



Semi-Automatic Classification Plugin Documentation

Release 6.4.0.2

Luca Congedo

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CHAPTER 1

Introduction

Developed by Luca Congedo, the **Semi-Automatic Classification Plugin (SCP)** is a free open source plugin for **QGIS** that allows for the semi-automatic classification (also known as supervised classification) of remote sensing images. It provides several tools for the download of free images, the preprocessing, the postprocessing, and the raster calculation (please see *What can I do with the SCP?* (page 230)).

The **overall objective** of *SCP* is to provide a set of intertwined tools for raster processing in order to make an automatic workflow and ease the land cover classification, which could be performed also by people whose main field is not remote sensing. The first version of the *SCP* was developed by Luca Congedo in 2012 for the “ACC Dar Project” in order to create a tool for the classification of land cover in an affordable and automatic fashion; following versions of *SCP* were developed as personal commitment to the remote sensing field and open source philosophy. *SCP* version 6 (codename: Greenbelt) is developed in the frame of Luca Congedo’s PhD in Landscape and Environment at Sapienza University of Rome.

This **user manual** provides information about the *Plugin Installation* (page 3) of SPC and the *The Interface of SCP* (page 21), with detailed information about all the functions. In addition, the *Brief Introduction to Remote Sensing* (page 109) illustrates the basic concepts and definitions which are required for using the *SCP*.

Basic Tutorials (page 139) are available for learning the main functions of *SCP*.

You are kindly invited to **contribute to SCP** (see *How to contribute to SCP* (page 231)) and join the **Facebook group**. Also, please read the *Frequently Asked Questions* (page 223).

For more information and tutorials visit the official site



From GIS to Remote Sensing

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the License. Semi-Automatic Classification Plugin is distributed in the hope that it will be useful, but WITHOUT ANY WARRANTY; without even the implied warranty of MERCHANTABILITY or FITNESS FOR A PARTICULAR PURPOSE. See the GNU General Public License for more details. You should have received a copy of the GNU General Public License along with Semi-Automatic Classification Plugin. If not, see <http://www.gnu.org/licenses/>.

Translators:

Language: Author

CHAPTER 2

Plugin Installation

The Semi-Automatic Classification Plugin requires the installation of [GDAL](#), [OGR](#), [NumPy](#), [SciPy](#) and [Matplotlib](#) (already bundled with QGIS).

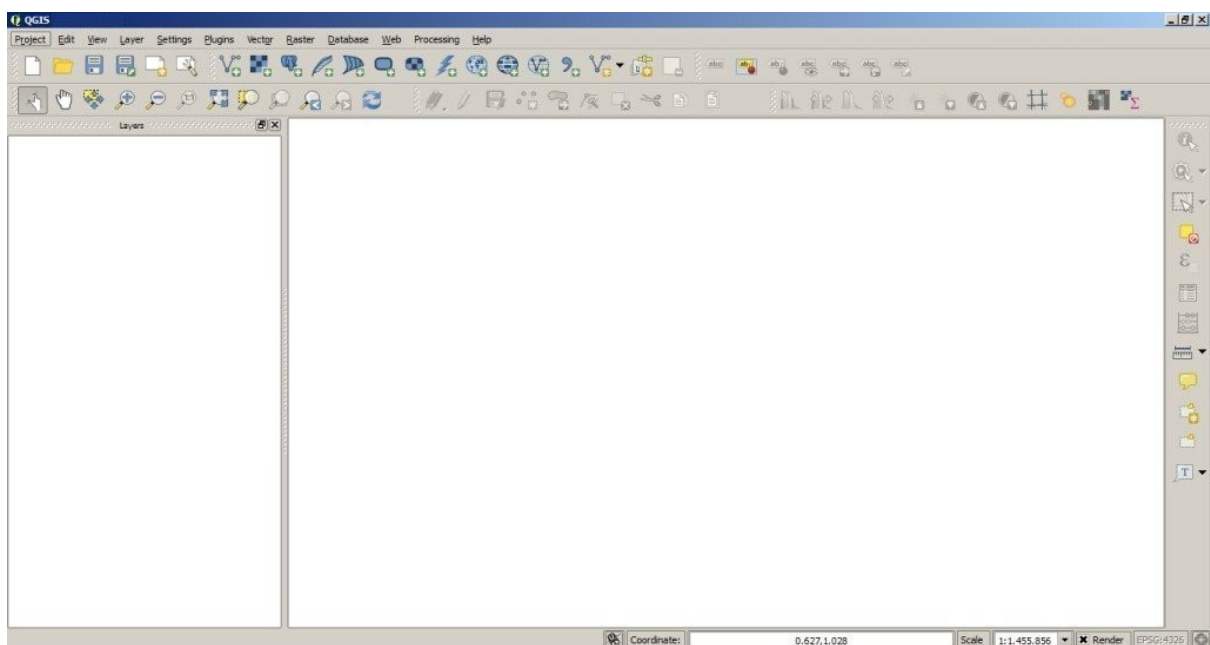
This chapter describes the installation of the Semi-Automatic Classification Plugin for the supported Operating Systems.

2.1 Installation in Windows 32 bit

2.1.1 QGIS download and installation

- Download the latest QGIS version 32 bit from [here](#) ;
- Execute the QGIS installer with administrative rights, accepting the default configuration.

Now, QGIS is installed.



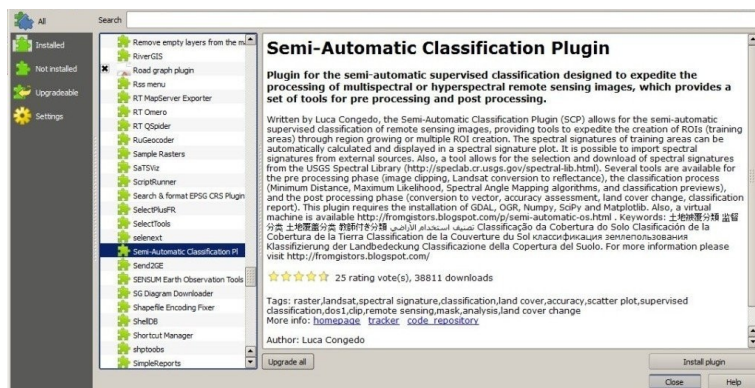
2.1.2 Semi-Automatic Classification Plugin installation

- Run QGIS;
- From the main menu, select **Plugins > Manage and Install Plugins**;

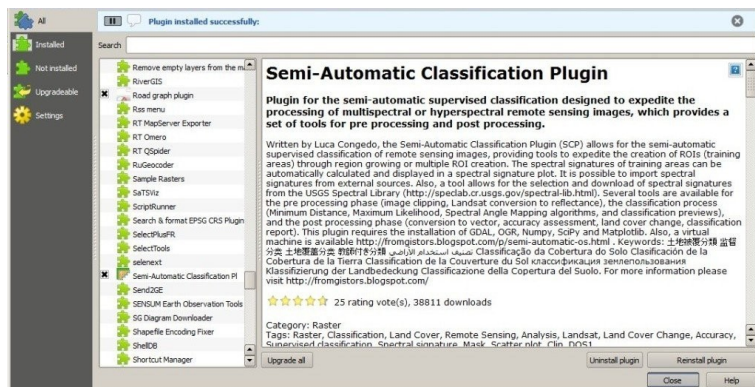


- From the menu **All**, select the **Semi-Automatic Classification Plugin** and click the button **Install plugin**;

TIP: in case of issues or an offline installation is required see [How to install the plugin manually?](#) (page 224) and [How to install the plugin from the official SCP repository?](#) (page 224).

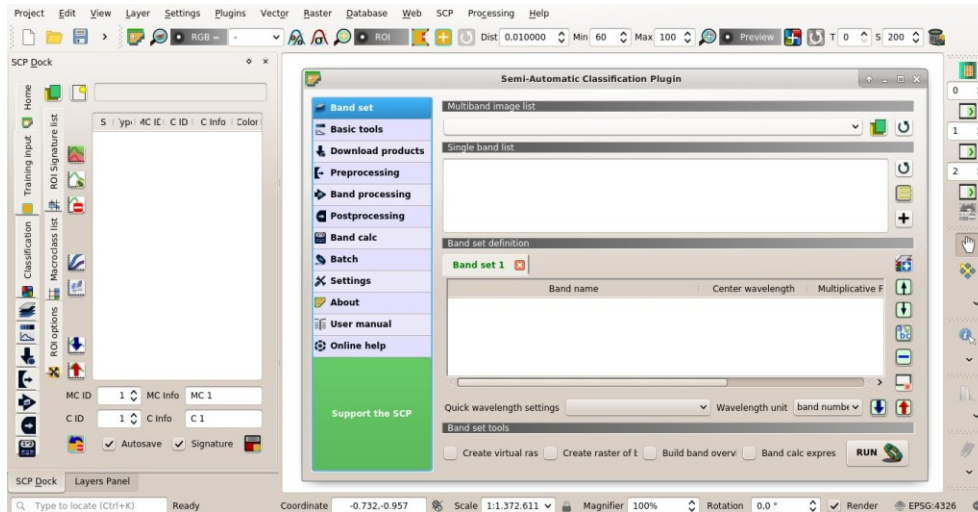


- The SCP should be automatically activated; however, be sure that the Semi-Automatic Classification Plugin is checked in the menu **Installed** (the restart of QGIS could be necessary to complete the SCP installation);



2.1.3 Configuration of the plugin

Now, the Semi-Automatic Classification Plugin is installed and a dock and a toolbar should be added to QGIS. Also, a SCP menu is available in the Menu Bar of QGIS. It is possible to move the toolbar and the dock according to your needs, as in the following image.

