers a variety of different image processing algorithms. To help the image analyst to remember the processing history of each file, a *.hst file is created, where all the parameters of the functions applied to the image are stored. History files are saved using the same name as the image file and are placed in the same folder.

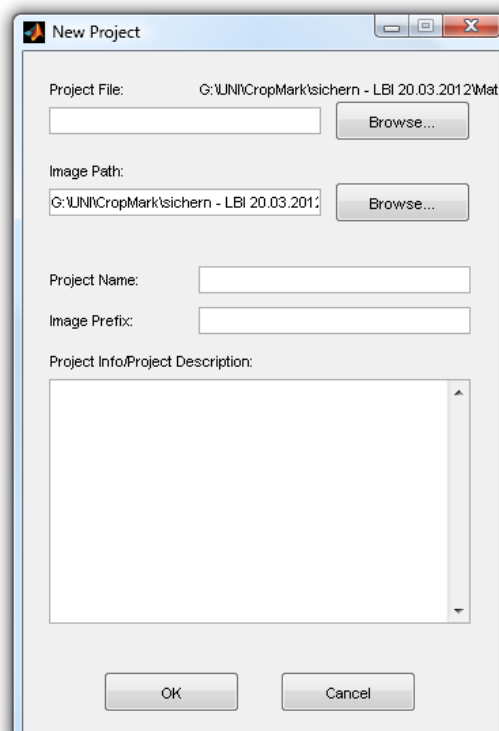
In ARCTIS, each image processing function results in a new image with a new file name. ARCTIS takes all the history information out of the original *.hst file and includes it in the *.hst file of the new image. So you can be sure that all the functions and parameters that produced your current image are included in its history file.



Function Reference: Project Functions

New Project

The button **New** allows you to create a new ARCTIS project. A window is displayed where you specify the project properties:



At first, you have to specify the **Project File**, the file and location of your project. You can do this either using the **Browse...** button, or – if you want your project to be located in the selected path - you enter the name for your project directly. If you omit the extension “.cpm”, it is added automatically.

The next step is to select your **Image Path**. By default, your image path is located in a newly created subdirectory named after your project file, but you can specify any path you want.

After that, you define the name of your project; this name is displayed in the top of the main window. By default, ARCTIS uses your project file name, but you can use anything you want.

The **Image Prefix** is automatically added to your image file names in order to distinguish the image files from each project. By default, ARCTIS uses your project file name, but you can use anything you want.

In the **Project Info/Project Description** field, you can enter additional information about your project like date/time, geographic location, image resolution etc. As this field is optional, you can leave it blank.

After you click **OK**, your project file and image path are created and your new project is loaded. As it does not contain any images yet, most of the ARCTIS functions are disabled. Your next step will be to [import new images](#).

Load Project

The button **Load Project** opens a file selection dialog where you can select a file you want to open. It is only possible to load ARCTIS Project Files (extension “.cpm”).

During the opening process, ARCTIS looks for the image path specified in the project file. If the path is incorrect (this may occur if you move the image path or if you transfer projects and images from one PC to another), ARCTIS displays a dialog box which requires you to select the image path for your opened project and then updates the image path definition in the project file.

After the Project file is loaded, ARCTIS looks for ARCTIS images in the image path. If suitable images are found, ARCTIS enables the image processing functions and loads the images so that you can select them using the [Active Image selection drop-down menu](#).

If you want to change the image path of a project, you can do this using the [Project Info](#) function.

Project Info

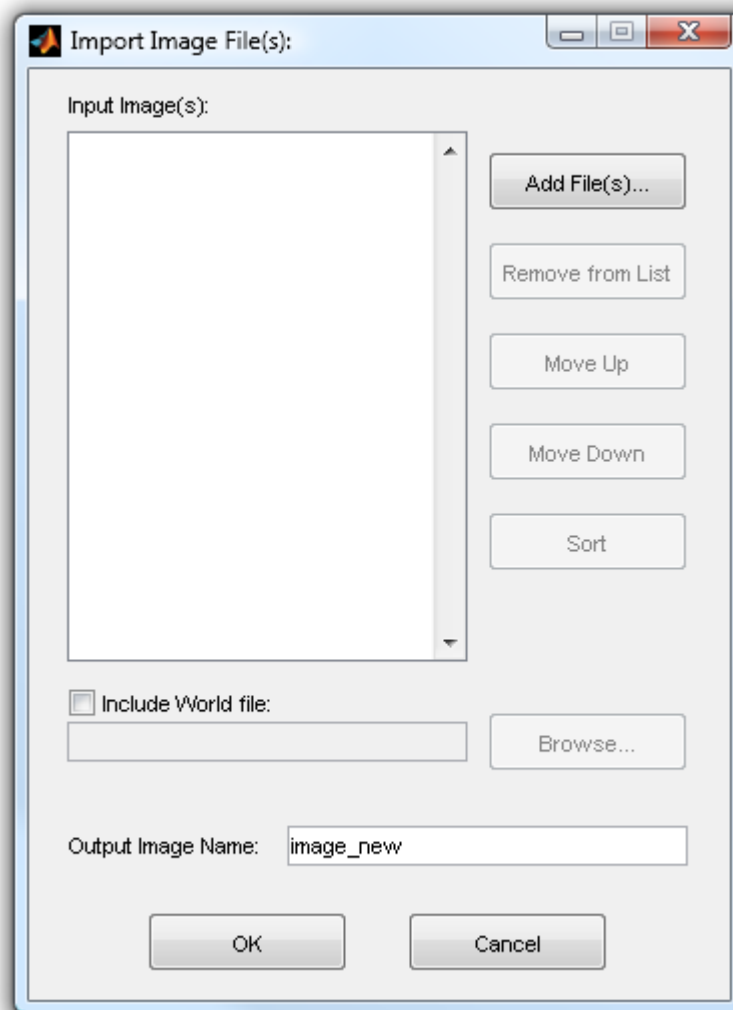
The button **Project Info** allows you to display and/or edit the image path and the info you entered in the **Project Info/Project Description** field of your project. **Close** closes the window while **Save** updates your project file with your changes.

Function Reference: Bands/Image Preprocessing Functions

Import/Stack

The button **Import/Stack** allows you to import one or more image files into ARCTIS. You can import either Bitmaps (".bmp"), TIFF Images (".tif"), ENVI Files (".dat" and ".hdr"), GIF Images (".gif"), JPG Images (".jpg") or ARCTIS image files (".mat").

If you click this button, a new window opens where you can select the files to import:



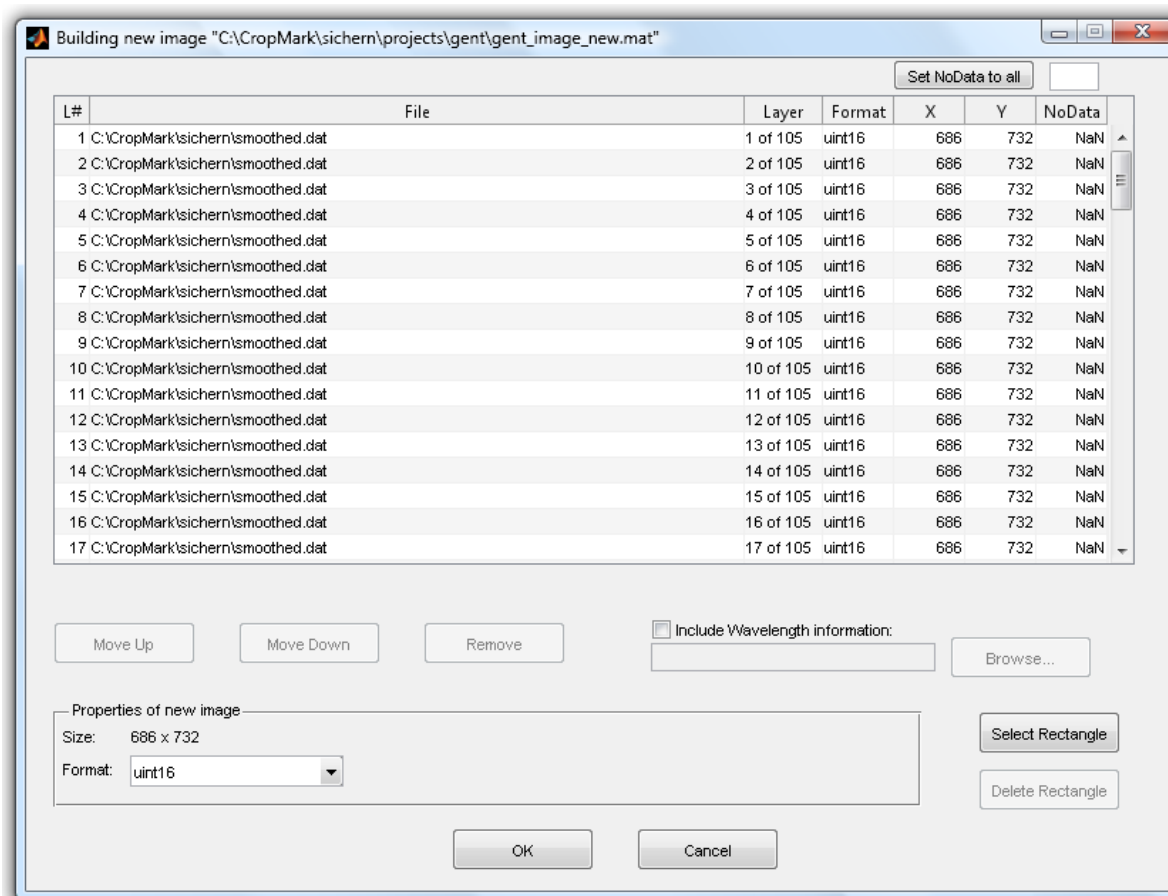
In this window, you can select files using the **Add File(s)...** button; it is also possible to **Remove** files from the list, move files **Up** and **Down** or **Sort** the image list alphabetically.

If you have information about the geographic location and resolution of your image available in a [World File](#), you can select this file and select **Include World file** to add this information.

If you are importing ENVI binary (".dat") file(s), the corresponding header file may already contain georeferencing information. In this case, information derived from a potential world file is discarded. Also, if you stack data from more than one ENVI file, georeferencing information from the last selected file is used, any other georeferencing data is discarded.

The last step is to define an **Output Image Name**. This is the name of your newly imported image in ARCTIS. After that, click **OK** to continue.

ARCTIS now reads the selected file(s) and displays a new window:



In this window, ARCTIS lists all Layers of all the files you selected in the order specified above. Here, you can change the order (**Move Up** or **Down**) of individual layers or **Remove** them.

ARCTIS shows each individual layer of your newly created image, its origin, which layer of the original image it is, which **data type** and the size of the image. If your image contains sources with different sizes, ARCTIS automatically adjusts the size of the new image to the smallest horizontal and vertical sizes available and crops all the other images starting from the upper left corner.

If your image contains **NoData**-Values (see [here](#)) and you want to interpolate them, you can define a no-data-value for each layer, or you can define the same value for all layers using the **Set NoData to all** button.

If you have information about the **wavelengths** available in a text file, you can add the file by selecting the **Include Wavelength information** checkbox and selecting the file using the **Browse...** button. Your wavelength text file has to contain at least one value for each layer, otherwise an error is issued.

If you are importing ENVI binary (".dat") file(s), the corresponding header file may already contain wavelength information. In this case, information derived from a potential wavelength file is

discarded. Also, if you stack data from more than one ENVI file, wavelength information from the last selected file is used, any other wavelength data is discarded.

If you don't want to use the whole image but a sub-image, you can click the **Select Rectangle** button. ARCTIS then asks you to select which **Band** of your data you want to display in which **Colormap**:



After you made the choices you want, click **Continue** and ARCTIS displays your selection where you can select sub-image by drawing a rectangle using your left mouse button. When you are finished, just close the window. You will see that the **Size** information in the **Properties of new image** section will change accordingly. If you decide to change the sub-image location, just click the **Select Rectangle** button again and draw a new selection; if you want to use the whole dataset, click **Delete Rectangle**.

As a last step, you have to decide which **Format** you want your data to be in ARCTIS. You have to options: 8 bit unsigned integer or 16 bit unsigned integer. It is recommended to use uint16, but if you know your source data to be only 8 bit, you can use uint8 too (more about data types can be found [here](#)).

ARCTIS will now import and automatically display your new image using the [best triple algorithm](#) after you click **OK**.

Export Image

The button **Export Image** allows you to export your image as multilayer TIF image or ENVI file. Using this function, ALL layers of the [active image](#) are exported; please note that the resulting image can differ a lot from the image displayed if you click the **View!** Button because no [contrast enhancement](#) is applied. Additionally, you need image processing software which is able to cope with multilayer images to display the exported file correctly.

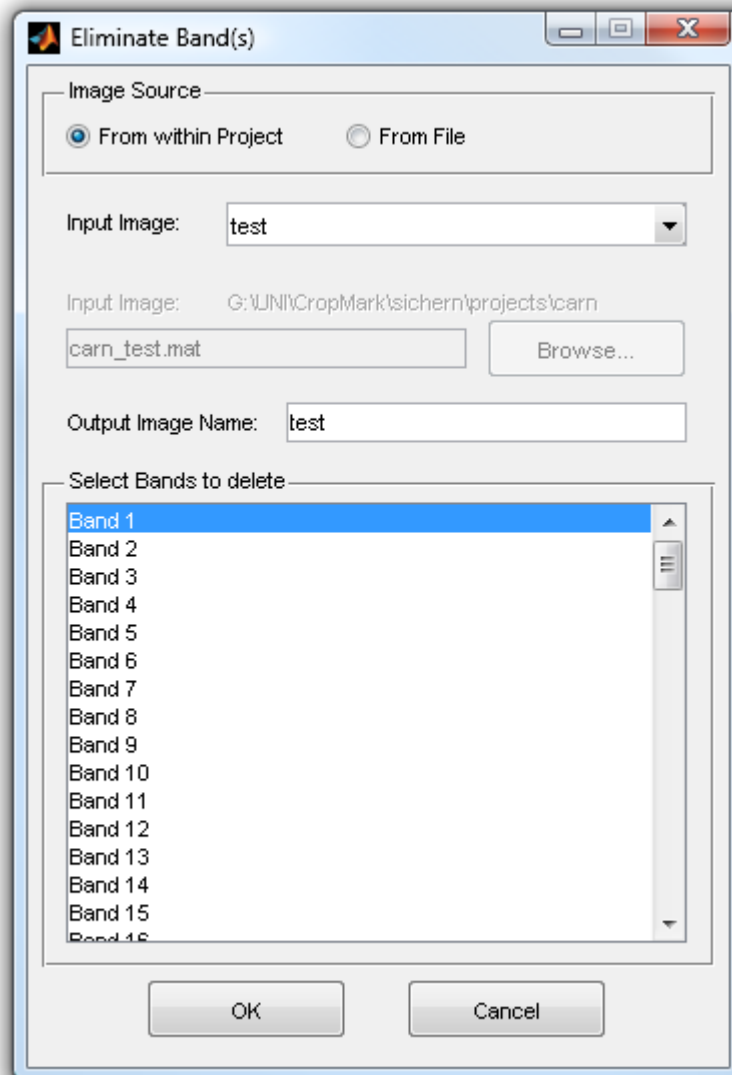
If you click the **Export Image** button, you are prompted for a file name and you have to select the file type of your image.

If you decided to export to an ENVI binary file, you may be prompted to enter additional georeferencing information in order to allow ARCTIS to calculate the data correctly. Additionally, if you have wavelength information associated with your image file, ARCTIS will export that to the ENVI header file, too.

ARCTIS will then save your [active image](#) to the file you specified.

Eliminate Bands

The button **Eliminate Bands** opens a new window where you can select individual bands of your multilayer image and delete them:



The upper section of this window allows you to select your input image. By default, the current [active image](#) is selected (more about input image selection in ARCTIS [here](#)).