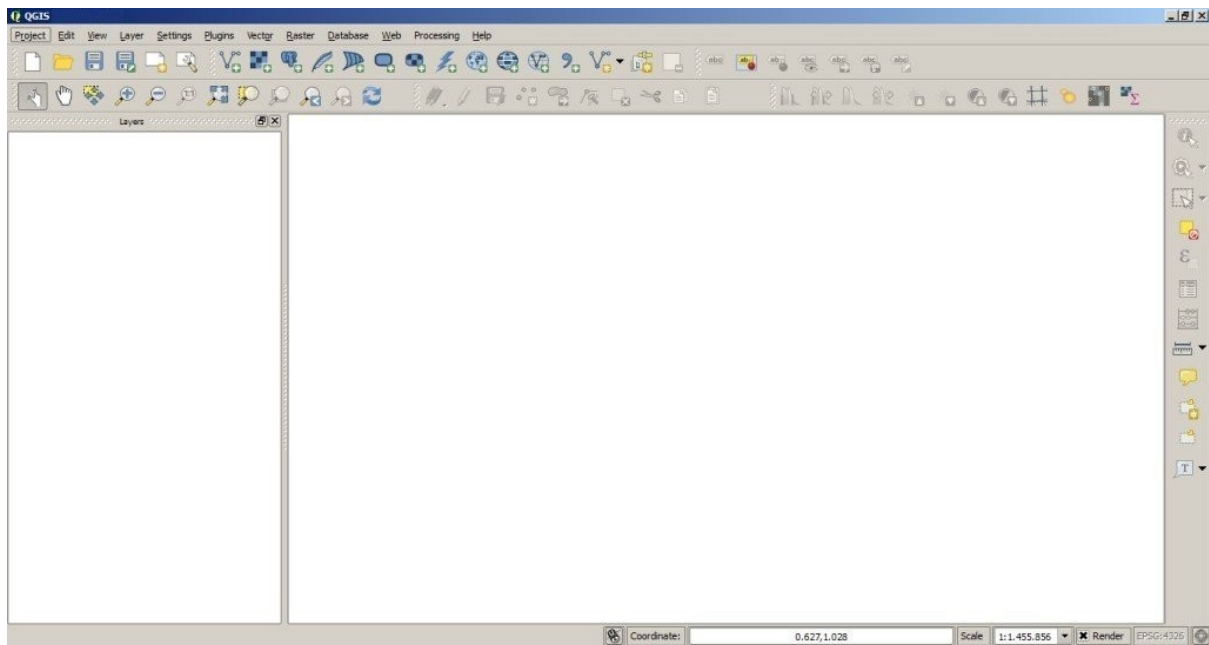


2.2 Installation in Windows 64 bit

2.2.1 QGIS download and installation

- Download the latest QGIS version 64 bit from [here](#) ;
- Execute the QGIS installer with administrative rights, accepting the default configuration.

Now, QGIS is installed.



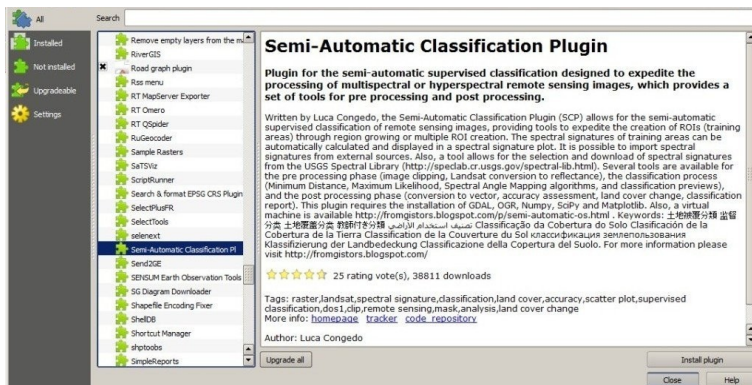
2.2.2 Semi-Automatic Classification Plugin installation

- Run QGIS;
- From the main menu, select **Plugins > Manage and Install Plugins**;

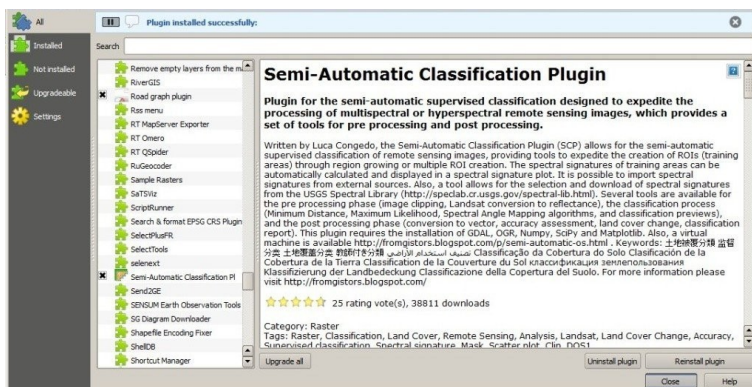


- From the menu All, select the Semi-Automatic Classification Plugin and click the button Install plugin;

TIP: in case of issues or an offline installation is required see [How to install the plugin manually?](#) (page 224) and [How to install the plugin from the official SCP repository?](#) (page 224).

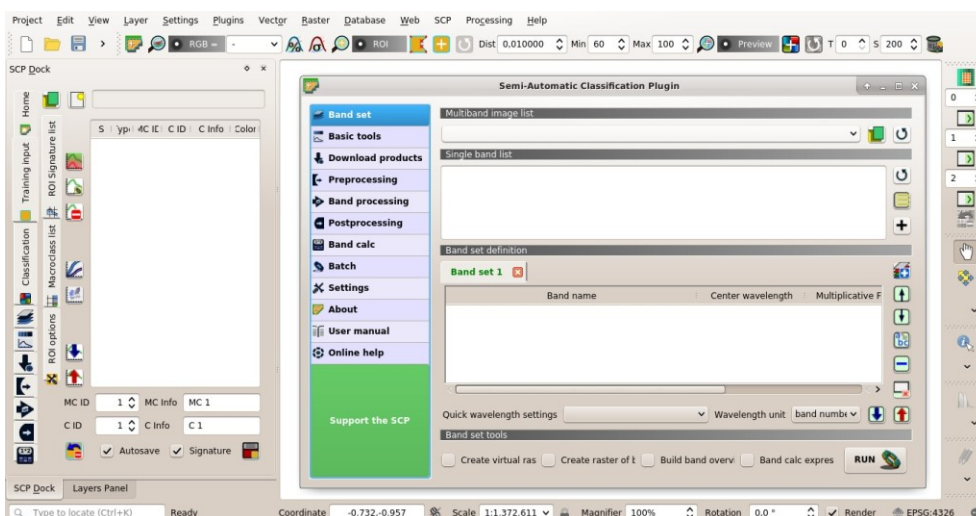



- The SCP should be automatically activated; however, be sure that the Semi-Automatic Classification Plugin is checked in the menu Installed (the restart of QGIS could be necessary to complete the SCP installation);

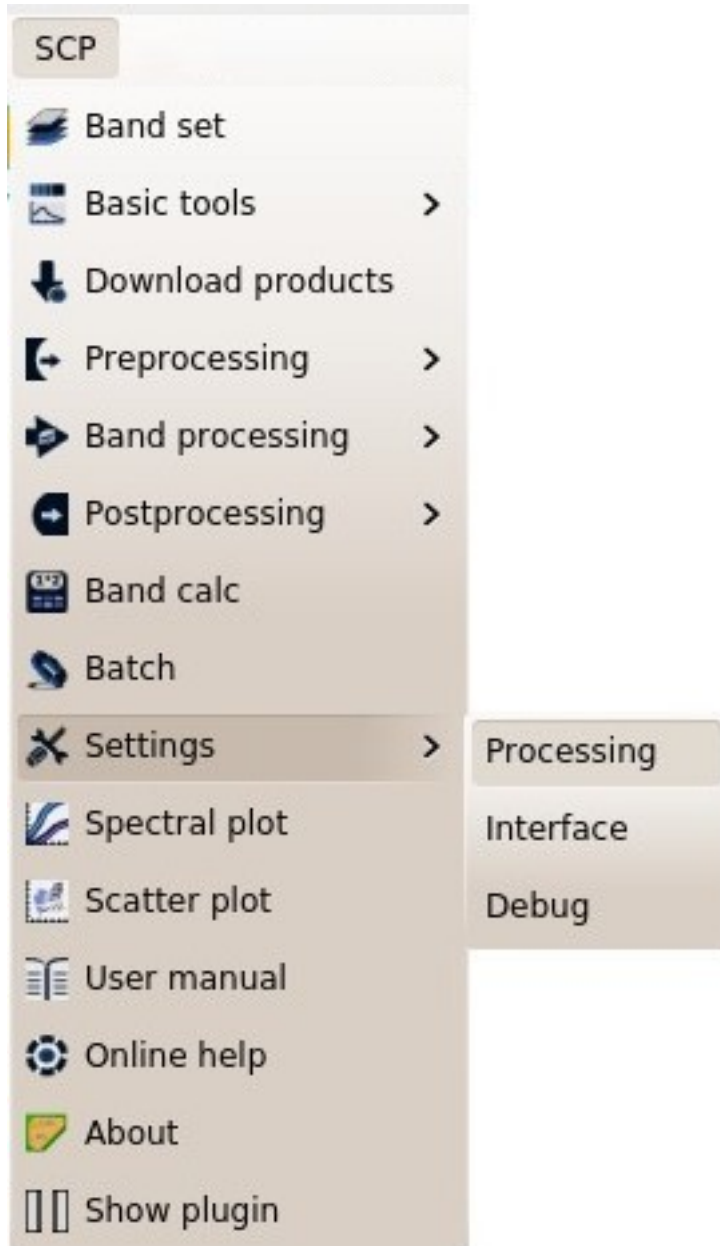


2.2.3 Configuration of the plugin

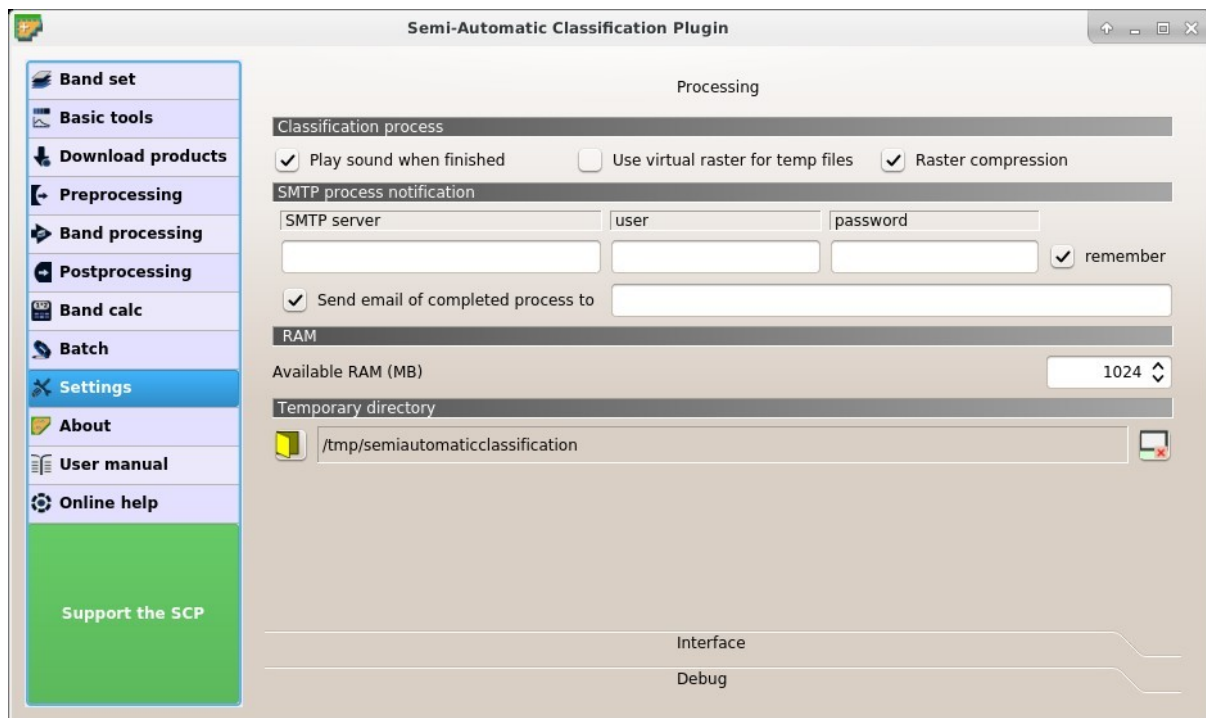
Now, the Semi-Automatic Classification Plugin is installed and a dock and a toolbar should be added to QGIS. Also, a SCP menu is available in the Menu Bar of QGIS. It is possible to move the toolbar and the dock according to your needs, as in the following image.



The configuration of available RAM is recommended in order to reduce the processing time. From the *SCP menu* (page 21) select  Settings > Processing.



In the *Settings* (page 94), set the Available RAM (MB) to a value that should be half of the system RAM. For instance, if your system has 2GB of RAM, set the value to 1024MB.



2.3 Installation in Ubuntu Linux

2.3.1 QGIS download and installation

- Open a terminal and type:

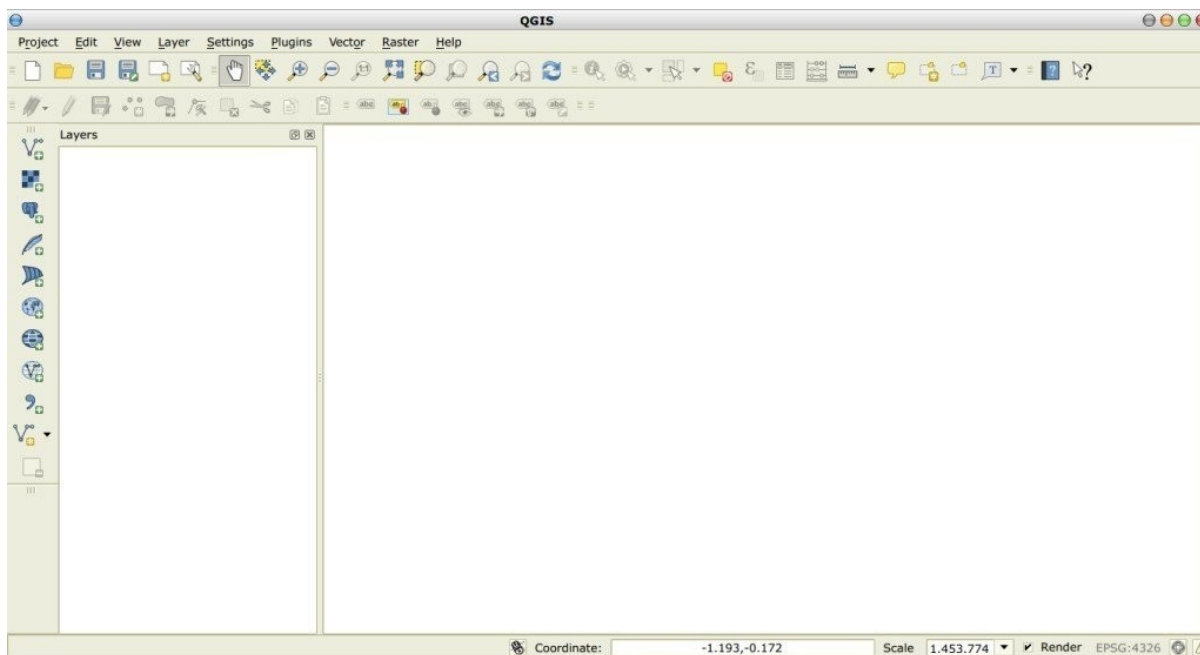
```
sudo apt-get update
```

- Press Enter and type the user password;
- Type in a terminal:

```
sudo apt-get install qgis python3-matplotlib python3-scipy
```

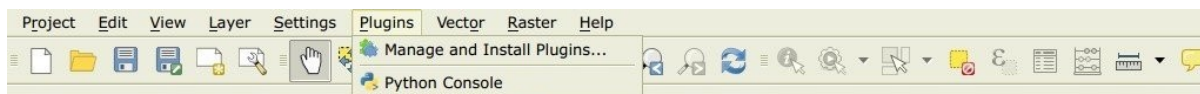
- Press Enter and wait until the software is downloaded and installed.

Now, QGIS is installed.



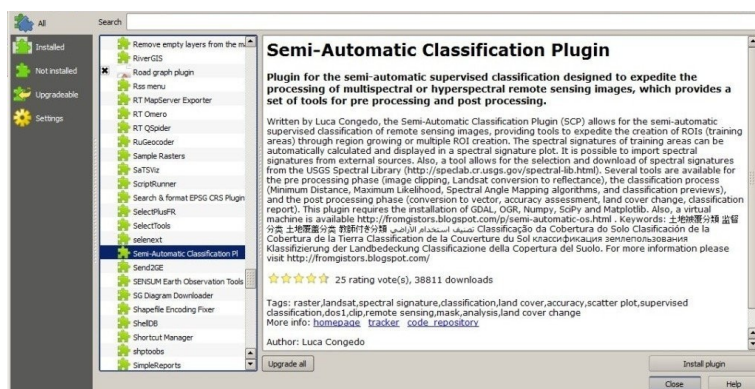
2.3.2 Semi-Automatic Classification Plugin installation

- Run QGIS;
- From the main menu, select **Plugins > Manage and Install Plugins**;

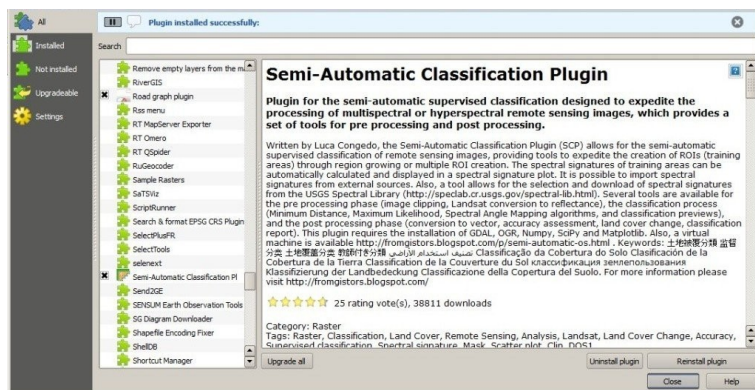


- From the menu **All**, select the **Semi-Automatic Classification Plugin** and click the button **Install plugin**;

TIP: in case of issues or an offline installation is required see [How to install the plugin manually?](#) (page 224) and [How to install the plugin from the official SCP repository?](#) (page 224).