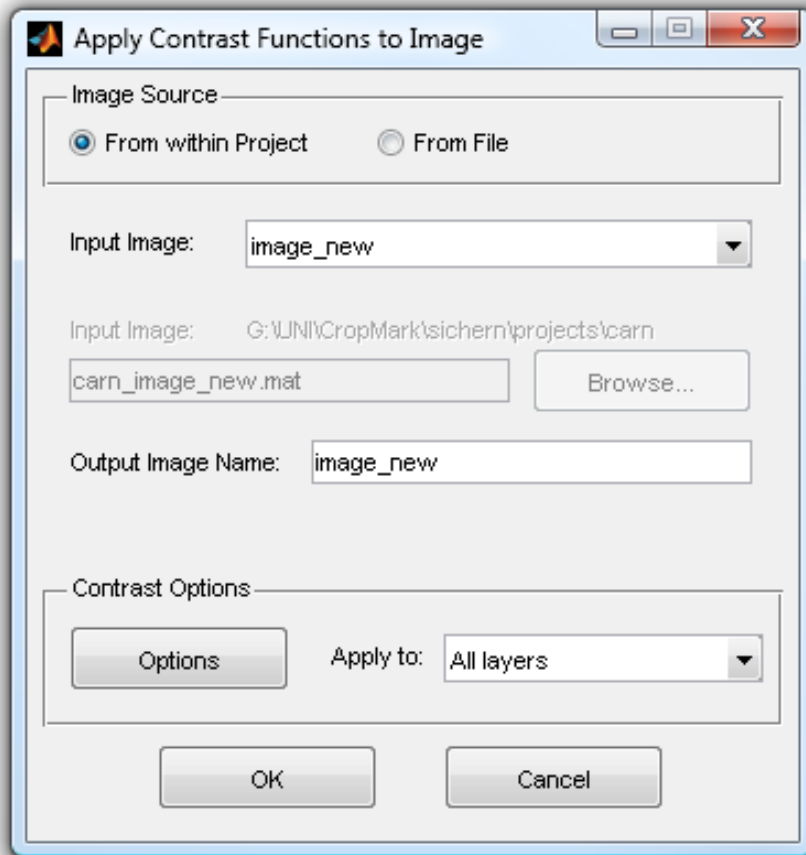
Below the file selection section, you have to specify your **Output Image Name**. Default setting is to use the name of the original image, so this file would be overwritten. If you want to keep your original image, specify a different file name.

Now, you have to **Select the Bands to delete** by clicking them with the left mouse button. If you want to delete more than one band, you can do this using the Shift or Ctrl key.

After you click OK, ARCTIS deletes the selected layers and displays the result using the [best triple algorithm](#).

Contrast

The button **Contrast** starts a function where you can change the contrast of one or all layers of your image. It opens the following window:

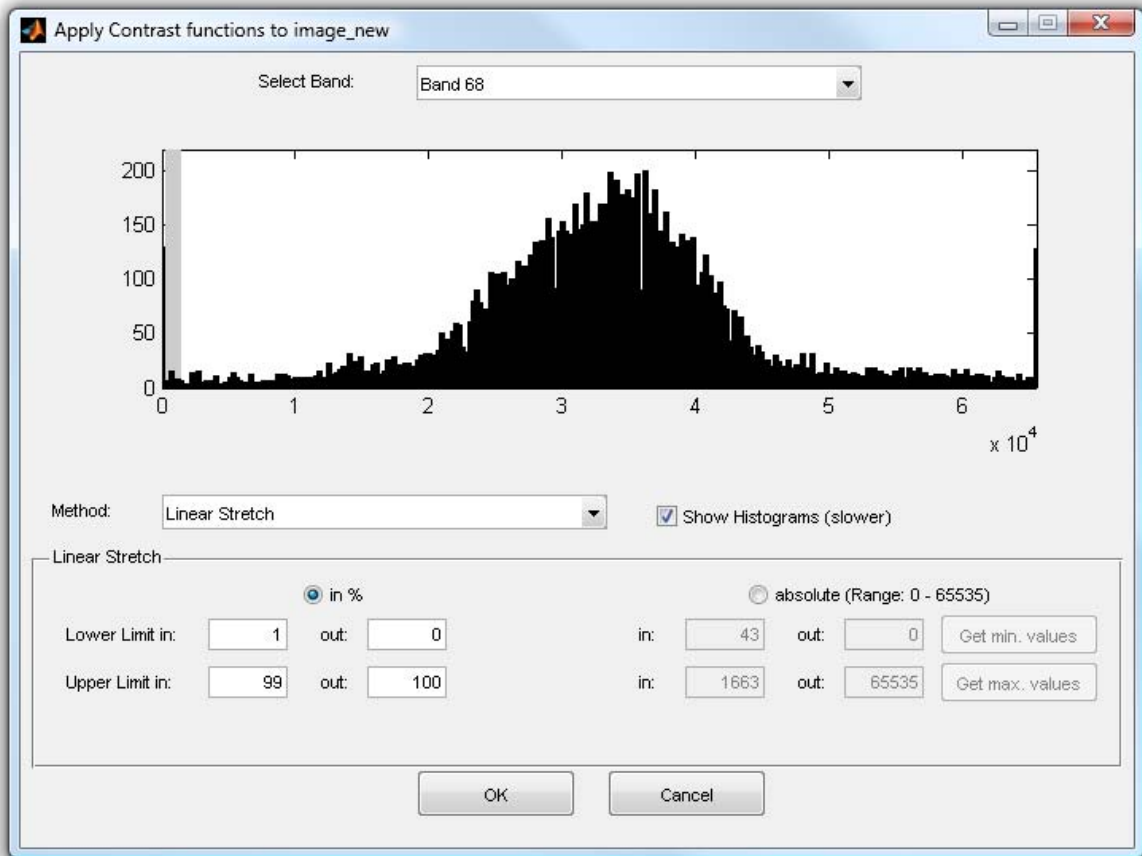


The upper section of this window allows you to select your input image. By default, the current [active image](#) is selected (more about input image selection in ARCTIS [here](#)).

Below the file selection section, you have to specify your **Output Image Name**. The default name is "image_new"; if you choose a name which is already in use, a warning is issued.

You now define if you want to apply the contrast functions to **All layers** or only the one **selected only** (by default layer number 1).

Clicking the button **Options** opens a new window where you can define the parameters for your contrast adjustment:



In the top section of the window you can select the band you want to use (if you chose to apply the contrast functions only to one layer before). Additionally, if you check the **Show histogram** checkbox, a histogram of the layer selected above before (grey) and after (black) applying the contrast function using the current parameters is displayed. In the screenshot above, a 16 bit image is shown which ranges originally from 0 to about 2000 (0.2×10^4). After the **Linear Stretch** function with lower limit in = 1%, upper limit in = 99%, lower limit out = 0% and upper limit out = 100% is applied, the image covers the whole range.

Your next step is to select the **Method** you want to use for your contrast change. You have several options available:

- [Linear Stretch](#)
- [Non-Linear Stretch \(Gamma Correction\)](#)
- [Decorrelation Stretch](#)
- [Histogram Equalization](#)
- [Contrast-limited adaptive Histogram Equalization](#)

Each of these methods works differently and needs different input parameters.

Linear Stretch

As the name implies, this method changes the image values using a linear equation. You have to define four parameters: Lower and upper limits for input and output. There are two ways how these parameters are determined:

1. **in %:**

You can define the input and output limits as a fractile in percent. Note that while output limits stay the same for each layer and are only determined by the data type (see [here](#); if you set the output limit to 50% and are using 16 bit images which range from 0 to 65535, ARCTIS calculates 50% = 32768), the input limits vary from layer to layer as they are determined by the layer histogram.

The advantage of the percentage input is that you obtain an image which uses the same value range in each layer. But, of course, dependencies between the layers are removed, especially if the value range of the input layers varies widely. So if you want to keep the correct relationship between the layers, it is recommended to use the second way of determining input and output limits:

2. **absolute values:**

You also can define the input and output limit values directly using the **absolute** method. This method applies the same formula to all layers, so the relationship between the layers is kept.

You have the possibility to automatically obtain the **minimum** and **maximum values** of your whole image (not layer!) by clicking the correspondent buttons. If you use these values, the resulting image covers the whole range (depending on the [data type](#)); if your image has 16 bit, the lowest value of all layers will be 0 and the highest 65535.

ARCTIS now calculates the output values applying the linear equation

$$out_{ij} = l_{out} + (u_{out} - l_{out}) * \left(\frac{in_{ij} - l_{in}}{u_{in} - l_{in}} \right)$$

to each pixel where

in_{ij}	= input pixel values
out_{ij}	= output pixel values
l_{in}	= lower limit in for the current layer
u_{in}	= upper limit in for the current layer
l_{out}	= lower limit out for the current layer
u_{out}	= upper limit out for the current layer.

Non-Linear Stretch (Gamma Correction)

This method is similar to the [linear stretch](#) method; the only difference is an additional fifth parameter, called **Gamma**. The other four parameters (lower and upper limits for input and output) are the same and are entered in the same way as written above. The above mentioned equation changes to the non-linear equation

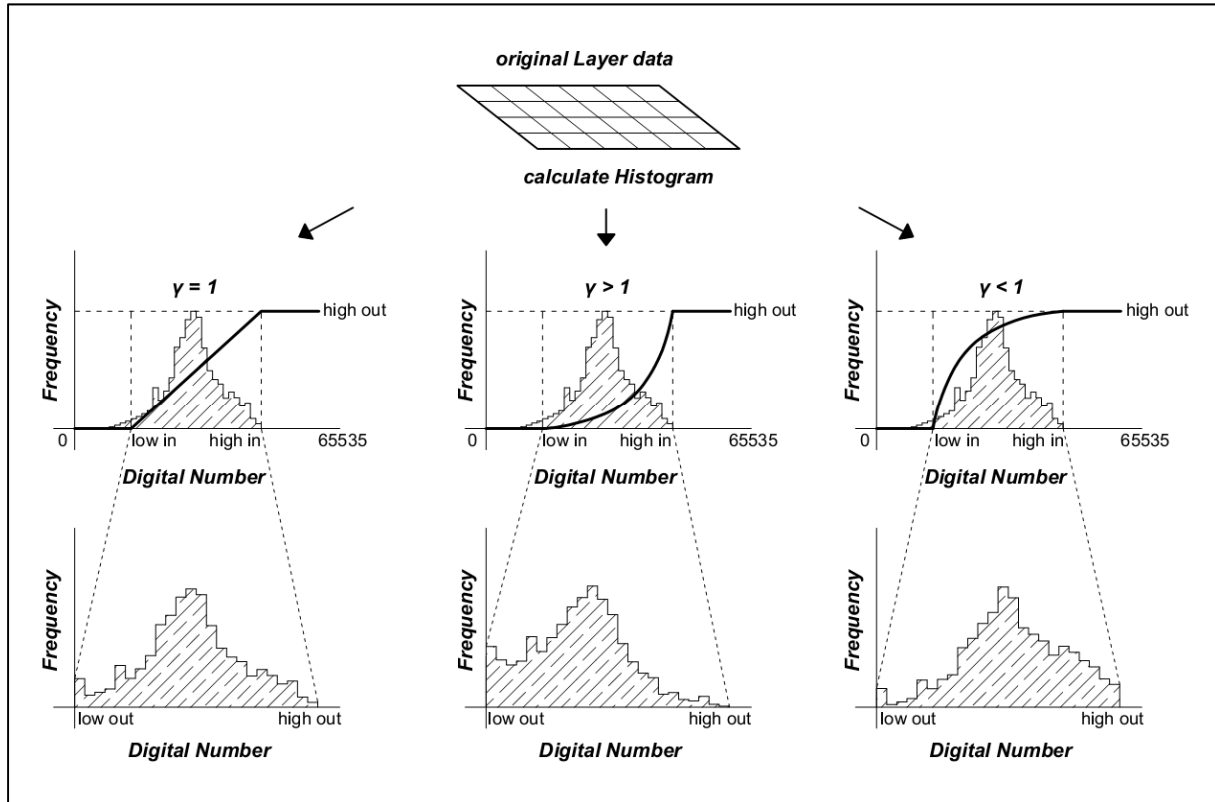
$$out_{ij} = l_{out} + (u_{out} - l_{out}) * \left(\frac{in_{ij} - l_{in}}{u_{in} - l_{in}} \right)^\gamma$$

where

in_{ij}	= input values
out_{ij}	= output values
γ	= Gamma
l_{in}	= lower limit in
u_{in}	= upper limit in

l_{out} = lower limit out
 u_{out} = upper limit out.

The chart below shows the way non-linear contrast adjustment works:



As you can see, if you specify $\gamma > 1$, pixel values are more likely assigned to lower values, which results in a darker image. If your $\gamma < 1$, you will get a brighter image.

Decorrelation Stretch

The decorrelation stretch method uses the [decorrstretch](#) function of MATLAB which tries to minimize the correlation between the layers using a covariance matrix. Decorrelation stretch is normally applied to RGB images, but it works on an arbitrary number of bands.

Note that this method is NOT applied layer per layer but to all layers at once, so the histogram preview of one layer might not be correctly calculated.

Histogram Equalization

This method uses the [histeq](#) function of MATLAB which tries to enhance the contrast of the image in such a way that the resulting image has a defined **Number of discrete Levels** (=values). ARCTIS tries to map a roughly even number of pixels to each level so that the resulting histogram is approximately flat.

This function works best when the number of levels is small in comparison to the number of different values in the input image. It may have problems if your input image only covers a small range, so it is not recommended to use this method as a first try to get information out of a newly imported image.

Contrast-limited adaptive Histogram Equalization (CLAHE)

This method uses the [adapthisteq](#) function of MATLAB. This function operates on small regions called tiles, which sizes are determined through the **Number of Tiles (Row x Column)** you define. The contrast of each tile is enhanced in a way that it fits the specified **Distribution: uniform** results in a flat histogram, **rayleigh** in a Bell-shaped curve and **exponential** in a curved histogram. The neighboring tiles are then combined using bilinear interpolation to eliminate artificially induced boundaries.

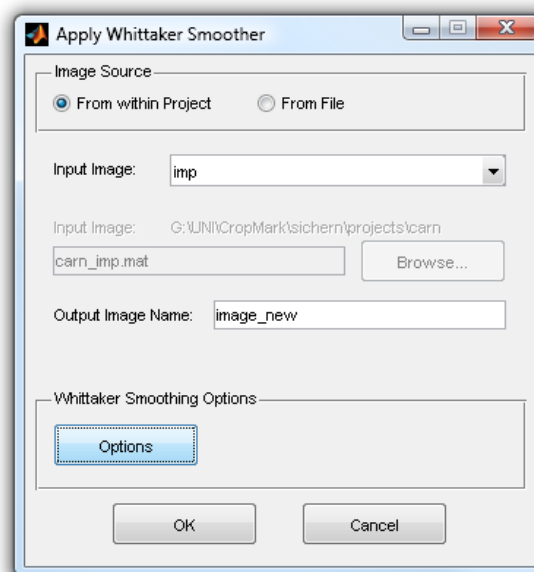
Other parameters you can define are

- **Clip Limit:** This number specifies a limit for contrast enhancement. It ranges from 0 to 1; higher numbers result in more contrast.
- **Number of Bins:** This value specifies the number of bins used during histogram calculation. Higher values result in greater dynamic range but in slower processing speed.
- **Range:** You can specify if your output image should cover the **full** possible range (0...65535 if you are working on a 16 bit image) or if ARCTIS should keep the range of the **original** image.
- **Alpha** (only used when **Distribution** is set to **rayleigh** or **exponential**): Distribution parameter

If you have entered your contrast enhancement settings, save them by clicking **OK**. Pressing **OK** again on the **Apply Contrast Functions to Image** window starts the process. If the calculation is finished, ARCTIS displays your newly created image using the [best triple algorithm](#).

Z-Smoothing

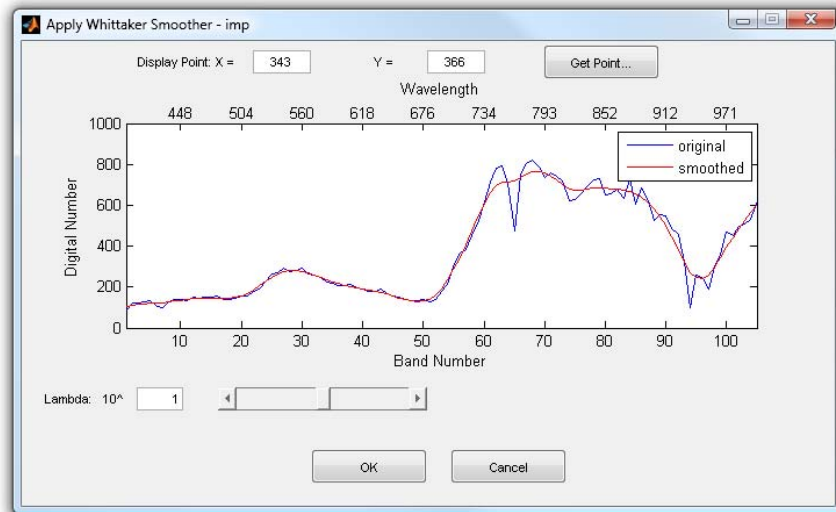
The button **Z-Smoothing** allows you to smooth the values of each pixel of your hyperspectral data cube in z-direction. It opens the following window:



The upper section of this window allows you to select your input image. By default, the current [active image](#) is selected (more about input image selection in ARCTIS [here](#)).

Below the file selection section, you have to specify your **Output Image Name**. The default name is “image_new”; if you choose a name which is already in use, a warning is issued.

Clicking the button **Options** opens a new window where you can define the smoothing parameter:

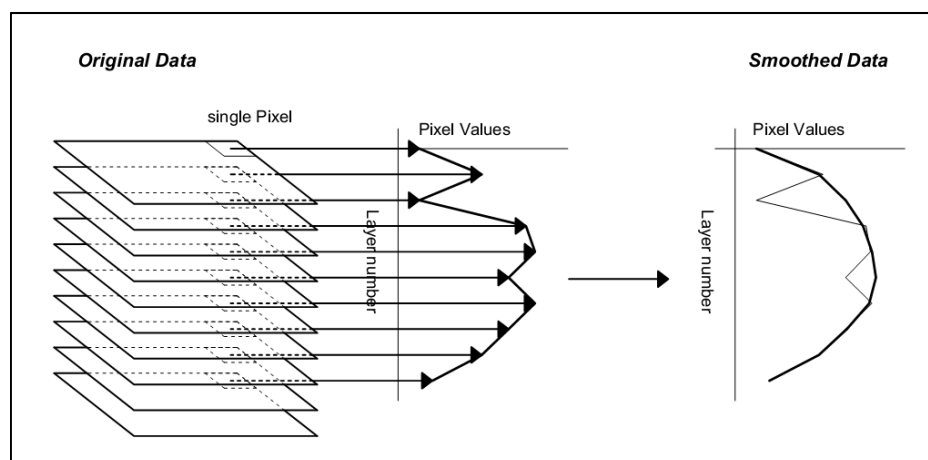


This window displays the values of each layer for a certain point. ARCTIS selects the center point of your image by default, but you can display every other point if you want to by clicking the **Get Point...** button (which starts the [point selection tool](#)) or by entering the **X** and **Y** value of your desired point directly.

ARCTIS displays the **original** profile in blue, calculates the **smoothed** values using the current smoothing parameter and shows the result in red. The smoothing parameter λ ranges from -4 to 6, with 1 being the default value. You can change λ using the slider or enter your desired value directly. As you do so, ARCTIS will adjust the graph accordingly.

Clicking **OK** saves the smoothing parameters; clicking **OK** again starts the smoothing function. ARCTIS calculates the new image and displays it using the [best triple algorithm](#) afterwards.

The chart below shows the principle of the smoothing process:



ARCTIS calculates the smoothed image pixel per pixel; for every pixel location, all the layer values are taken, smoothed values are calculated and written into a new image. Especially if you are working with larger images, the smoothing process may take a while.

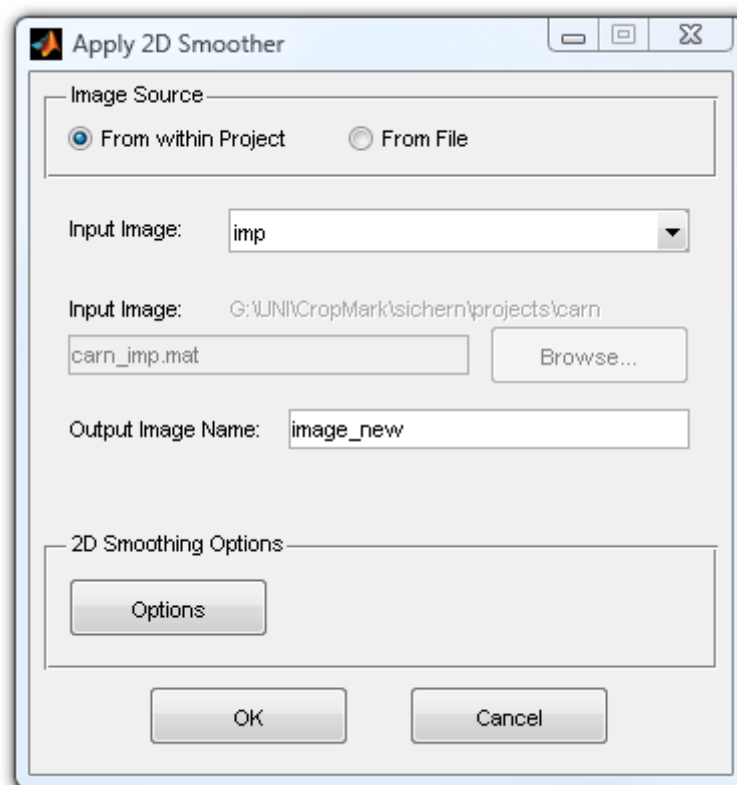
The smoothing algorithm used in ARCTIS was originally developed by Whittaker ([Whittaker, 1923](#)) and modified and implemented in MATLAB by Paul Eilers ([Eilers, 2003](#)). For a detailed explanation of the mathematical background, please refer to the original documents.

Please note that the smoother in ARCTIS treats all bands as if they were equally spaced in the wavelength range.

It is strongly recommended to apply the **Z-Smoothing** algorithm to each image as a second step after importing.

XY-Smoothing

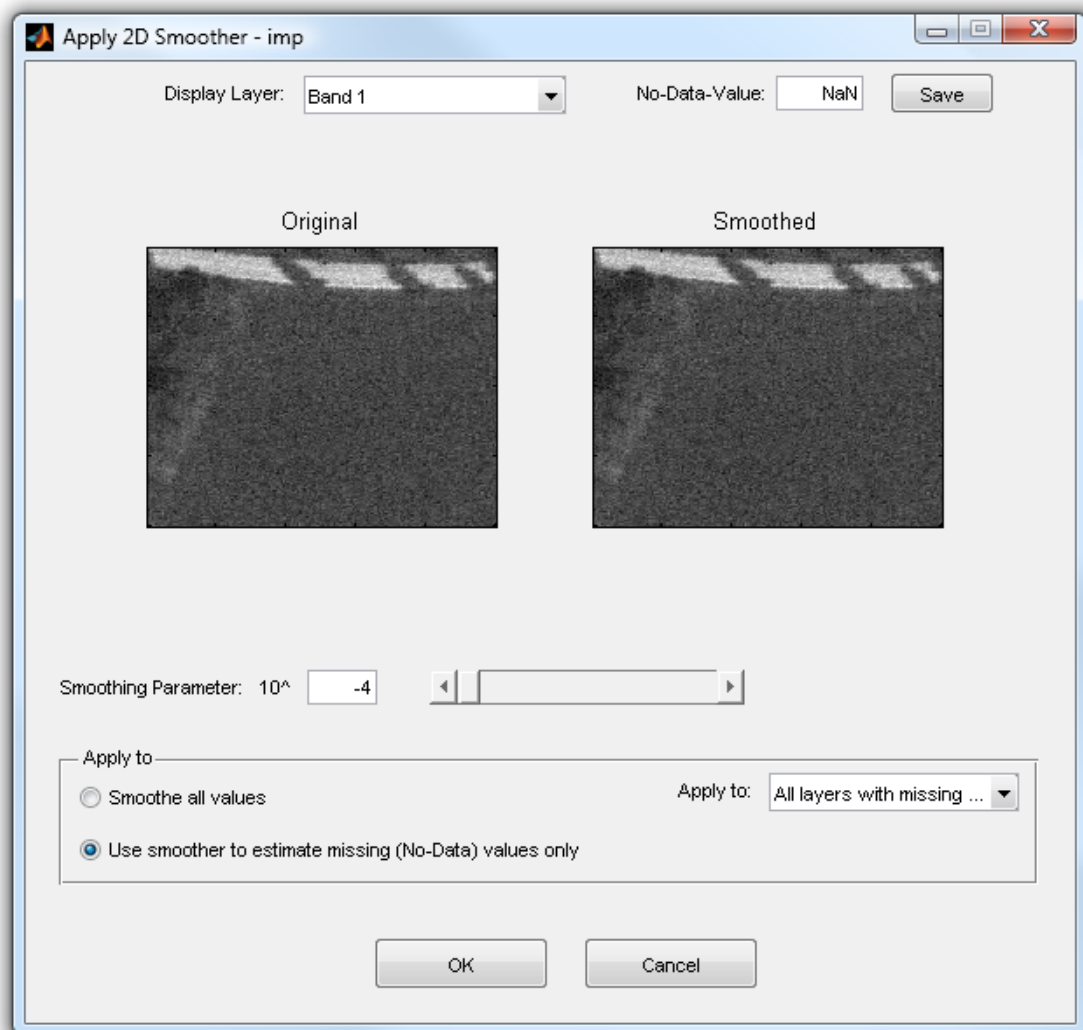
The button **XY-Smoothing** allows interpolate/extrapolate to remove missing values or you to smooth your image layer per layer:



The upper section of this window allows you to select your input image. By default, the current [active image](#) is selected (more about input image selection in ARCTIS [here](#)).

Below the file selection section, you have to specify your **Output Image Name**. The default name is “image_new”; if you choose a name which is already in use, a warning is issued.

Clicking the button **Options** opens a new window where you can define the smoothing options:



In this window, ARCTIS shows a small part of an individual layer of your image before and after the smoothing process. You can change the layer displayed using the **Display Layer** drop-down menu. Additionally, you can enter and **Save a NoData-Value** for each layer which indicates missing values.

Using the **Smoothing Parameter** slider, you can change the parameter of the smoother. Below, you have to decide which values you want the smoothing algorithm to adapt. You can **Smooth all values** or **use the smoother only to estimate missing values**; if this option is selected, original values remain unaffected.

You also have to select which layers you want the smoother to change. You can apply it only to layers for which you have entered NoData-Values (**All layers**) or only to the displayed, **Selected layer**.

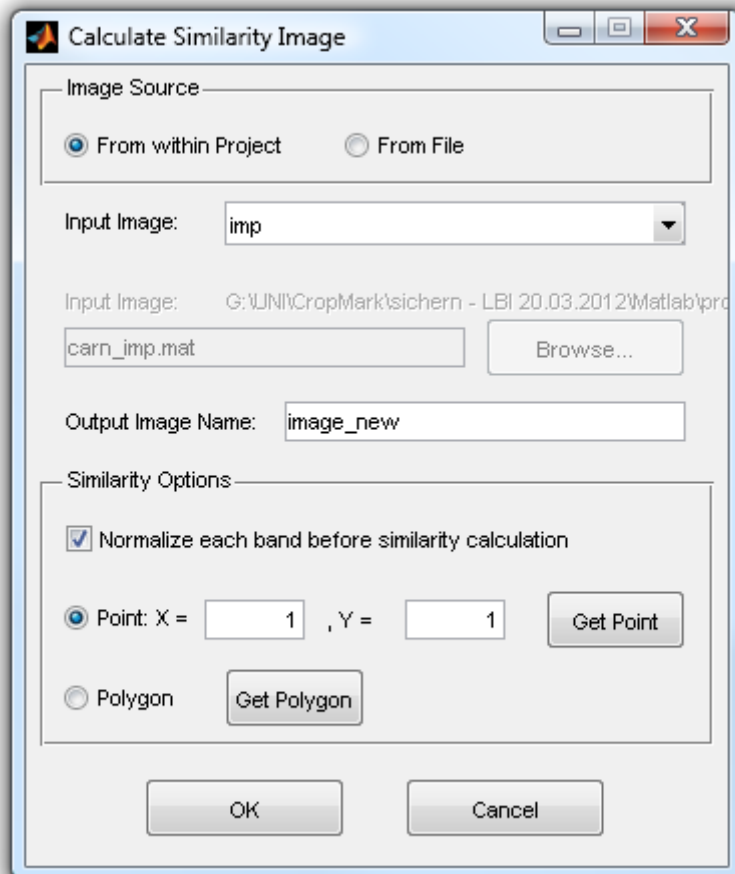
The smoothing algorithm ARCTIS uses for XY-smoothing was developed and implemented in MATLAB by Garcia ([Garcia, 2009](#)) and is loosely based on the Whittaker smoothing method ([Whittaker, 1923](#)). For a detailed explanation of the mathematical background, please refer to the original documents.

Clicking **OK** saves the smoothing options; clicking **OK** again starts the smoothing function.

Function Reference: Image Processing Functions

Similarity

The button **Similarity** starts a function which allows you to create a new image which shows the Euclidian distance between a selected pixel or polygon and every other pixel. If you click the button, the following window is displayed:



The upper section of this window allows you to select your input image. By default, the current [active image](#) is selected (more about input image selection in ARCTIS [here](#)).

Below the file selection section, you have to specify your **Output Image Name**. The default name is "image_new"; if you choose a name which is already in use, a warning is issued.

In the **Similarity Options** section, you have to decide if you want ARCTIS to normalize each band before the similarity calculation. If enabled, ARCTIS [stretches](#) each layer in a way that its values cover the whole [data range](#). To accommodate different variability in each band, normalization is recommended.

You also have to select whether you want to calculate the similarity to a **Point** or to the mean value of a **Polygon**:

- Similarity to a point: Select the point you want using the **Get Point** button (more about point selection [here](#)) or enter the **X** and **Y** values directly.

ARCTIS calculates the Euclidian distance using the formula

$$out_{ij} = \sum_{layer=1}^n (in_{layer,ij} - p_{layer})^2$$

where

$in_{layer,ij}$	= input pixel values of each layer
out_{ij}	= output pixel values
n	= number of layers
p_{layer}	= pixel value to which the similarity is calculated.

- Similarity to the mean of a polygon: Select a polygon using the **Get Polygon** button (more about polygon selection [here](#)).

ARCTIS calculates the Euclidian distance using the formula

$$out_{ij} = \sum_{layer=1}^n (in_{layer,ij} - \frac{1}{k} \sum_{m=1}^k p_{layer,m})^2$$

where

$in_{layer,ij}$	= input pixel values of each layer
out_{ij}	= output pixel values
n	= number of layers
k	= number polygon pixels
$p_{layer,m}$	= pixel values of the polygon to which the similarity is calculated to.

If you click **OK**, ARCTIS starts the calculation using the formulas above. Then the output values are normalized so that they range from 0 to 1 and subtracted from 1 in order to get a resulting image where the lowest similarity is 0 and the highest 1. As a last step, the resulting image is [stretched](#) to cover the whole available range, and then displayed.

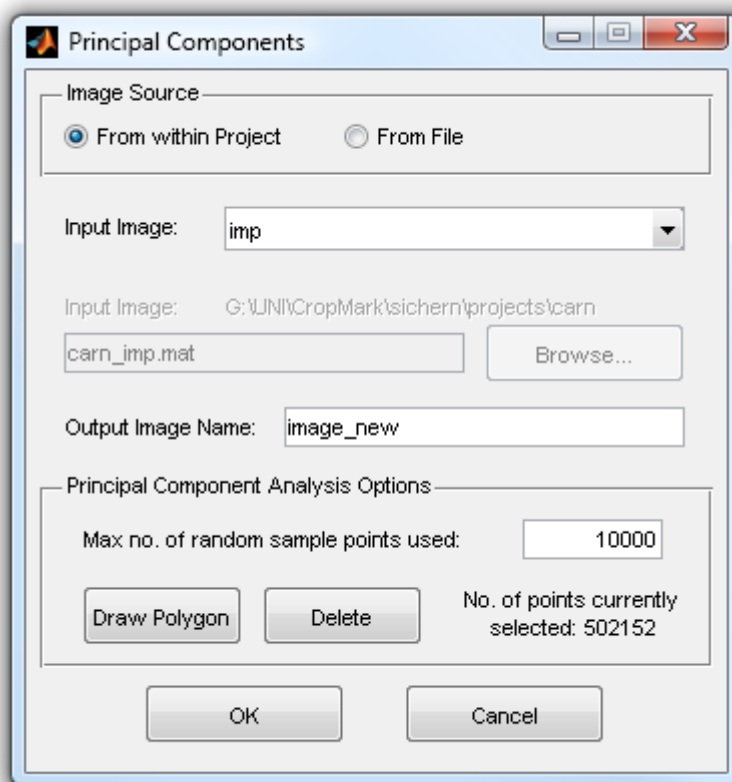
Principal Component Analysis (PCA)

The button **PCA** starts a function which is able to calculate the principal components of an input image. If you click the button, the following window is displayed:

The upper section of this window allows you to select your input image. By default, the current [active image](#) is selected (more about input image selection in ARCTIS [here](#)).