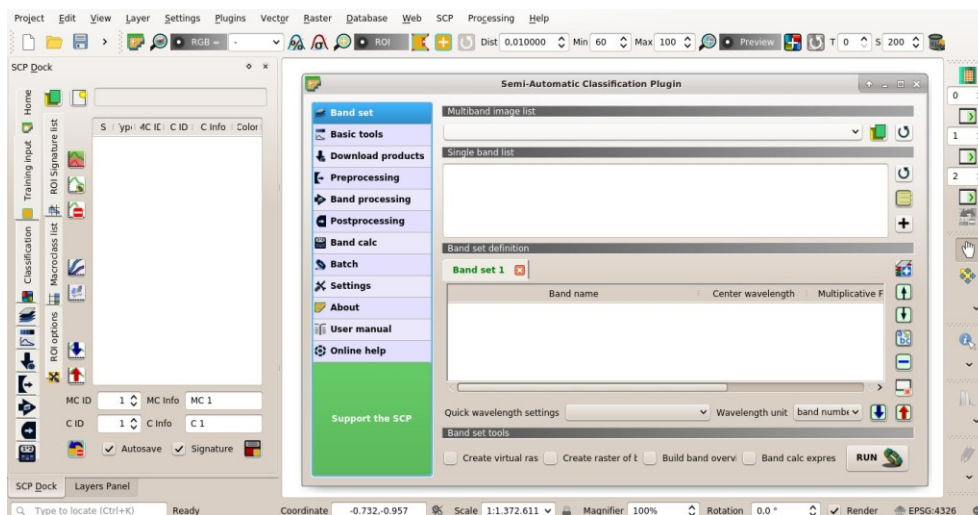



- The SCP should be automatically activated; however, be sure that the Semi-Automatic Classification Plugin is checked in the menu **Installed** (the restart of QGIS could be necessary to complete the SCP installation);

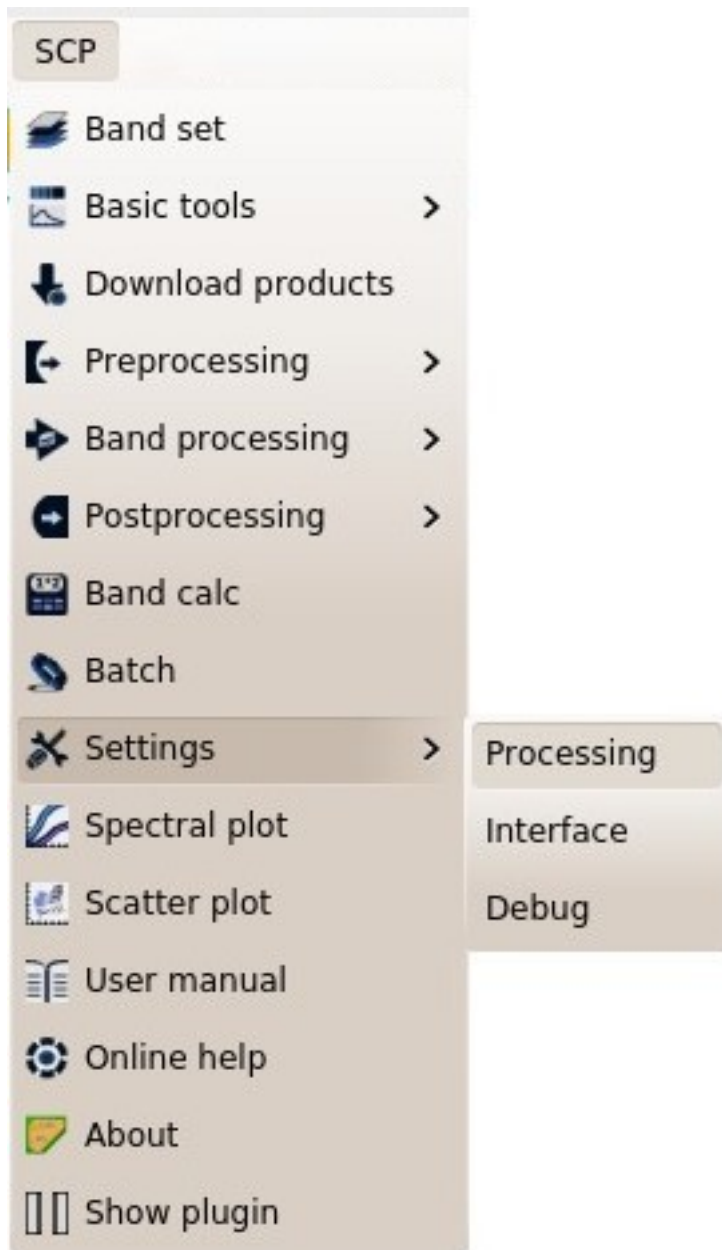


2.3.3 Configuration of the plugin

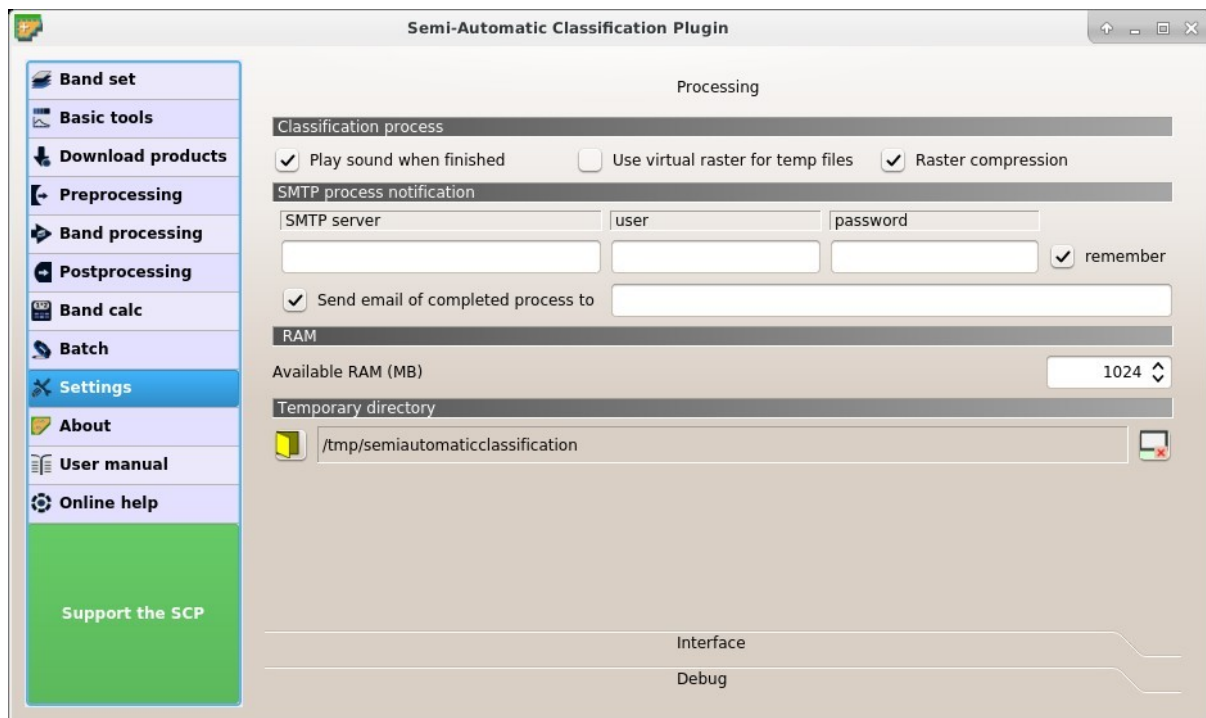
Now, the Semi-Automatic Classification Plugin is installed and a dock and a toolbar should be added to QGIS. Also, a SCP menu is available in the Menu Bar of QGIS. It is possible to move the toolbar and the dock according to your needs, as in the following image.



The configuration of available RAM is recommended in order to reduce the processing time. From the *SCP menu* (page 21) select  Settings > Processing.



In the [Settings](#) (page 94), set the `Available RAM (MB)` to a value that should be half of the system RAM. For instance, if your system has 2GB of RAM, set the value to 1024MB.