Below the file selection section, you have to specify your **Output Image Name**. The default name is "image_new"; if you choose a name which is already in use, a warning is issued.

Principal Component Analysis is an often effective method to reduce the amount of data by "compressing" the available information into an image with fewer layers and appeared for example in the work of Pearson ([Pearson, 1901](#)).



Due to memory reasons, ARCTIS offers the possibility to reduce the number of points that are used for calculation in two different ways:

1. You can define the **Maximum number of random sample points used** by changing the value in the text box (default setting: 10000 points). ARCTIS then uses a randomly distributed subsample of points for the generation of the transformation matrix. If you specify a sample size larger than your image, all points of the input image are used.
2. You can specify a polygon by clicking the **Draw polygon** button (more about polygon selection in ARCTIS [here](#)). If you do so, the **Number of currently selected points** changes to the size of your polygon. If your **Maximum number of random sample points used** (see above) is larger than your polygon size, all points of the polygon are used. If it is smaller, ARCTIS selects a random sample only out of the polygon points. If you are unsatisfied with your polygon selection, click **Delete**.

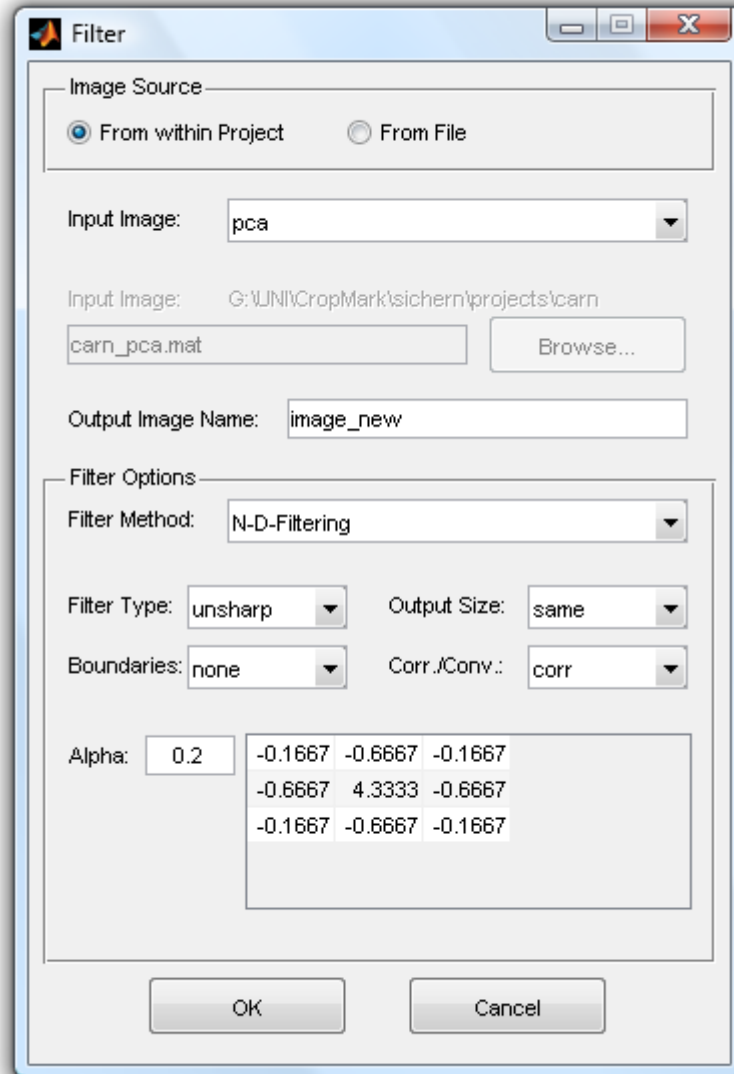
The polygon method is a good way to focus your principal component analysis on a certain area you are interested in. Of course, the transformation matrix is then applied to the whole image.

If you are satisfied with your selection, click **OK** to start the function. After the calculation has finished and the data was saved, ARCTIS shows an RGB image of the first three principal components (red: PC 1, green: PC 2, blue: PC 3). The percentage shown above gives an indication about how many “information” available in the original data cube is “explained” in each principal component.

ARCTIS also displays a second window, which shows a smaller view of the first four principal components (if available) in greyscale.

Filter/Edges

The button **Filter/Edges** starts a function which allows you to apply several filtering techniques or edge detection algorithms to your image. If you click the button, the following window is displayed:



The upper section of this window allows you to select your input image. By default, the current [active image](#) is selected (more about input image selection in ARCTIS [here](#)).

Below the file selection section, you have to specify your **Output Image Name**. The default name is "image_new"; if you choose a name which is already in use, a warning is issued.

ARCTIS offers three different **Filter Methods** with different parameters:

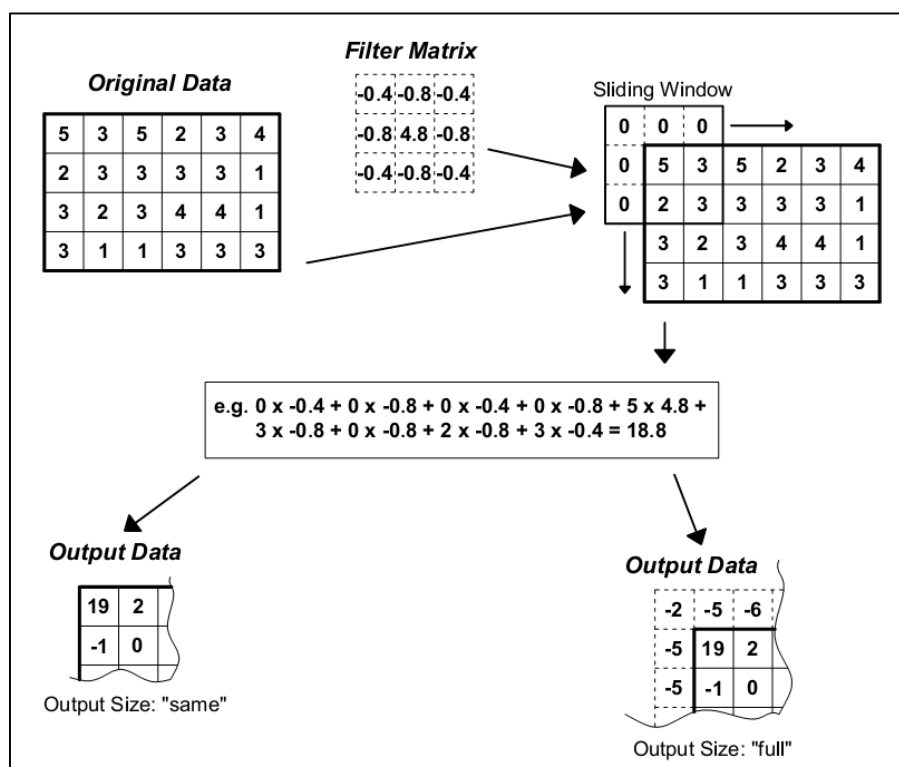
1. N-D-Filtering
2. 2-D-Adaptive noise removal filtering (Wiener Method)
3. Edge Detection

N-D-Filtering

All of the **Filter Types** found under the method N-D-Filtering are based on the MATLAB command [imfilter](#). The filtered image is calculated using a filter matrix, the so-called filter kernel. Depending on the values of the matrix, the filter may produce different results (e.g. sharpened or averaged image). You have several parameter options:

- **Filter Type:**
 - *unsharp*
 - *laplacian*
 - *log*
 - *prewitt*
 - *sobel*
 - *user-defined*
- **Output Size:** If you select *same* (default; recommended), your output image has the same size as the input image; the option *full* produces – depending on the kernel size – an image which is 2 or 4 pixel larger, as the values outside of the bounds of the input array are also kept and stored.
- **Boundaries:** This option only changes the result if you select Output Size fill, otherwise it has no effect. It changes the way ARCTIS pads the values out of bounds of the input array. By default, they are padded with zeros (*none*). *Symmetric* mirror-reflects the values across the image border, *replicate* assumes the values outside the bounds to equal the nearest value, and *circular* assumes periodic image values
- **Correlation/Convolution:** *Correlation* uses the filter kernel as it is, *convolution* rotates it by 180 degrees

The picture below explains the way the filter kernel is applied to the image; you can also see the difference between the output sizes:



The negative values occurring in this example are eliminated by [stretching](#) the resulting image layers to range from 0 to 255 (uint8) or 0 to 65535 (uint16).

Filter type “unsharp”

This filter type uses a 3-by-3-kernel for contrast enhancement. It creates the unsharp filter kernel from the negative of the Laplacian filter with parameter **alpha**. **Alpha** controls the shape of the Laplacian and must be in the range 0.0 to 1.0. The default value for alpha is 0.2. The kernel is calculated using

$$k = \frac{1}{(\alpha + 1)} * \begin{bmatrix} -\alpha & \alpha - 1 & -\alpha \\ \alpha - 1 & \alpha + 5 & \alpha - 1 \\ -\alpha & \alpha - 1 & -\alpha \end{bmatrix}$$

Filter type “Laplacian”

This filter type uses a 3-by-3-kernel approximating the shape of the two-dimensional Laplacian operator. The parameter **alpha** controls the shape of the Laplacian and must be in the range 0.0 to 1.0. The default value for alpha is 0.2. The kernel is calculated using

$$k = \frac{4}{(\alpha + 1)} * \begin{bmatrix} \frac{\alpha}{4} & \frac{1 - \alpha}{4} & \frac{\alpha}{4} \\ \frac{1 - \alpha}{4} & -1 & \alpha - 1 \\ \frac{\alpha}{4} & \frac{1 - \alpha}{4} & \frac{\alpha}{4} \end{bmatrix}$$

Filter type “Laplacian of Gaussian (log)”

This filter type uses a rotationally symmetric Laplacian of Gaussian kernel of size 3x3 or 5x5 with standard deviation **alpha** (must be positive). The kernel is calculated using

$$h_{g(x,y)} = e^{\frac{-(x^2+y^2)}{2\alpha^2}}$$

and

$$k_{x,y} = \frac{(x^2 + y^2 - 2\alpha^2) * h_{g(x,y)}}{2\pi\alpha^6 \sum_x \sum_y h_g}$$

Filter type “prewitt”

This filter type uses a 3-by-3 kernel that emphasizes **horizontal** or **vertical** edges by approximating a vertical gradient.

Filter type “sobel”

This filter type uses a 3-by-3 kernel that emphasizes **horizontal** or **vertical** edges using the smoothing effect by approximating a gradient.

Filter type “user-defined”

This filter type allows you to define your own 3-by-3 or 5-by-5 kernel which is then applied to the image.

2D-adaptive noise removal filtering (Wiener method)

This method lowpass-filters each layer image as if it has been degraded by constant power additive noise. It2 uses a pixelwise adaptive Wiener method based on statistics estimated from a local neighborhood of each pixel. You have to specify the **Size** of the neighborhood used to estimate the local image mean and standard deviation.

ARCTIS calculates the local mean and variance around each pixel:

$$\mu = \frac{1}{N^2} \sum_x \sum_y a_{x,y}$$

and

$$\sigma^2 = \frac{1}{N^2} \sum_x \sum_y a_{x,y}^2 - \mu^2$$

where N is the neighborhood size. It then creates a pixel-wise Wiener filter using these estimates,

$$b = \mu + \frac{\sigma^2 - v^2}{\sigma^2} (a_{x,y} - \mu)$$

where v² equals the average of all the local estimated variances.

Edge detection

This method allows you to apply several edge detection algorithms to your image. Edge detection algorithms try to locate edges in each layer of the input images. The resulting output image consists of as many layers as the input image and is in binary format where 0 = no edge found and 1 = edge found. If you check the **Generate Sum Image** option, an additional image is produced which represents the sum of all the edge layers. It is stored in the project folder and named [image name]_sum.

Several different edge detection methods are implemented in ARCTIS which require different parameters:

Method “sobel”

The **sobel** method uses the sobel operator to calculate the image gradient. If you set a **Threshold** value, all edges not stronger than this value are ignored. Otherwise, the threshold value is chosen automatically.

You can also set the **Direction** of the edges you want ARCTIS to look for (**horizontal**, **vertical** or **both**). Additionally, you can choose to skip an optional edge thinning stage (**nothinning**) or apply it (**thinning**).

Method “canny”

The **canny** method applies two thresholds to the gradient: a high threshold for low edge sensitivity and a low threshold for high edge sensitivity. It starts with the low sensitivity result and then grows it

to include connected edge pixels from the high sensitivity result. This helps fill in gaps in the detected edges (MATLAB Docs).

Sigma represents the standard deviation of the Gaussian filter. MATLAB chooses the size of the filter automatically based on the value of sigma.

Method “Laplacian of Gaussian”

This method uses the Laplacian of Gaussian approach for edge detection.

Sigma represents the standard deviation of the Laplacian of Gaussian filter. MATLAB chooses the size of the filter automatically based on the value of sigma.

Method “roberts”

The **roberts** method uses equations proposed by Lawrence Roberts ([Roberts, 1963](#)). If you set a **Threshold** value, all edges not stronger than this value are ignored. Otherwise, the threshold value is chosen automatically.

Additionally, you can choose to skip an optional edge thinning stage (**nothinning**) or apply it (**thinning**).

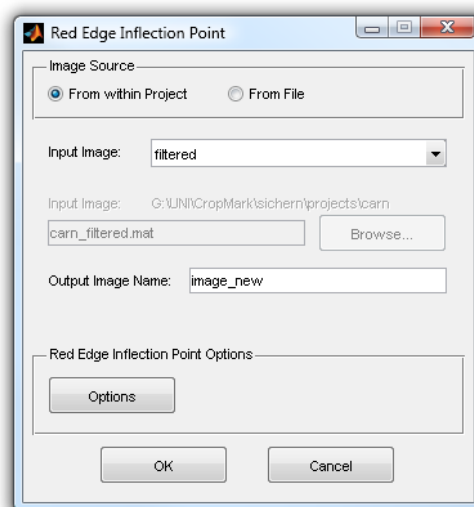
Method “zerocross”

This method uses a zero cross approach for edge detection. If you set a **Threshold** value, all edges not stronger than this value are ignored. Otherwise, the threshold value is chosen automatically.

Additionally, you can choose to skip an optional edge thinning stage (**nothinning**) or apply it (**thinning**).

Red Edge Inflection Point (REIP)

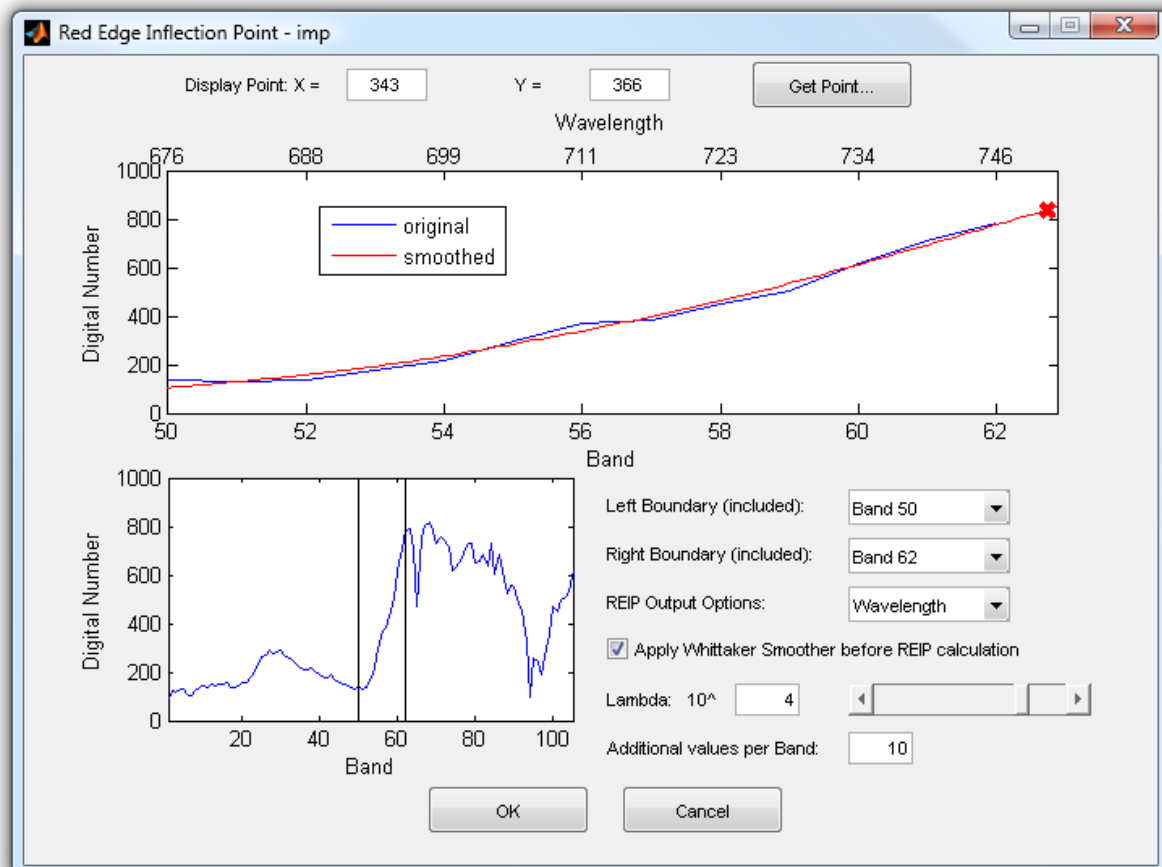
The button **REIP** starts a function which looks for the location of the highest gradient in the spectral profile curve in a given range (often the red edge, thus the name, but you can calculate the maximum gradient in every wavelength range you want – nevertheless, this point will be referred to as red edge inflection point below). If you click the button, the following window is displayed:



The upper section of this window allows you to select your input image. By default, the current [active image](#) is selected (more about input image selection in ARCTIS [here](#)).

Below the file selection section, you have to specify your **Output Image Name**. The default name is “image_new”; if you choose a name which is already in use, a warning is issued.

The button **Options** opens a new window:



In the upper section of this window, the spectral profile of the point selected above ranging from **Left Boundary** to **Right Boundary** is displayed in blue. The current location of the highest gradient is marked with an x. Per default, ARCTIS chooses the center point of the image, but you can change the point displayed using either the **Get Point...** button or enter the **X** and **Y** values directly (more on point selection in ARCTIS [here](#)).

Below, you see the complete profile including marks for the selected boundaries for your orientation.

If you imported [wavelength information](#), you can select whether you want ARCTIS to output the band number or the corresponding wavelength. The result may differ if each of your bands do not cover the same wavelength range, but please note that the smoother (see below) treats all bands as equally-spaced.

To get more accurate results, ARCTIS allows you to use the whittaker smoother not only to smooth the data, but also to interpolate any number of fictional “bands” between your data values. If you want to do this, check the **Apply Whittaker Smoother before REIP calculation** checkbox. ARCTIS will then calculate smoothed values (see [here](#)) using the smoothing parameter **Lambda** and add the

number of bands specified in ***Additional values per band***. Please note that you may have to adjust the smoothing parameter each time you change the number of additional values per band.

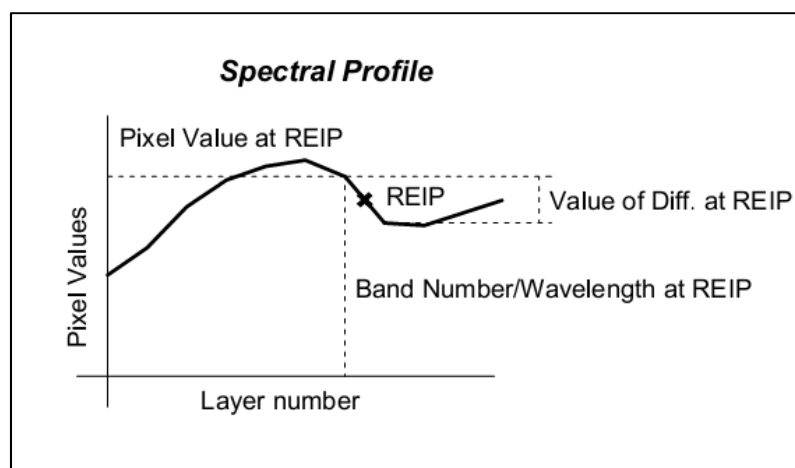
After you click **OK**, ARCTIS calculates the REIP values pixel-wise and outputs an image with three layers which represent:

Layer 1: Band or wavelength of REIP location

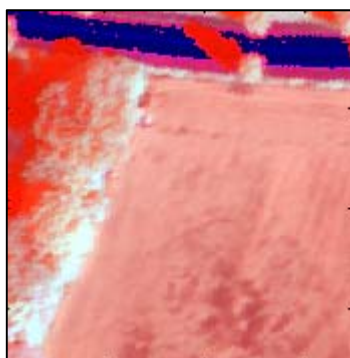
Layer 2: Value of difference between value at REIP location and the next value

Layer 3: Pixel Value at REIP

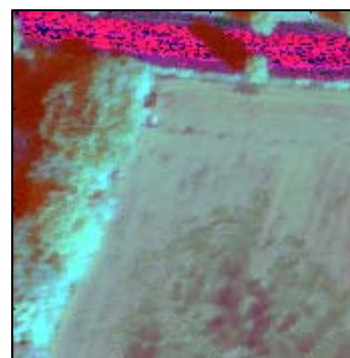
As the spectral profile is a continuous curve but represented by discrete band values here, ARCTIS calculates the differences between the one pixel value and the next value along the spectral profile. The maximum difference is considered to be the REIP. It will lie “between” two bands, but in order to output the result, ARCTIS takes the next lower band number and treats it as REIP:



Even if you calculate the REIP for the same input image using the same parameters, the result may differ a lot if you choose to or not to use the smoother:



REIP output with smoothing
(stretched 1% to 99%)



REIP output without smoothing
(stretched 1% to 99%)

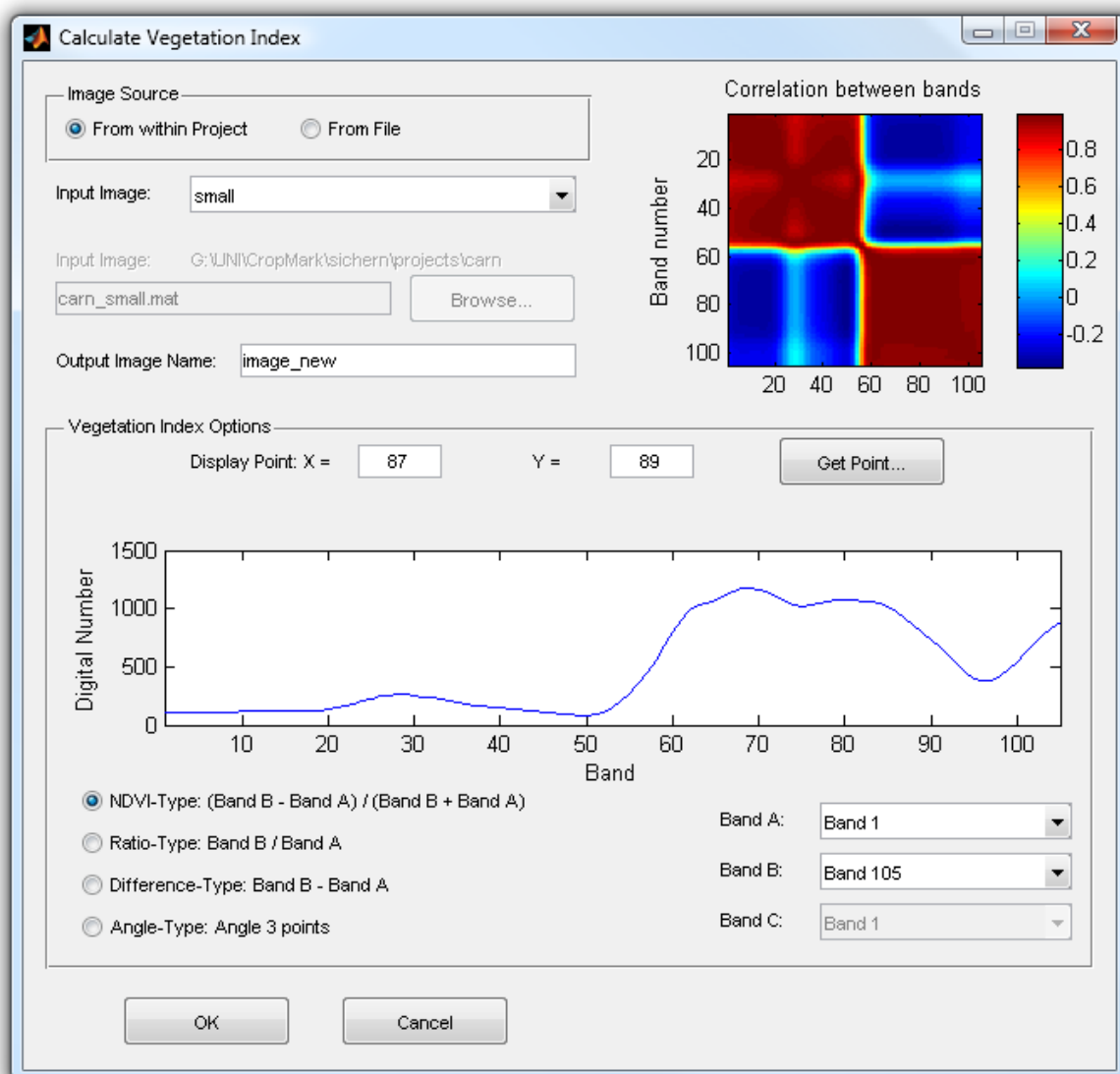
Without smoothing, the biggest difference often occurs at the beginning or end of the selected range (especially if you have mixed land cover types in your image, like vegetation and a road in the

example above), so the REIP is found at the lowest or highest band number. With smoothing (and interpolation), the profile at the edges of the selected range may look very different and the REIP is found somewhere else.

ARCTIS looks for the maximum difference regardless of the difference being positive or negative, but for the result in layer 2 (value of difference) the sign is taken into consideration.

Vegetation Indices

The button **Vegetation Indices** starts a function which allows you to calculate various forms of vegetation indices. If you click the button, the following window is displayed:



The upper section of this window allows you to select your input image. By default, the current [active image](#) is selected (more about input image selection in ARCTIS [here](#)).

Below the file selection section, you have to specify your **Output Image Name**. The default name is "image_new"; if you choose a name which is already in use, a warning is issued.

On the upper right corner of the window, ARCTIS displays the correlation matrix between the bands of your image. It is designed to help you decide which bands you use for calculating a vegetation index; if you use two highly-correlated bands, the results may not be useful.

Below, the spectral profile of the point selected above is displayed in blue. Per default, ARCTIS chooses the center point of the image, but you can change the point displayed using either the **Get Point...** button or enter the **X** and **Y** values directly (more on point selection in ARCTIS [here](#)).

Below, you can select which bands you want to use as **Band A**, **B** and **C** for your vegetation index calculation and which of these for index types you want to calculate:

NDVI-Type

For NDVI-type (Normalized Difference Vegetation Index) vegetation indices, the output value for each pixel is calculated using the formula

$$out_{ij} = \frac{(b_{ij} - a_{ij})}{(b_{ij} + a_{ij})}$$

where

out_{ij} = output pixel values
 a_{ij} = Band A Pixel values
 b_{ij} = Band B pixel values.

Ratio-type

For ratio-type vegetation indices, the output value for each pixel is calculated using the formula

$$out_{ij} = \frac{b_{ij}}{a_{ij}}$$

where

out_{ij} = output pixel values
 a_{ij} = Band A Pixel values
 b_{ij} = Band B pixel values.

Difference-type

For difference-type vegetation indices, the output value for each pixel is calculated using the formula

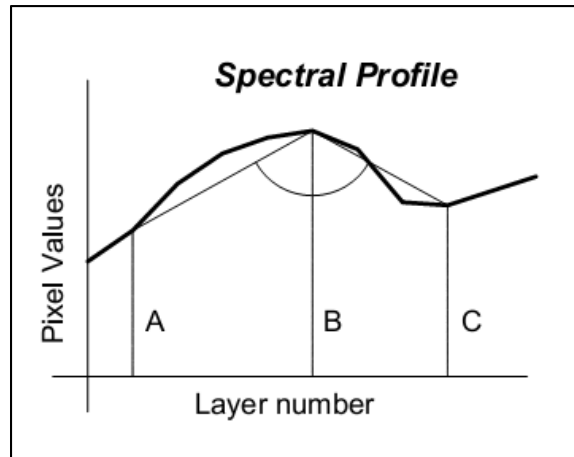
$$out_{ij} = b_{ij} - a_{ij}$$

where

out_{ij} = output pixel values
 a_{ij} = Band A Pixel values
 b_{ij} = Band B pixel values.

Angle-type

For angle-type vegetation indices, ARCTIS calculates the angle of two vectors which are spanned by the pixel values of the three Bands A, B and C. The order in which the Bands are selected (A can be the lowest, highest or in the middle) makes no difference, as ARCTIS always calculates the angle at the middle band:

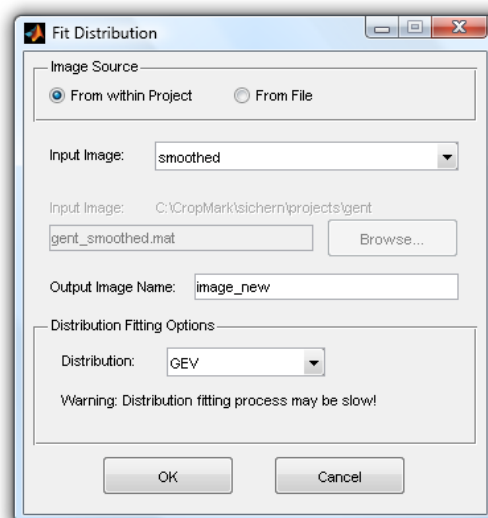


As indicated in the image above, the angle is always calculated below the profile and can range from 0 to 360°.

After clicking **OK**, the selected index tape is calculated. After calculation, the image is stretched to cover the full range and then displayed using the current contrast enhancement settings.

Distribution Fitting

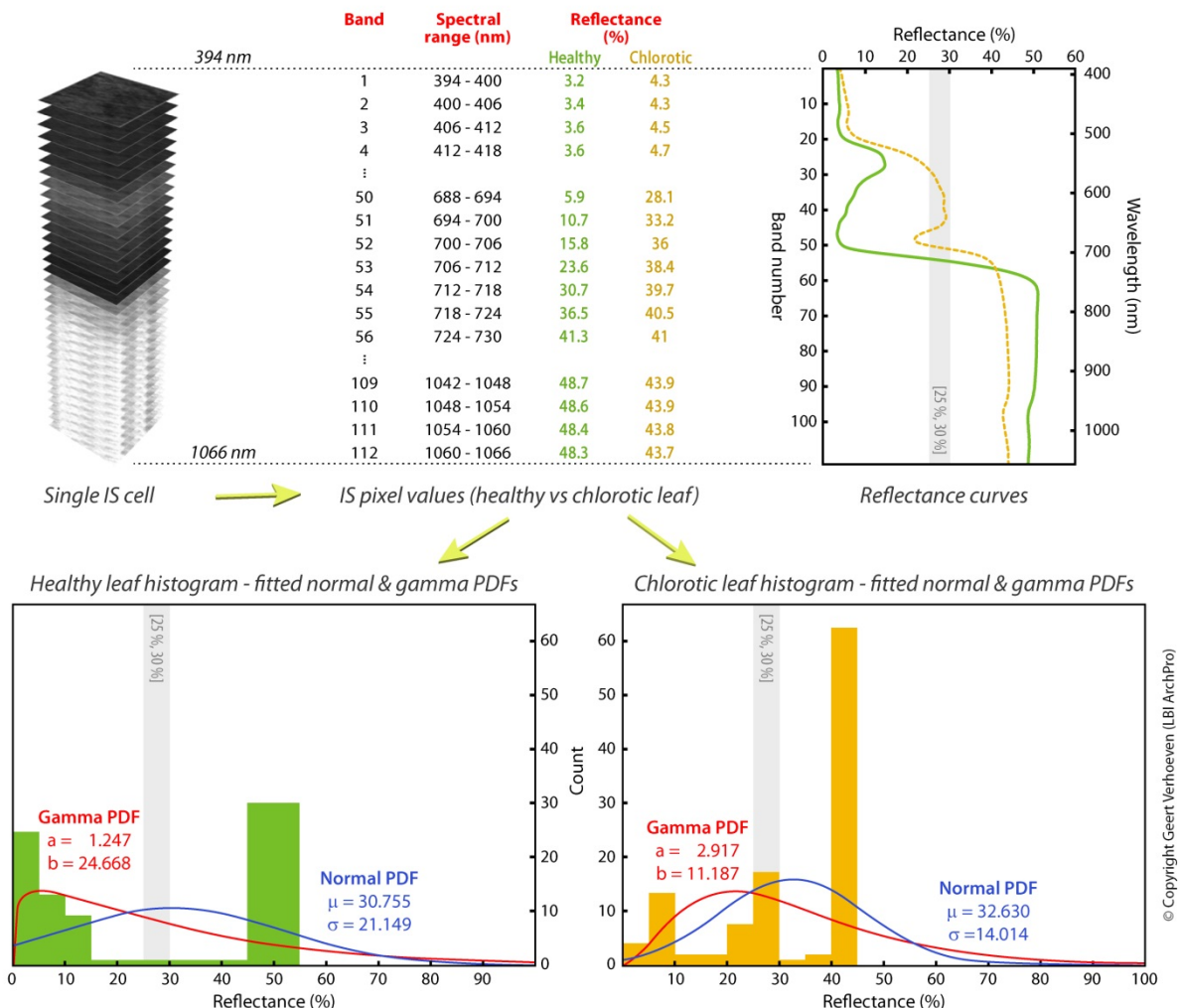
The button Distribution starts a new function which tries to fit a given distribution to the histogram of the spectral profile of each pixel and outputs the calculated parameters of the selected distribution. If you click this button, a new window is displayed:



The upper section of this window allows you to select your input image. By default, the current active image is selected (more about input image selection in ARCTIS here).