2.4 Installation in Debian Linux

2.4.1 QGIS download and installation

- Open a terminal and type:

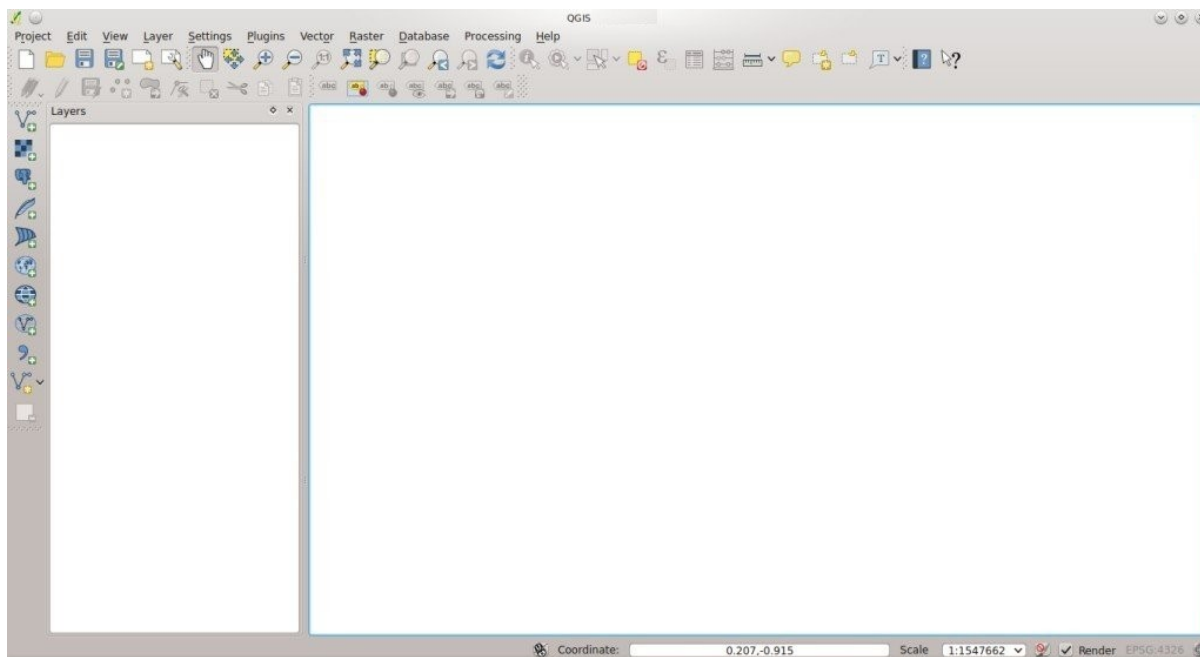
```
sudo apt-get update
```

- Press Enter and type the user password;
- Type in a terminal:

```
sudo apt-get install qgis python3-matplotlib python3-scipy
```

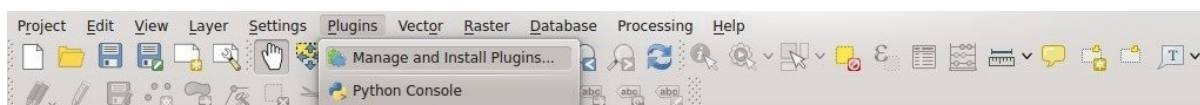
- Press Enter and wait until the software is downloaded and installed.

Now, QGIS is installed.



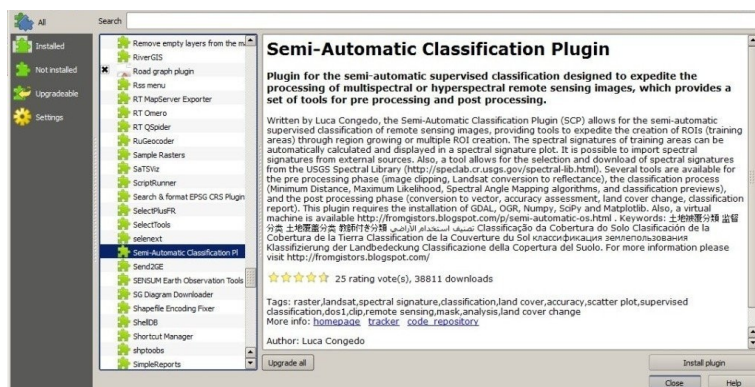
2.4.2 Semi-Automatic Classification Plugin installation

- Run QGIS;
- From the main menu, select **Plugins > Manage and Install Plugins**;

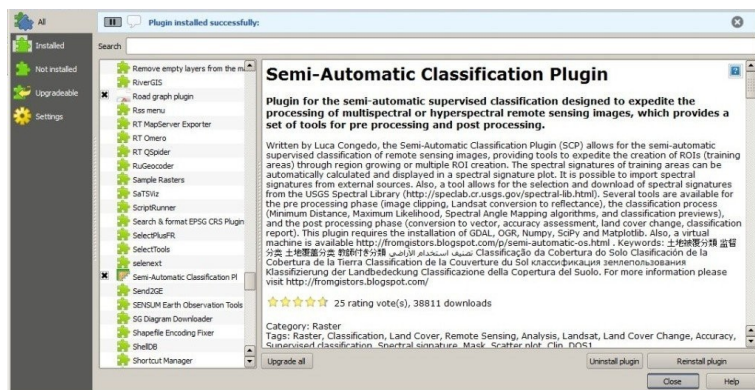


- From the menu **All**, select the **Semi-Automatic Classification Plugin** and click the button **Install plugin**;

TIP: in case of issues or an offline installation is required see [How to install the plugin manually?](#) (page 224) and [How to install the plugin from the official SCP repository?](#) (page 224).

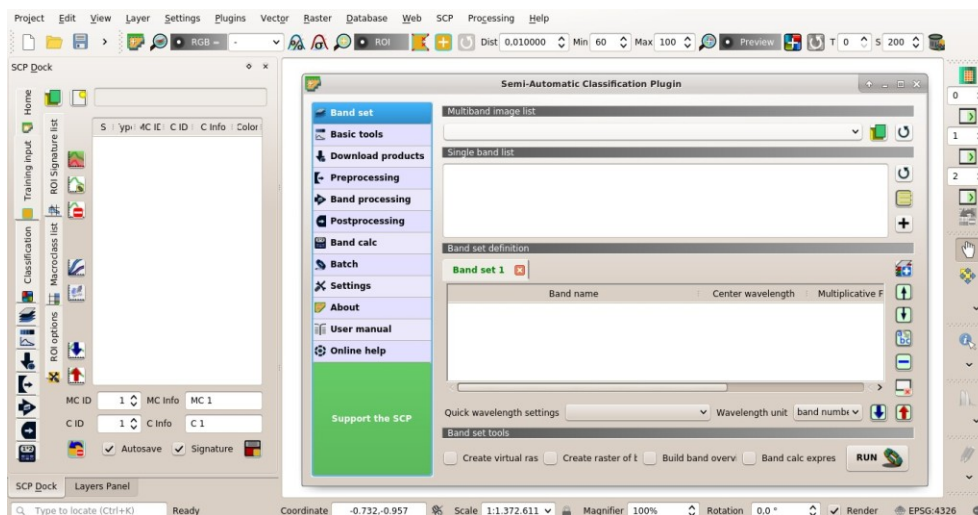



- The SCP should be automatically activated; however, be sure that the Semi-Automatic Classification Plugin is checked in the menu **Installed** (the restart of QGIS could be necessary to complete the SCP installation);