Below the file selection section, you have to specify your **Output Image Name**. The default name is “image_new”; if you choose a name which is already in use, a warning is issued.

Below, you can select which **Distribution** you want to fit to your data. After clicking **OK**, ARCTIS processes the data in the following way:



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The image above explains the way the distribution fitting works: ARCTIS takes the spectral profile from every pixel and creates the histogram for it. Then it tries to fit a distribution to it.

Depending on the distribution selected, the output image may have one to three layers, each representing one of the parameters.

Generalized Extreme Value (GEV)

This option uses the MATLAB function [gevfit](#), which tries to fit the generalized extreme value distribution to the data. It results in a three-layer-output image, where the first layer represents the shape parameter **k**, the second the scale parameter **sigma** and the third the location parameter **mu**.

For further information about the implementation of the GEV-distribution in MATLAB, please refer to the link above.

Weibull

This option uses the MATLAB function [wblfit](#), which tries to fit the Weibull distribution to the data. It results in a two-layer-output image, where the first layer represents the Weibull parameter α , the second the parameter b .

For further information about the implementation of the Weibull distribution in MATLAB, please refer to the link above.

Poisson

This option uses the MATLAB function [poissfit](#), which tries to fit the Poisson distribution to the data. It results in a one-layer-output image which represents the Poisson parameter λ .

For further information about the implementation of the Poisson distribution in MATLAB, please refer to the link above.

Normal

This option uses the MATLAB function [normfit](#), which tries to fit the normal distribution to the data. It results in a four-layer-output image, where the first layer represents the **mean value μ** , the second the **standard deviation σ** and the third and the fourth the lower and upper bound of the **confidence interval** for μ .

For further information about the implementation of the normal distribution in MATLAB, please refer to the link above.

Log-Normal

This option uses the MATLAB function [lognfit](#), which tries to fit the lognormal distribution to the data. It results in a two-layer-output image, where the first layer represents the **mean value μ** , the second the **standard deviation σ** .

For further information about the implementation of the lognormal distribution in MATLAB, please refer to the link above.

Beta

This option uses the MATLAB function [betafit](#), which tries to fit the beta distribution to the data. It results in a two-layer-output image, where the first layer represents the parameter α , the second the parameter b .

For further information about the implementation of the beta distribution in MATLAB, please refer to the link above.

Gamma

This option uses the MATLAB function [gamfit](#), which tries to fit the gamma distribution to the data. It results in a two-layer-output image, where the first layer represents the parameter α , the second the parameter b .

For further information about the implementation of the gamma distribution in MATLAB, please refer to the link above.

There is no indication of how well the selected distribution fits to the given input data, and ARCTIS will always return a result, even if the fitted distribution does not fit at all to the input histogram. So this function is to be seen as an attempt to look at the data in a new and different way, not to find possible common distributions in the data.

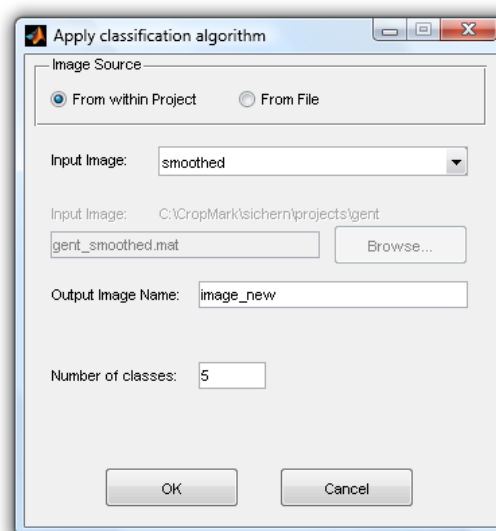
Please also note that for some distributions, the fitting process uses an iterative algorithm which – as it needs to be applied pixel-wise – can be very time-consuming.

After the calculation of the parameters, each layer is stretched to cover the full possible range and the result is displayed in a new window.

Classification

The button Classification starts a function which allows you to use a simple classification algorithm to segment your data in any number of classes: the [kmeans](#) clustering algorithm. It uses the MATLAB function with the same name and allows you to create a new image.

It opens the following window:



The upper section of this window allows you to select your input image. By default, the current [active image](#) is selected (more about input image selection in ARCTIS [here](#)).

Below the file selection section, you have to specify your **Output Image Name**. The default name is “image_new”; if you choose a name which is already in use, a warning is issued.

Below, you have to select the **Number of classes** you want to put your data in. Selecting a very high number can lead to an error in MATLAB as empty classes are not possible.

After you click **OK**, ARCTIS creates a new image consisting of one layer which represents the result of the kmeans classification.

For more information about the mathematical procedures behind the kmeans clustering algorithm, please refer to the MATLAB documentation and its references.

Function Reference: Viewing Images

Active Image, Display Method and Band Selection

In the uppermost part of the **View** section, the popup menu for selecting the [active image](#) is displayed. Below, ARCTIS displays another popup menu labeled **Display Method**. There you can switch between two options: RGB view and single band view.

Depending on the display method you choose, ARCTIS displays either three popup menus for selecting bands for the red, green and blue channel (RGB view) or one popup menu for selecting a band to display and a second one for choosing your desired [colormap](#).

The View Button

This button displays the [active image](#) using the current contrast enhancement settings. Each click on this button results in a new window, regardless of the number of the currently open windows – you can have as many as you want.

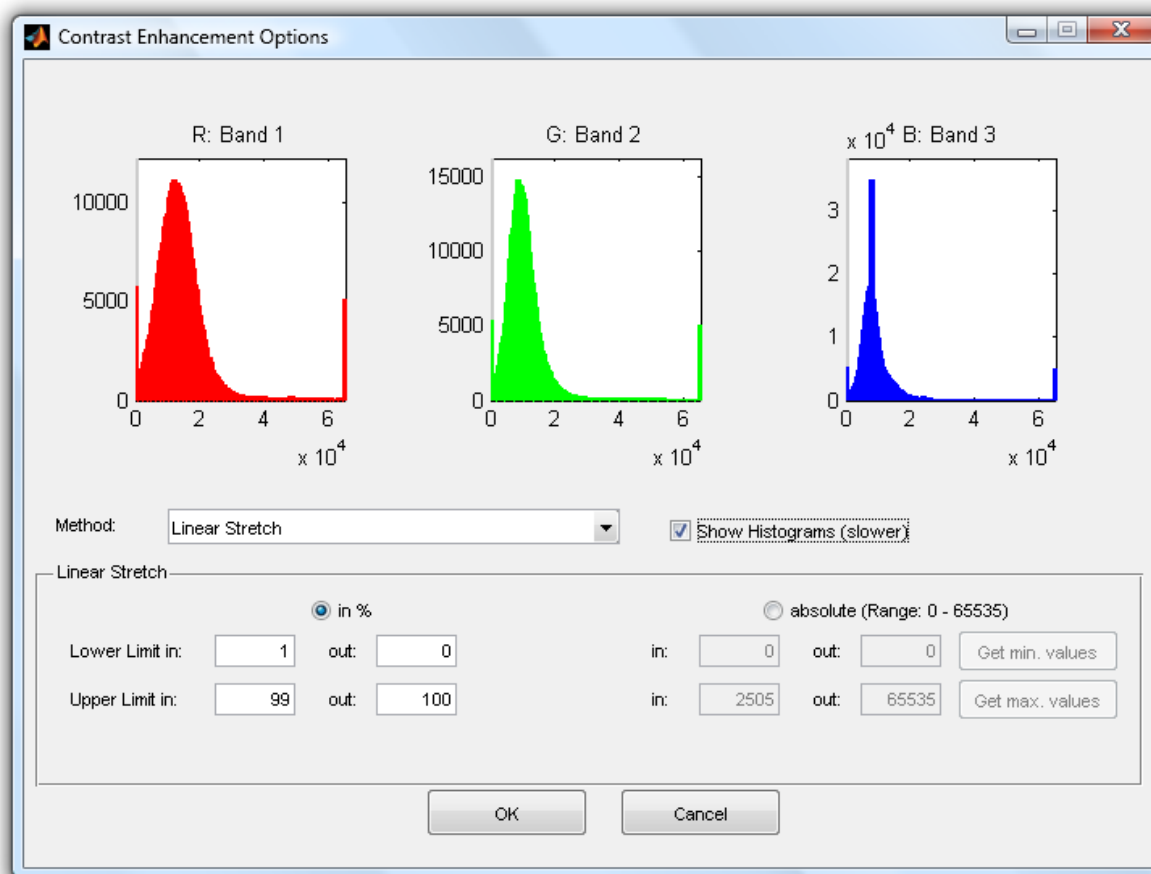
Contrast Options

The values of images in ARCTIS might range – depending on the format – from 0 to 255 (uint8) or from 0 to 65535 (uint16). Depending on your data source, type and preprocessing steps, your image data might vary in a much smaller range, so if ARCTIS would display the data as if the values mentioned above were the highest and lowest, you are likely to not see anything. This being the case, ARCTIS offers various possibilities to enhance the contrast of your image and to “stretch” the data to cover a wider range.

By default, ARCTIS enables contrast stretching; if you want to display the original data, just disable the **Enhance Contrast** checkbox.

The difference to the [contrast functions](#) from the preprocessing section mentioned above is that ARCTIS does not really alter the data, it just changes the way the data is displayed.

ARCTIS offers several contrast enhancing methods/algorithms; you can select them using the **Options** button:



ARCTIS displays a contrast option window similar to the one from the preprocessing steps above: You can decide if you want ARCTIS to display histograms using the **Show histogram** checkbox. If you do so, a histogram of the layer(s; depending on the display method – RGB or single band) before (grey) and after (colored) applying the contrast function using the current parameters is displayed. In the screenshot above, a 16 bit image is shown which ranges originally from 0 to about 2500. After the **Linear Stretch** function with lower limit in = 1%, upper limit in = 99%, lower limit out = 0% and upper limit out = 100% is applied, the image covers the whole range.

Your next step is to select the **Method** you want to use for your contrast change. You have several options available:

- [Linear Stretch](#)
- [Non-Linear Stretch \(Gamma Correction\)](#)
- [Decorrelation Stretch](#)
- [Histogram Equalization](#)
- [Contrast-limited adaptive Histogram Equalization](#)

Each of these methods works differently and needs different input parameters.

Linear Stretch

As the name implies, this method changes the image values using a linear equation. You have to define four parameters: Lower and upper limits for input and output. There are two ways how these parameters are determined:

3. in %:

You can define the input and output limits as a fractile in percent. Note that while output limits stay the same for each layer and are only determined by the data type (see [here](#); if you set the output limit to 50% and are using 16 bit images which range from 0 to 65535, ARCTIS calculates 50% = 32768), the input limits vary from layer to layer as they are determined by the layer histogram.

The advantage of the percentage input is that you obtain an image which uses the same value range in each layer. But, of course, dependencies between the layers are removed, especially if the value range of the input layers varies widely. So if you want to keep the correct relationship between the layers, it is recommended to use the second way of determining input and output limits:

4. **absolute values:**

You also can define the input and output limit values directly using the **absolute** method. This method applies the same formula to all layers, so the relationship between the layers is kept.

You have the possibility to automatically obtain the **minimum** and **maximum values** of your whole image (not layer!) by clicking the correspondent buttons. If you use these values, the resulting image covers the whole range (depending on the [data type](#)); if your image has 16 bit, the lowest value of all layers will be 0 and the highest 65535.

ARCTIS now calculates the output values applying the linear equation

$$out_{ij} = l_{out} + (u_{out} - l_{out}) * \left(\frac{in_{ij} - l_{in}}{u_{in} - l_{in}} \right)$$

to each pixel where

in_{ij}	= input pixel values
out_{ij}	= output pixel values
l_{in}	= lower limit in for the current layer
u_{in}	= upper limit in for the current layer
l_{out}	= lower limit out for the current layer
u_{out}	= upper limit out for the current layer.

Non-Linear Stretch (Gamma Correction)

This method is similar to the [linear stretch](#) method, the only difference is an additional fifth parameter, called **Gamma**. The other four parameters (lower and upper limits for input and output) are the same and are entered in the same way as written above. The above mentioned equation changes to the non-linear equation

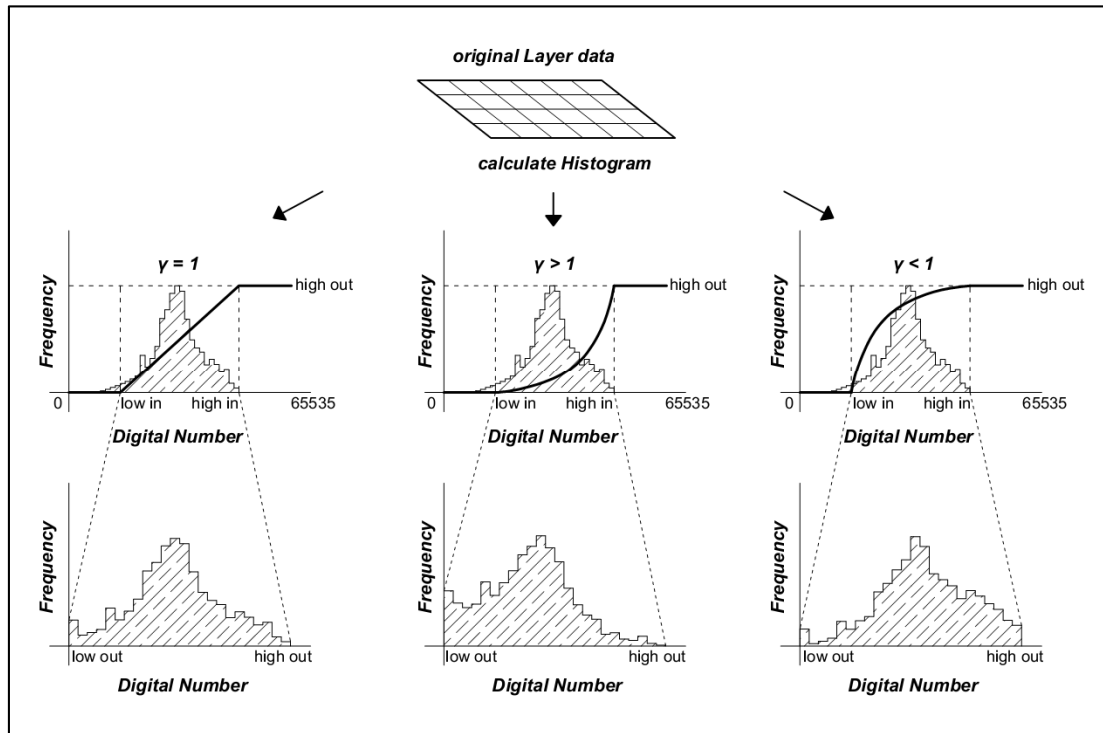
$$out_{ij} = l_{out} + (u_{out} - l_{out}) * \left(\frac{in_{ij} - l_{in}}{u_{in} - l_{in}} \right)^\gamma$$

where

in_{ij}	= input values
out_{ij}	= output values
γ	= Gamma
l_{in}	= lower limit in
u_{in}	= upper limit in

l_{out} = lower limit out
 u_{out} = upper limit out.