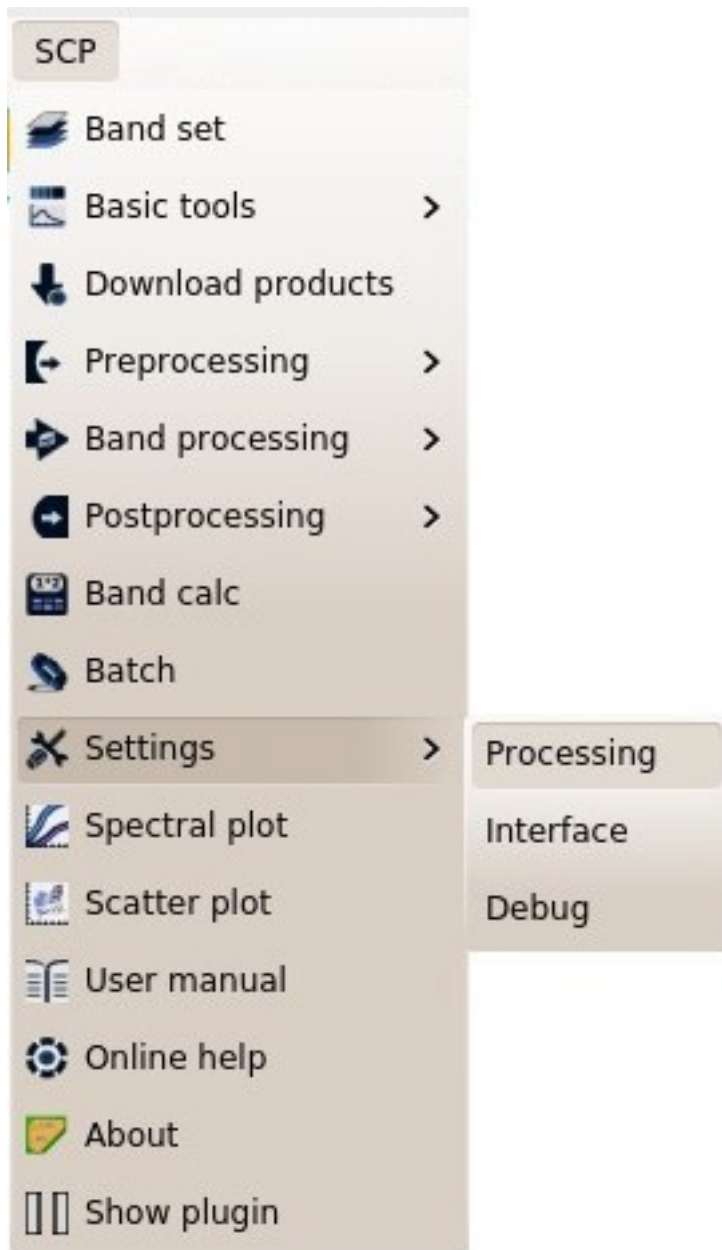


2.4.3 Configuration of the plugin

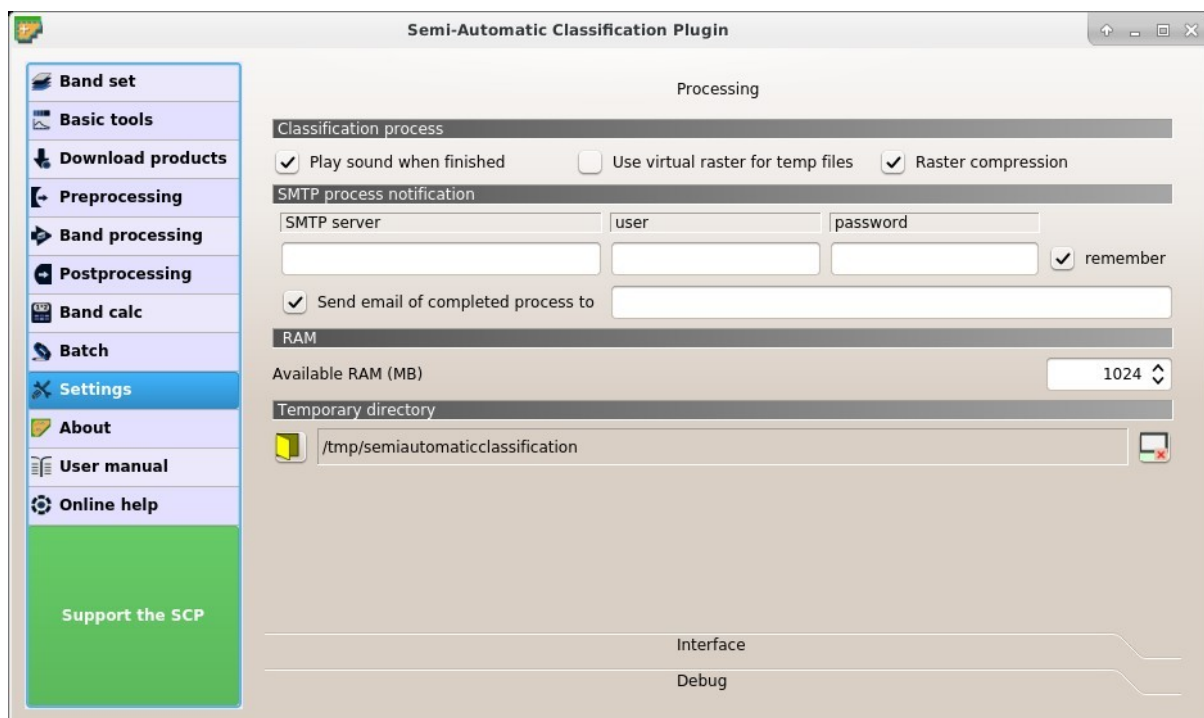
Now, the Semi-Automatic Classification Plugin is installed and a dock and a toolbar should be added to QGIS. Also, a SCP menu is available in the Menu Bar of QGIS. It is possible to move the toolbar and the dock according to your needs, as in the following image.



The configuration of available RAM is recommended in order to reduce the processing time. From the *SCP menu* (page 21) select  Settings > Processing.



In the [Settings](#) (page 94), set the Available RAM (MB) to a value that should be half of the system RAM. For instance, if your system has 2GB of RAM, set the value to 1024MB.

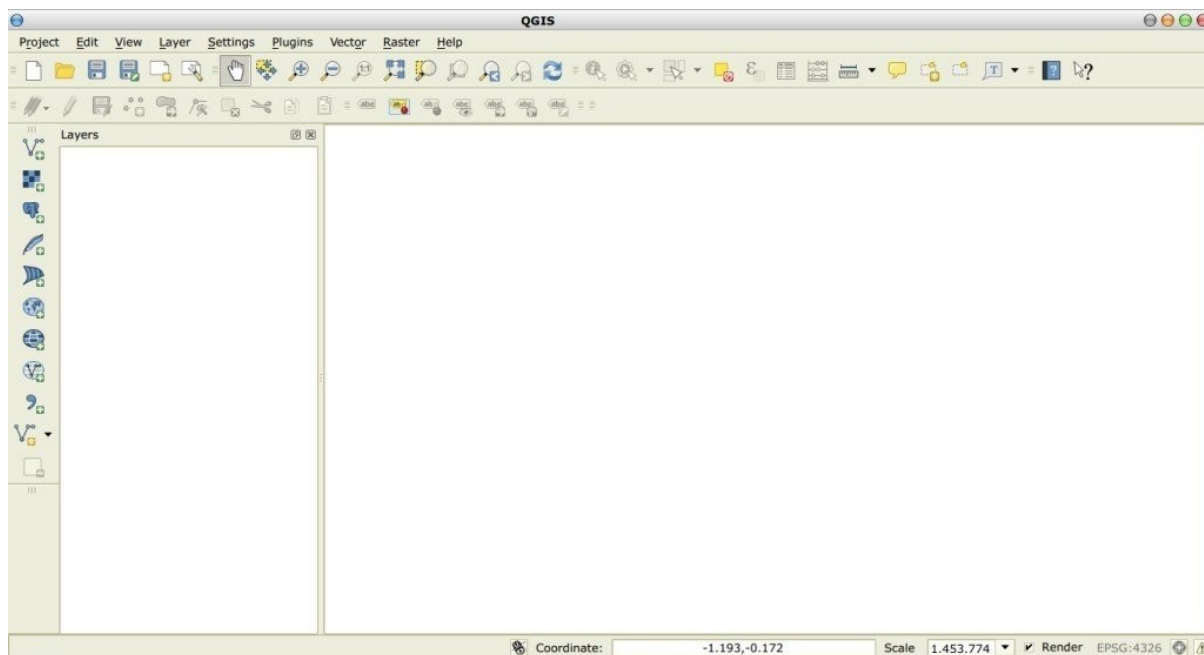


2.5 Installation in Mac OS

2.5.1 QGIS download and installation

- Download and install the latest version of QGIS and GDAL from [here](#) .

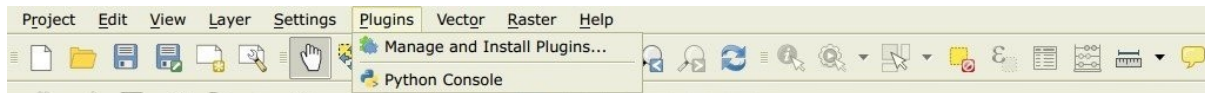
Now, QGIS is installed.



2.5.2 Semi-Automatic Classification Plugin installation

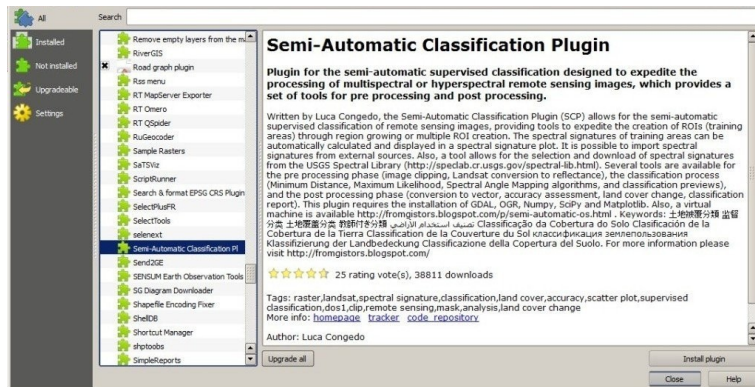
- Run QGIS;

- From the main menu, select **Plugins > Manage and Install Plugins**;

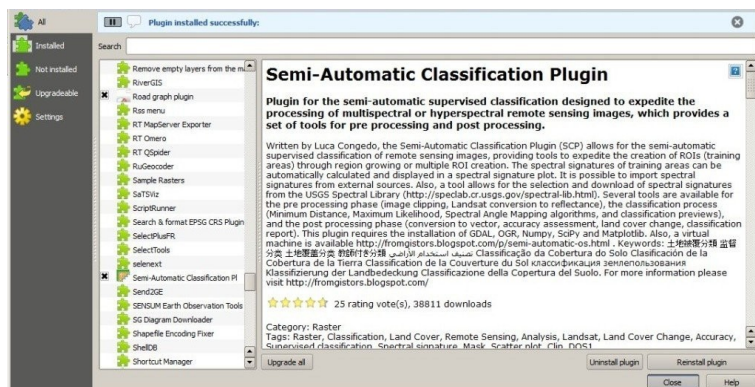


- From the menu **All**, select the **Semi-Automatic Classification Plugin** and click the button **Install plugin**;

TIP: in case of issues or an offline installation is required see [How to install the plugin manually?](#) (page 224) and [How to install the plugin from the official SCP repository?](#) (page 224).