The chart below shows the way non-linear contrast adjustment works:



As you can see, if you specify $\gamma > 1$, pixel values are more likely assigned to lower values, which results in a darker image. If your $\gamma < 1$, you will get a brighter image.

Decorrelation Stretch

The decorrelation stretch method uses the [decorstretch](#) function of MATLAB which tries to minimize the correlation between the layers using a covariance matrix. Decorrelation stretch is normally applied to RGB images, but it works on an arbitrary number of bands.

Note that this method is NOT applied layer per layer but to all layers at once, so the histogram preview of one layer might not be correctly calculated.

Histogram Equalization

This method uses the [histeq](#) function of MATLAB which tries to enhance the contrast of the image in such a way that the resulting image has a defined **Number of discrete Levels** (=values). ARCTIS tries to map a roughly even number of pixels to each level so that the resulting histogram is approximately flat.

This function works best when the number of levels is small in comparison to the number of different values in the input image. It may have problems if your input image only covers a small range, so it is not recommended to use this method as a first try to get information out of a newly imported image.

Contrast-limited adaptive Histogram Equalization (CLAHE)

This method uses the [adapthisteq](#) function of MATLAB. This function operates on small regions called tiles, which sizes are determined through the **Number of Tiles (Row x Column)** you define. The

contrast of each tile is enhanced in a way that it fits the specified **Distribution**: *uniform* results in a flat histogram, *rayleigh* in a Bell-shaped curve and *exponential* in a curved histogram. The neighboring tiles are then combined using bilinear interpolation to eliminate artificially induced boundaries.

Other parameters you can define are

- **Clip Limit**: This number specifies a limit for contrast enhancement. It ranges from 0 to 1; higher numbers result in more contrast.
- **Number of Bins**: This value specifies the number of bins used during histogram calculation. Higher values result in greater dynamic range but in slower processing speed.
- **Range**: You can specify if your output image should cover the *full* possible range (0...65535 if you are working on a 16 bit image) or if ARCTIS should keep the range of the *original* image.
- **Alpha** (only used when **Distribution** is set to *rayleigh* or *exponential*): Distribution parameter

If you have entered your contrast enhancement settings, save them by clicking **OK**. Pressing **OK** again on the **Apply Contrast Functions to Image** window starts the process. If the calculation is finished, ARCTIS displays your newly created image using the [best triple algorithm](#).

True Color, False Color IR

These functions preselect certain band combinations depending on the wavelengths of each band. They are only available if wavelength information is available to ARCTIS - see [here](#).

ARCTIS looks for the wavelengths closest to the values

- Blue: 470 nanometers
- Green: 540 nanometers
- Red: 650 nanometers
- NIR: 800 nanometers

and then selects the bands found in the band selection popup menus. Be careful: even if the wavelengths of your data are far away from the values above, ARCTIS will always find suitable bands as it just takes the bands with wavelengths nearest to those values.

Save As

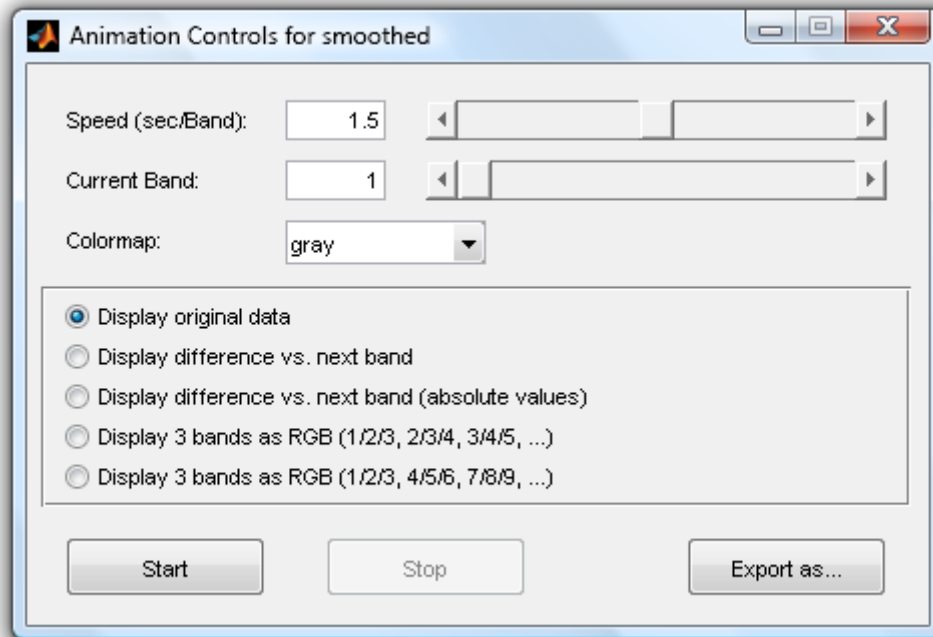
This button allows you to export your [active image](#) as it would display in ARCTIS using the current contrast enhancement settings. It makes no difference if you already clicked the **View!** button to display it; ARCTIS just calculates how the image would look like and allows you to save it as a JPG or JPG2000 file.

Please note that ARCTIS saves only the currently selected bands, so it differs from the [export](#) function above.

Function Reference: Other Tools

Animation

This tool allows you to display and export animated images of your dataset. If you click the button, ARCTIS shows the [active image](#) in a new window and also displays the animation control window:



In this window, you can change the **Speed** of the animation using either the slider or enter the desired value directly. In ARCTIS, you specify the animation speed in seconds per band, so the value defines how long a single band/band combination is displayed.

You are also able to jump to any band you want using either the **Current Band** slider or you can enter the desired band number directly. Also you can change the **Colormap** you want to use when displaying an image.

Below, you can select the way ARCTIS displays the animation. There are several possibilities:

Original Data

If you select this option, ARCTIS displays each band as it is. Nevertheless, if the [Enhance Contrast](#) checkbox is checked, ARCTIS applies the currently selected contrast enhancement algorithm with the current parameters to the each band before displaying it.

Difference vs. Next Band

If you select this option, ARCTIS calculates the difference between the current and the next band and displays the result using the selected colormap. If the [Enhance Contrast](#) checkbox is checked, ARCTIS applies the currently selected contrast enhancement algorithm with the current parameters to the each band before displaying it.

When ARCTIS reaches the last layer, it continues with the first one again. This may result in unexpected results, as one “animation slide” is the calculated difference between the first and the last layer.

Difference vs. Next Band (absolute values)

If you select this option, ARCTIS calculates the difference between the current and the next band, convert the values to absolute values and displays the result using the selected colormap. This option differs from the one above in the way that ARCTIS does not distinguish positive or negative differences; just the absolute values of the differences are displayed. If the [Enhance Contrast](#) checkbox is checked, ARCTIS applies the currently selected contrast enhancement algorithm with the current parameters to the each band before displaying it.

When ARCTIS reaches the last layer, it continues with the first one again. This may result in unexpected results, as one “animation slide” is the calculated difference between the first and the last layer.

3 Bands as RGB (1/2/3, 2/3/4, 3/4/5)

If you select this option, ARCTIS displays three bands as an RGB image before. The first image of your animation consists of band 1 shown in the red, 2 in the green and 3 in the blue channel. The second image shows band 2 in the red, 3 in the green and 4 in the blue channel and so on. The resulting image has as many layers as the original one, as each layer is used three times.

If the [Enhance Contrast](#) checkbox is checked, ARCTIS applies the currently selected contrast enhancement algorithm with the current parameters to the each band before displaying it.

When ARCTIS reaches the last layer, it continues with the first one again.

3 Bands as RGB (1/2/3, 3/4/5, 6/7/8)

If you select this option, ARCTIS displays three bands as an RGB image before. The first image of your animation consists of band 1 shown in the red, 2 in the green and 3 in the blue channel. The second image shows band 4 in the red, 5 in the green and 6 in the blue channel and so on. The resulting image only one third of the layers as the original one, as each layer is only used once.

If the [Enhance Contrast](#) checkbox is checked, ARCTIS applies the currently selected contrast enhancement algorithm with the current parameters to the each band before displaying it.

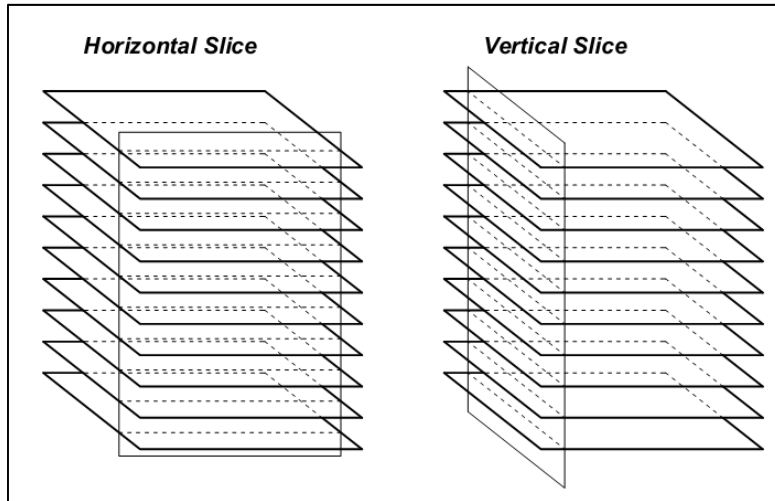
When ARCTIS reaches the last layer, it continues with the first one again.

Below, there are buttons to **Start** and **Stop** your animation; while it is running, the **Current Band** slider is disabled.

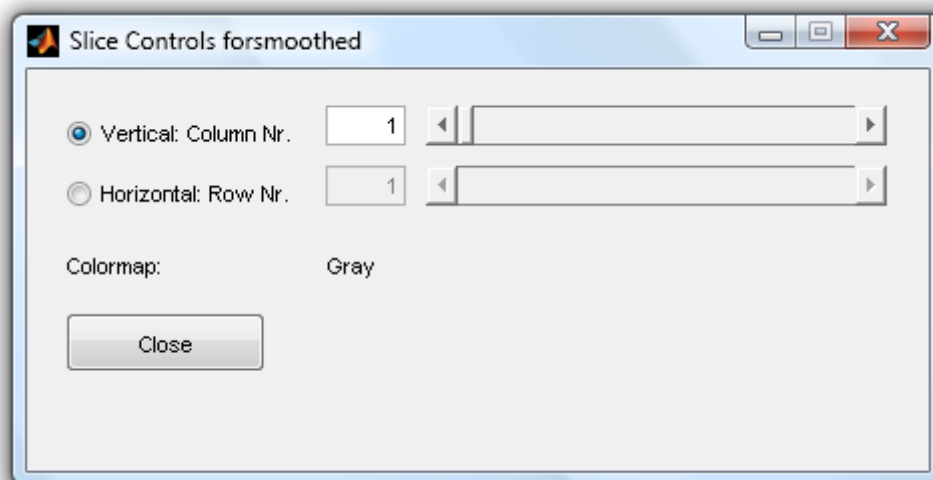
There is also the possibility to **Export** your current animation as an animated GIF image, AVI movie file or Motion JPEG movie. Please note that MATLAB does not support the creation of 16bit-GIF or AVI files. If you try to export a 16bit image to AVI or GIF, a warning is issued and the animation is converted to 8bit.

Slice

This function allows the user to display “slices” of the data cube. The graph below shows the principle:



ARCTIS displays one row or column (depending on if you select horizontal or vertical slices) of each layer at the selected location. For selecting the location, ARCTIS displays the **Slice Controls** window:



There you can switch **between** Vertical and **Horizontal** slices and select the number of the column or row you want to display (starting from the upper left corner).

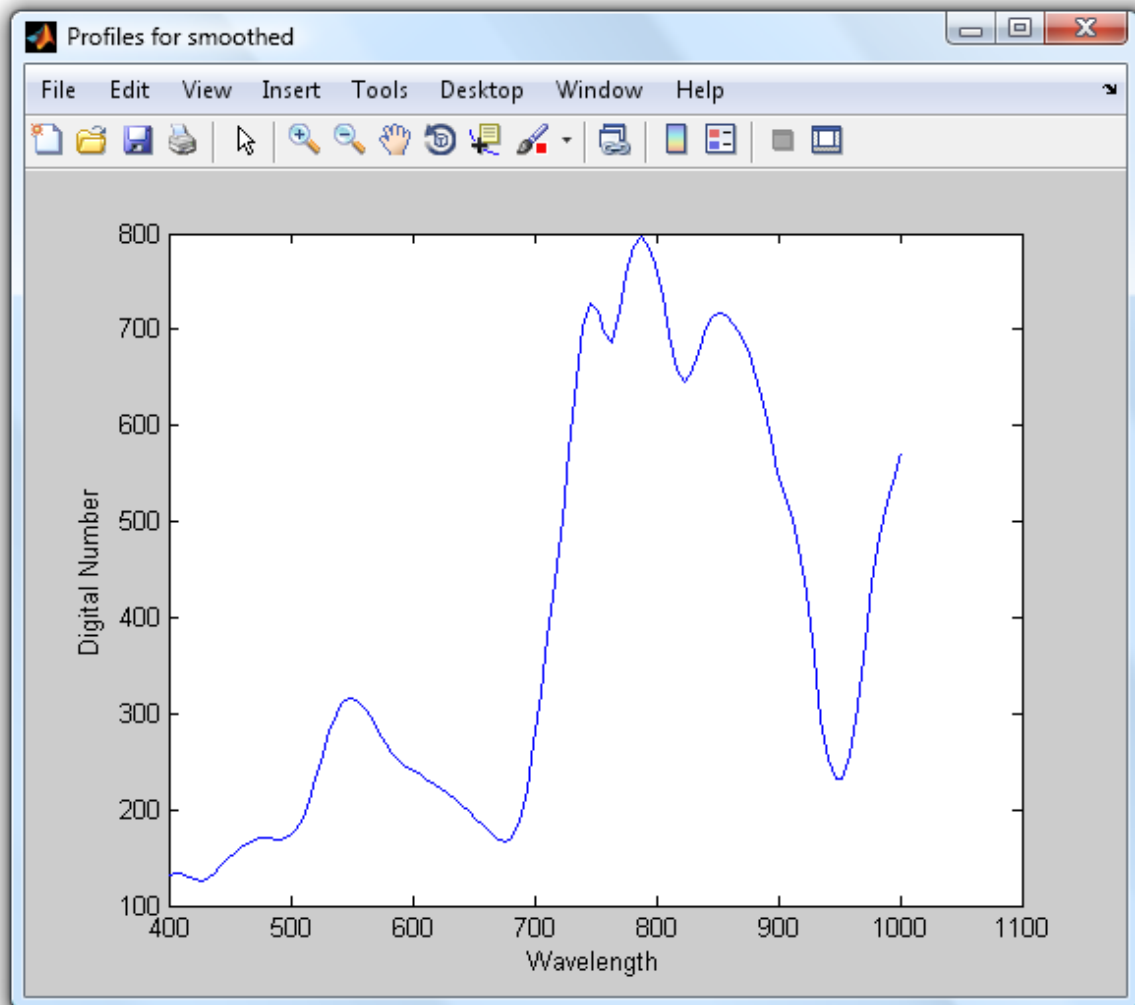
If the Enhance Contrast checkbox is checked, ARCTIS applies the currently selected contrast enhancement algorithm with the current parameters to the slice before displaying it.