- The SCP should be automatically activated; however, be sure that the Semi-Automatic Classification Plugin is checked in the menu **Installed** (the restart of QGIS could be necessary to complete the SCP installation);



In case of missing dependencies, you could get error messages such as the following example with matplotlib:

```
Couldn't load plugin 'SemiAutomaticClassificationPlugin-master' due to an error when calling its classFactory() method

ModuleNotFoundError: No module named 'matplotlib'

Traceback (most recent call last):
  File "/Applications/QGIS3.6.app/Contents/MacOS/.../Resources/python/qgis/utils.py", line 335, in startPlugin
    plugins[packageName] = package.classFactory(iface)
```

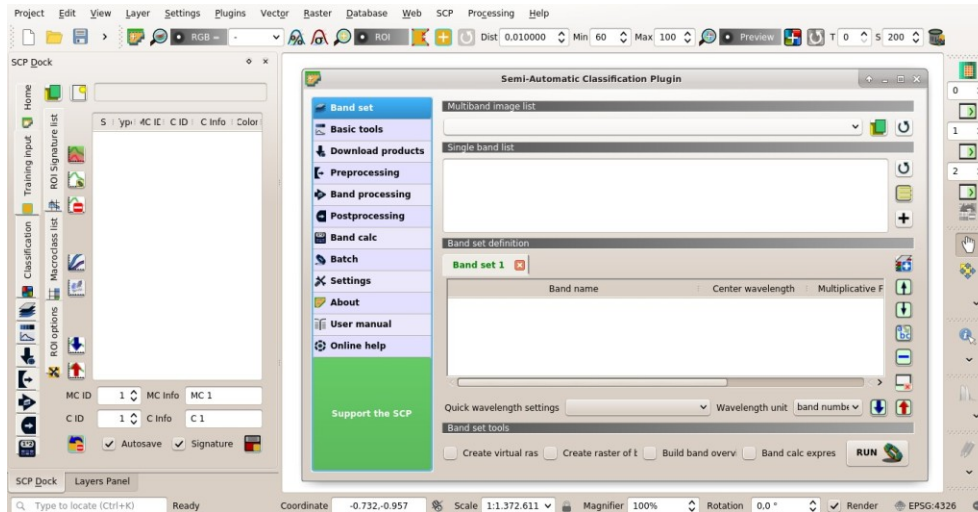
To install matplotlib type in a terminal:


```
sudo pip3 install matplotlib
```

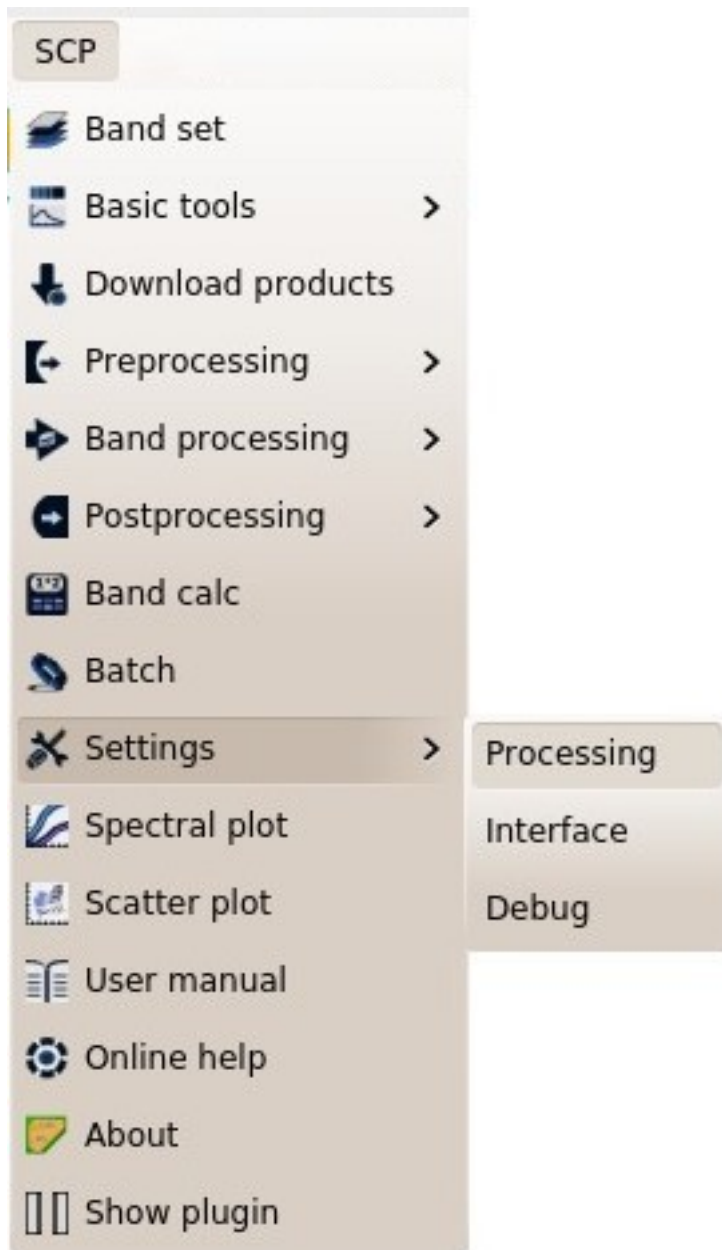
and repeat this step for other missing dependencies.

2.5.3 Configuration of the plugin

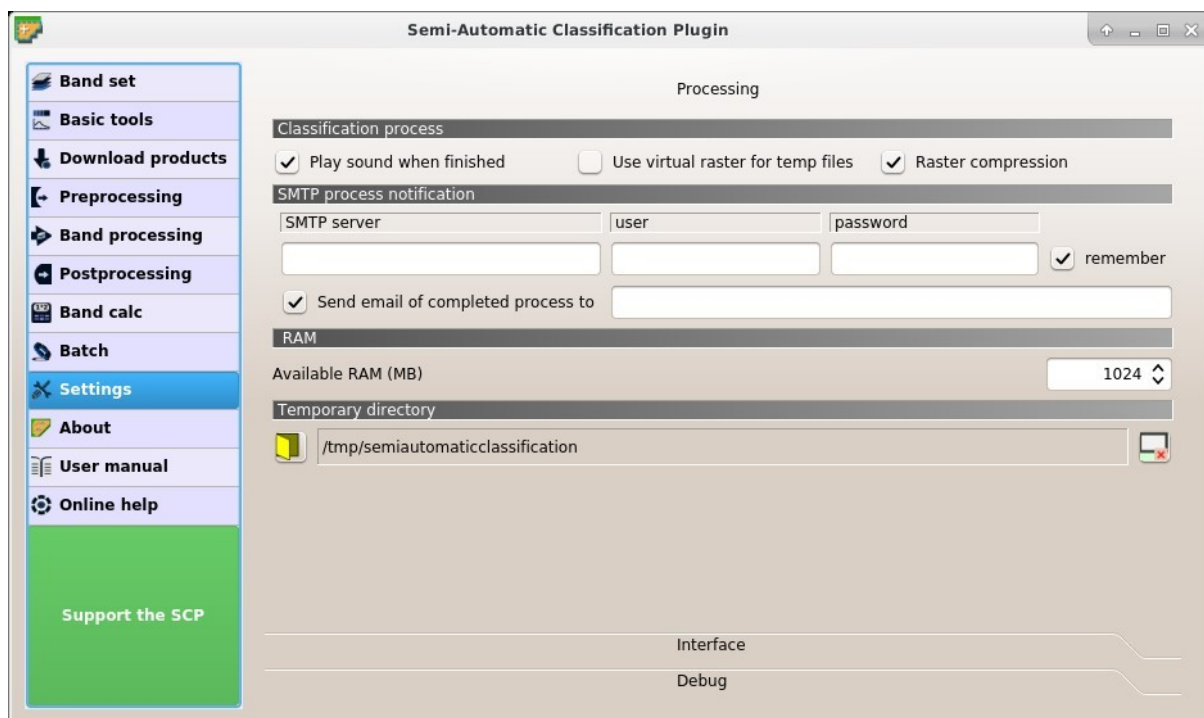
Now, the Semi-Automatic Classification Plugin is installed and a dock and a toolbar should be added to QGIS. Also, a SCP menu is available in the Menu Bar of QGIS. It is possible to move the toolbar and the dock according to your needs, as in the following image.



The configuration of available RAM is recommended in order to reduce the processing time. From the *SCP menu* (page 21) select  Settings > Processing.



In the [Settings](#) (page 94), set the Available RAM (MB) to a value that should be half of the system RAM. For instance, if your system has 2GB of RAM, set the value to 1024MB.