Spectral Profile

This function allows you to display one or more spectral profiles at any location you want. If you click on the **Spectral Profile** button, ARCTIS looks for open windows which display images. If none are

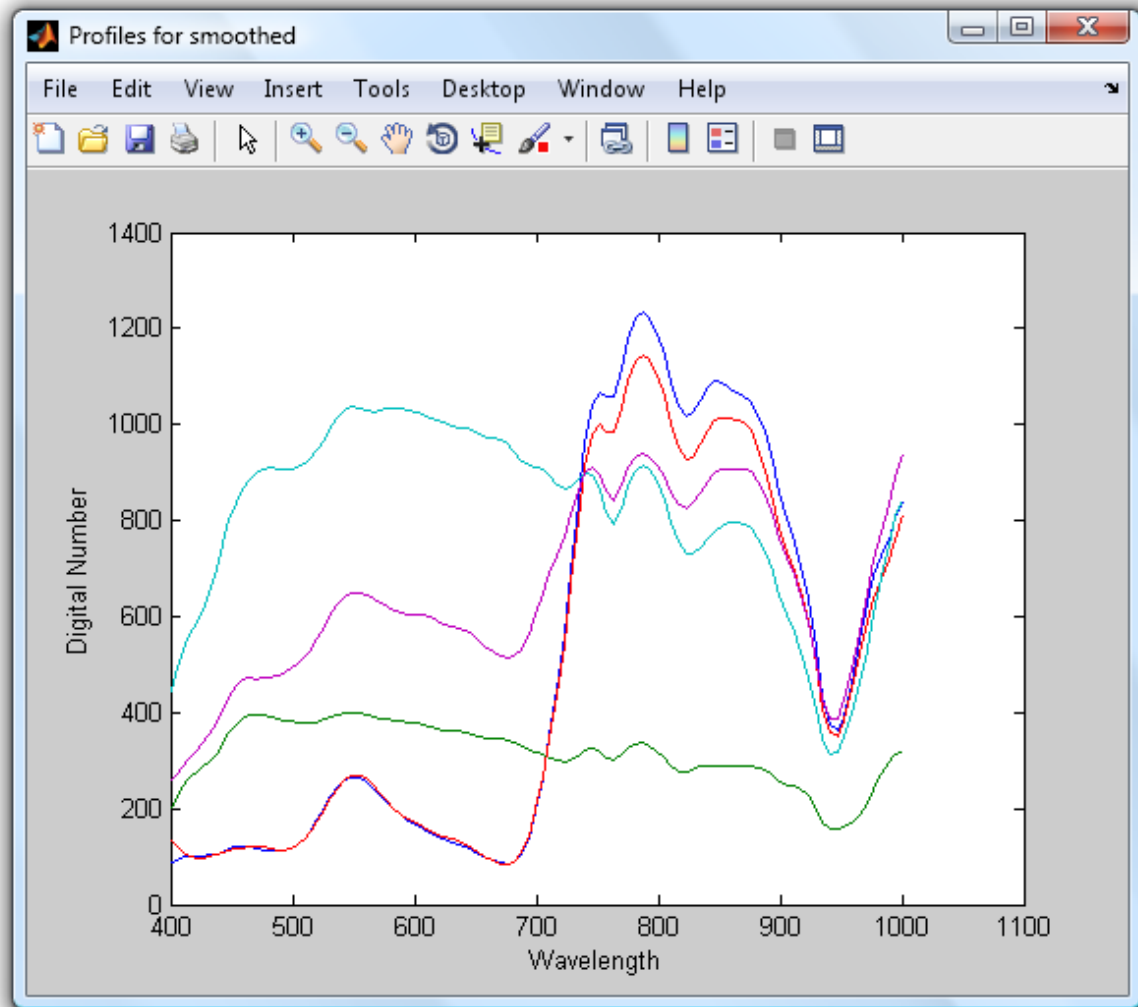
found, an error message is displayed. Otherwise, ARCTIS waits for you to select one of the images by clicking on it. If you did so, the cursor changes to a crosshair as ARCTIS wants you to select your desired profile location. You do this by clicking on it again.

After that, ARCTIS displays the spectral profile of the selected point in a new window:



As the original data is displayed, the **Enhance Contrast** checkbox has no effect on this function.

If you want to, you can select other points of the same image by clicking the **Spectral Profile** button again. If you select more than one points in the same image, ARCTIS displays all the profiles in the same window; if you select a different image, a new profile window is opened:

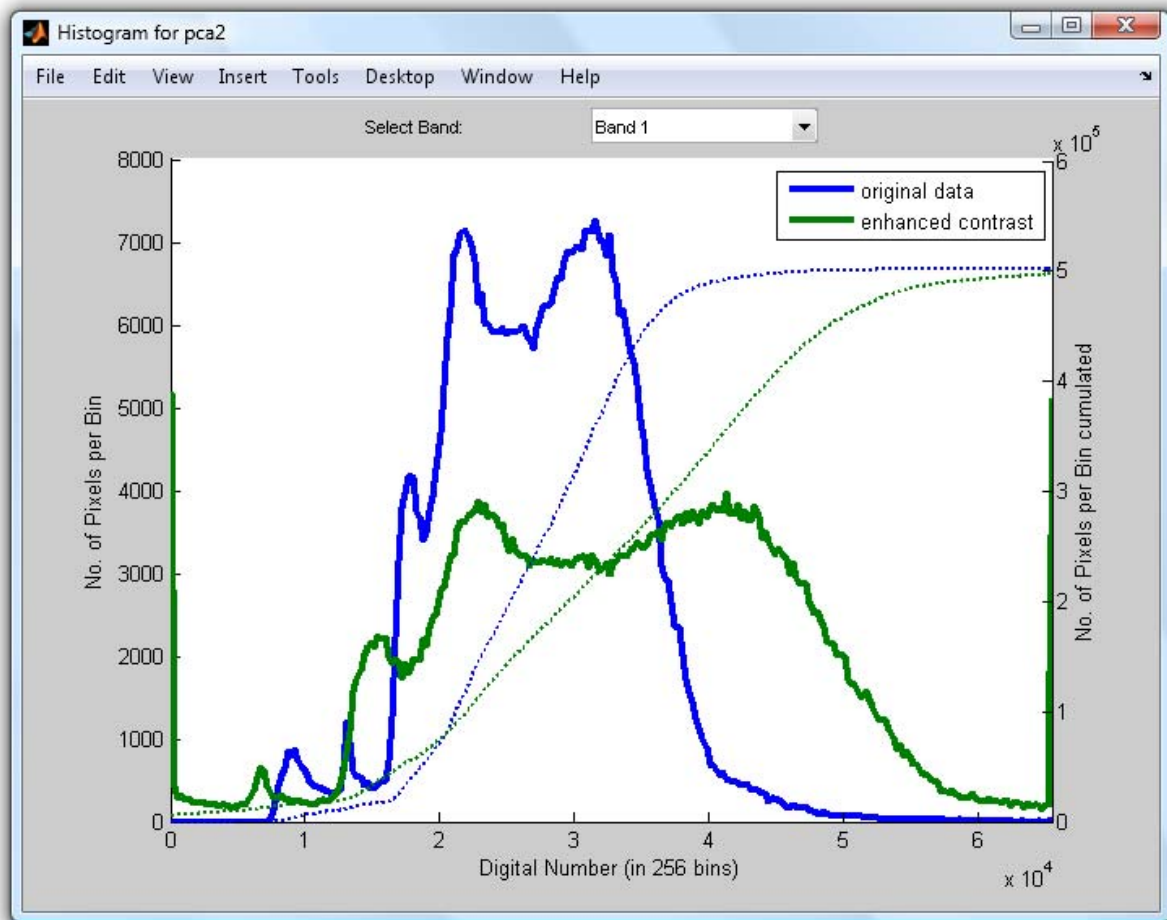


In the case of more than one profile of one image, the point markers displayed on the original image match the color of the profile lines.

If you included [wavelength information](#), ARCTIS plots the wavelength on the x-axis, otherwise the band number is used.

Show Histogram

This button calculates the histogram of every layer of your [active image](#) and displays it in a new window. If the [Enhance Contrast](#) checkbox is enabled, ARCTIS shows the histogram of the original data in blue, the one of the enhanced image in green. The dotted line represents the cumulated histogram:

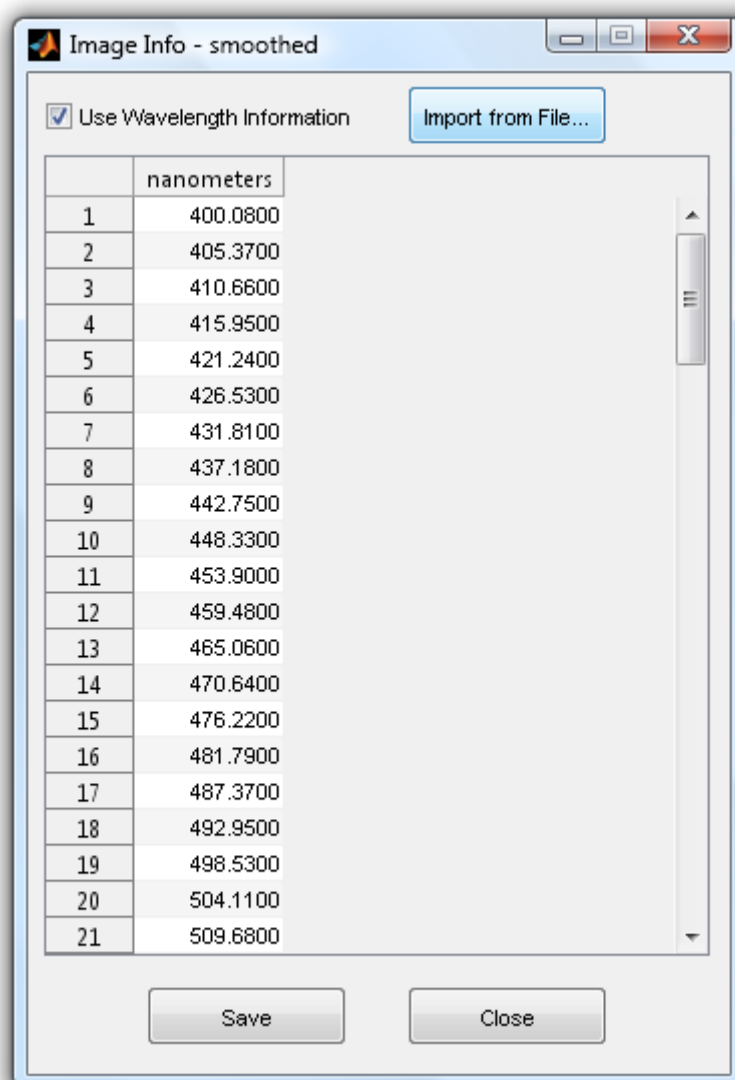


Using the popup menu above, you can select the layer you want to display. By default, ARCTIS starts to display the first layer.

ARCTIS uses the MATLAB function [imhist](#) for the histogram calculation; it does not generate the number of each pixel value but separates the whole range into a certain number of pins (depending on the image format) and shows the number of pixels per bin.

Image info

The button **Image Info** allows you to view, modify and delete any wavelength information you have stored with your image. If you click in this button, ARCTIS displays the following window:



In the uppermost part of this window, you can decide if you want ARCTIS to associate wavelength information with the current active image by (de-)selecting the **Use Wavelength Information** checkbox. Be careful: if you disable the checkbox, ARCTIS will constantly remove any wavelength data stored with this image.

There, ARCTIS displays a list of the wavelength in nanometers associated with each band. You can change the values by either editing them directly or by **importing** your information from a text file.

If you are satisfied with your wavelength information, click **Save** and then **Close** the window.

More about the way ARCTIS handles wavelength data can be found [here](#).

Close All

This function closes all open ARCTIS figures, windows and images – it closes everything except the main window.

Zoom2Cursor

This function allows you to interactively zoom to the cursor location. If you start this function, ARCTIS looks for open windows which display images. If none are found, an error message is displayed. Otherwise, ARCTIS waits for you to select one of the images by clicking on it. The cursor then changes to a crosshair and ARCTIS zooms the image to the cursor location.

Clicking the left mouse button increases the magnification, clicking the right decreases it. A double click on any mouse button resets the zoom to the original size.

If you want to close the function, just click the little X in the lower left corner of the window.

Stretch2Cursor

This function allows you to display the area around the cursor stretched from 5% to 95%. You can use it to analyze every part of your image in detail. If you move the cursor around on your image, ARCTIS calculates the stretched subimage on time and displays it at the cursor location.

If you start this function, ARCTIS looks for open windows which display images. If none are found, an error message is displayed. Otherwise, ARCTIS waits for you to select one of the images by clicking on it. The cursor then changes to a crosshair and ARCTIS displays the small overlay image. By default, its size is 200 by 200 pixels, but you can change the size using the scroll wheel; double clicking any mouse button resets the size to its default.

If you want to close the function, just click the little red X in the lower left corner of the window.

Appendix

Data Types

In ARCTIS, images typically have two data types: 8 or 16 bit unsigned integer. Consequently, image values reach any non-negative integer between 0 and 255 (8 bit) or 0 and 65535 (16 bit).

During calculations, it is often necessary to convert the image values into other data types, but the output images are always converted back to the input format before saving.

Although we tried to avoid this effect, it sometimes may occur that during one or the other calculation, a result may reach an out-of-bounds-value. In these cases, the result is set to either 0, 255 or 65535 automatically.

Image Stretching

ARCTIS is mainly a tool for displaying data. Therefore, after many operations, ARCTIS automatically adjusts the result in order to make it cover the whole possible range. Nevertheless, it is still possible to get ones hands on the original results where it is reasonable:

ARCTIS stores two parameters in the ImageInfo Variable called ImageInfo.Param1 and Imageinfo.Param2. To see the original results you just need to apply the following calculation in MATLAB:

$$orig_{data} = data * Param1 + Param2$$

Selecting Files in ARCTIS

ARCTIS generally allows you to select every file you want as input data during most image processing operations (just select the **From File** radio button and use the **Browse...** button for file selection). Of course, the input files have to be ARCTIS images and should have the same size and geographic location as the ones already existing in your project. So it is recommended to import every image using the [import](#) function before applying any image processing operations to it.

World Files

ARCTIS is able to read world files for obtaining georeferencing information. A world file is a plain text file consisting of 6 lines ([WIKIPEDIA](#), 2012):

- Line 1: A: pixel size in the x-direction in map units/pixel
- Line 2: D: rotation about y-axis
- Line 3: B: rotation about x-axis
- Line 4: E: pixel size in the y-direction in map units, almost always negative[3]
- Line 5: C: x-coordinate of the center of the upper left pixel
- Line 6: F: y-coordinate of the center of the upper left pixel.

ARCTIS generally uses the extension “.tfw” for world files and names them after the raster image they belong to.

Point Selection in ARCTIS

Point selection in ARCTIS typically consists of two steps. First, you have to select the image you want to select a point in by clicking on it once with the left mouse button. After that, your cursor turns into a crosshair and allows you to select the point you want by clicking on it a second time.

For many operations, it is not important on which image you click as the image is only needed to get the location information. However, you may experience some problems if you have images of different projects open at the same time or if your images in one project have different sizes, which is not recommended.

Polygon Selection in ARCTIS

Polygon Selection in ARCTIS typically consists of three steps. First, you have to select the image you want to select a point in by clicking on it once with the left mouse button. After that, your cursor turns into a crosshair and you can draw the vertexes of your polygon by single-clicking with the left mouse button. If you want to close your polygon, you can either double click anywhere or click the starting vertex of your polygon again. You now have the possibility to move your polygon around using drag&drop or you can move single vertexes in the same way. As a third step, if you are satisfied with your polygon, double-click it. It now turns red and your polygon has been selected.

Note: It may sometimes take some time for ARCTIS to process your clicks and actions during polygon selection, so wait a little after each click in order to wait for ARCTIS to process your actions.

NoData-Values

ARCTIS offers very limited support of NoData values. It does this via calculating a mask which identifies each data point as “Data” or “NoData”. NoData-Values are set during the [import process](#), and cannot be changed afterwards.

ARCTIS ignores NoData-Values only for the [contrast enhancement](#) operations; for every other image processing operation, these values are treated as normal values. Therefore it is recommended to use only images without any missing data for the analysis in ARCTIS.

Colormaps and Indexed Data

Generally, there are two types of images in MATLAB: RGB images consisting of three bands representing the red, green and blue spectra, and indexed images, consisting of one layer and a colormap.

Consequently, you can decide if you want to display three bands of your data as an RGB composite image, or just one layer using a colormap.

A colormap just tells ARCTIS which color to assign to which value. The number of different colors in a colormap depends on the data type of your image: if you use 16bit images, the colormap needs to have 65536 different entries as this is the number possible values of your image; for 8bit, the number is 256.

ARCTIS offers several different colormaps predefined in MATLAB. For more information, please refer to the MATLAB command [colormap](#).

Wavelength Information

ARCTIS offers the possibility to associate wavelength information with each image. This is done either by importing a text file or by reading it from an ENVI header file. In ARCTIS, the way wavelength info is stored is simple: For each band of your image, a corresponding wavelength is saved. ARCTIS then simply treats each band as if it covers exactly this wavelength.

It is important that you use nanometers for the wavelength unit in order to use the functions **True Color** and **False Color IR** because they are looking for certain wavelengths predefined in this unit.

The Best-Triple Algorithm

This algorithm is used to preselect a band combination which allows you to get as much information as possible out of a newly created image. It first generates a correlation matrix out of the whole image and locates the two least correlated bands. Then it looks which band has the least correlation to these two bands and takes it as the third band.

Results may vary because due to memory reasons, ARCTIS does not take the whole image but only a random sample for the generation of the correlation matrix. But as stated above, this algorithm is only used to give you a quick overview of your newly created image, and you can select any band combination you want for further analysis.

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