The Interface of SCP

The *SCP* interface is composed of several parts that are described in detail in the following paragraphs.

3.1 SCP menu

The *SCP menu* allows for the selection of the main functions of the *Main Interface Window* (page 36), the *Spectral Signature Plot* (page 98), and the *Scatter Plot* (page 104).

-  *Band set* (page 37);
-  *Download products* (page 51);
-  *Basic tools* (page 40);
-  *Preprocessing* (page 56);
-  *Postprocessing* (page 75);
-  *Band calc* (page 87);
-  *Spectral Signature Plot* (page 98);
-  *Scatter Plot* (page 104);
-  *Batch* (page 91);
-  *Settings* (page 94);
-  *User manual*: open the online user manual in a web browser;

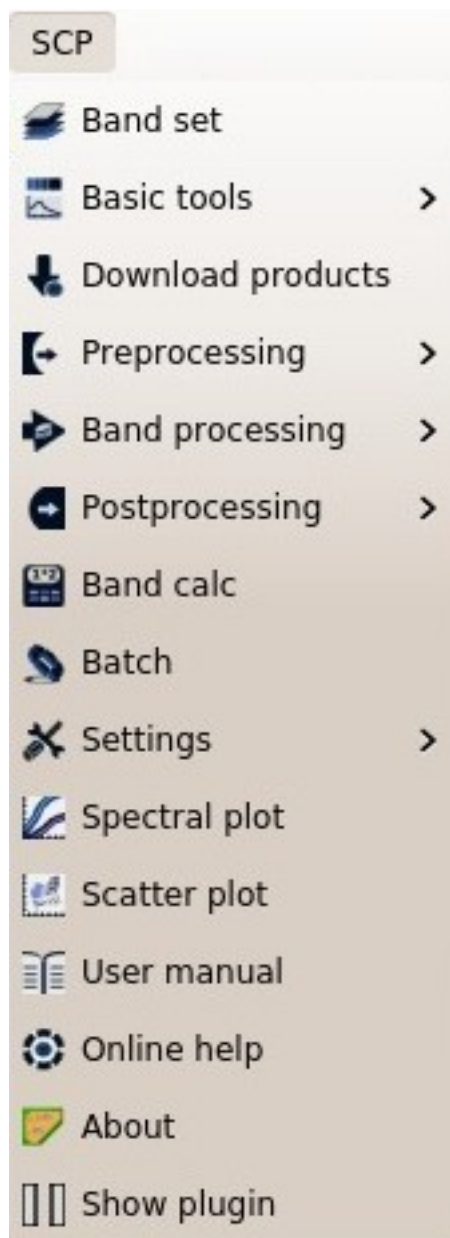




Fig. 1: *SCP menu*

-  *Online help*: open the [Online help](#) in a web browser; also, a [Facebook group](#) is available for sharing information and asking for help about SCP;
-  *Show plugin*: show all the SCP toolbars and dock if previously hidden;

3.2 SCP dock

The *SCP dock* allows for the the creation of ROIs (Regions Of Interest) and spectral signatures, and the classification of a *Band set* (page 37). The *Training input* (page 24), created with *SCP*, stores the ROI polygons and spectral signatures used for the land cover classification (see *Tutorial 1: Your First Land Cover Classification* (page 139)).

ROIs are polygons used for the definition of the spectral characteristics of land cover classes. Spectral signatures of classes are calculated from the ROIs or can be imported from other sources (see *Import signatures* (page 44)). It is worth pointing out that classification is always based on spectral signatures.

SCP allows for the creation of *temporary ROI polygons* using a region growing algorithm or drawn manually with the tools provided in the *Working toolbar* (page 34). *Temporary ROI polygons* can be saved in the *Training input* (page 24) along with the spectral signatures of the ROI.

The *Training input* (page 24) is composed of a vector part (i.e. a shapefile) and a spectral signature part which are independent. The attribute table of the vector contains four fields as in the following table.

Training input fields

Description	Field name	Field type
Macroclass ID	MC_ID	int
Macroclass Information	MC_info	string
Class ID	C_ID	int
Class Information	C_info	string

In *SCP*, land cover classes (and ROIs) are defined with a system of *Classes* (*Class ID*) and *Macroclasses* (*Macroclass ID*) (see *Classes and Macroclasses* (page 118)) that are used for the classification process; each *Macroclass ID* is related to a *Macroclass Information* (e.g. macroclass name) and each *Class ID* is related to a *Class Information* (e.g. class name), but only *Macroclass ID* and *Class ID* are used for the classification process.

The use of the *Macroclass ID* or *Class ID* for classifications is defined with the option *Use MC ID or C ID* in the *Algorithm* (page 31). It is worth highlighting that when using *Macroclass ID* all the spectral signatures are evaluated separately and each pixel is classified with the corresponding *MC ID* (i.e. there is no combination of signatures before the classification).

The **classification** can be performed for the entire image (*Algorithm* (page 31)) or a part of it, creating a *Classification preview* (page 35).

The *SCP dock* contains the following tabs:









- *Home* (page 24)
 - *SCP news* (page 24)
- *Training input* (page 24)
 - *ROI Signature list* (page 27)
 - *Macroclasses* (page 28)
 - *ROI options* (page 28)
- *Classification* (page 31)
 - *Algorithm* (page 31)

- *Land Cover Signature Classification* (page 33)
- *Classification output* (page 33)

The left side of *SCP dock* contains buttons for accessing the main functions of *SCP*.

3.2.1 Home

The tab *Home* contains the buttons for accessing the main functions of *SCP*:

-  *Band set* (page 37);
-  *Basic tools* (page 40);
-  *Download products* (page 51);
-  *Preprocessing* (page 56);
-  *Band processing* (page 70);
-  *Postprocessing* (page 75);
-  *Band calc* (page 87);
-  *Batch* (page 91);

SCP news

This section displays news about the *SCP* and related services. News are downloaded on startup (internet connection required). It can be enabled or disabled in the settings *Dock* (page 97).

It also contains the following buttons:

- *User manual*: open the link to the user manual;
- *Ask a question*: open the link to the online help;
- *Support the SCP*: open the link to support the *SCP* ;

3.2.2 Training input

This tool allows for the creation of the training input file (*.scp*) required for storing ROIs and spectral signatures. The training input file is created according to the characteristics of the *active band set* defined in *Band set* (page 37). A new training input file should be created for every *band set*, unless the *band sets* have the same spectral characteristics and coordinate reference system.



-  : open a training input file; ROIs and spectral signatures are loaded in *ROI Signature list* (page 27); the vector part of the training input is loaded in QGIS;
-  : create an empty training input file (*.scp*); the vector part of the training input is loaded in QGIS; also a backup file is created (a file *.scp.backup* in the same directory as the file *.scp*) when the training input file is saved;

Fig. 2: *Home*



Fig. 3: Training input

- *Training input*  : it displays the path to the training input file;

The training input is displayed in QGIS as vector file. ROIs and spectral signatures are displayed in the *ROI Signature list* (page 27). Macroclasses are defined in the *Macroclasses* (page 28).









ROI Signature list

The tab *ROI Signature list* displays the ROI polygons and spectral signatures contained in the training input file. If an item is a ROI polygon, double click the item to zoom to that ROI in the map. Items in the table can be highlighted with the mouse left click.









Changes in the *ROI Signature list* are applied to the file *Training input* (page 24) only when the QGIS project is saved. ROIs can be edited, deleted and merged from this table.

ROIs and spectral signatures can be imported from other sources (see *Import signatures* (page 44)) and exported (see *Export signatures* (page 46)).

WARNING: In order to avoid data loss, do not edit the vector *Training input* using the QGIS tools. Use only the tools of SCP for managing the *Training input*.

-  **ROI Signature list:**
 - *S*: selection checkbox; only the spectral signatures checked in this list are used for the classification process;
 - **Type: type of the item:**
 - * *R* = only ROI polygon;
 - * *S* = only spectral signature;
 - * *B* = both ROI and spectral signature;
 - *MC ID*: ROI Macroclass ID [int]; it can be edited with a single click; *MC Info* is displayed in *Macroclasses* (page 28); if the ID of a spectral signature is set 0, then pixels belonging to this signature are labelled as unclassified;
 - *C ID*: ROI Class ID [int]; it can be edited with a single click;
 - *C Info*: ROI Class Information [text]; it can be edited with a single click;
 - *Color*: C ID color; double click to select a color for the class that is used in the classification; if the ID of a spectral signature is set 0, then pixels belonging to this signature are labelled as unclassified;
-  : merge highlighted spectral signatures or ROIs obtaining a new signature calculated as the average of signature values for each band (covariance matrix is excluded);
-  : calculate spectral signatures of highlighted ROIs using the *active band set* in *Band set* (page 37);
-  : delete highlighted ROIs and signatures;
-  : show the ROI spectral signature in the *Spectral Signature Plot* (page 98); spectral signature is calculated from the *Band set* (page 37);
-  : open the *Scatter Plot* (page 104);
-  : open the tab *Import signatures* (page 44);
-  : open the tab *Export signatures* (page 46);




ROI Signature list is complementary to the *Working toolbar* (page 34) and it allows for saving ROIs to the *Training input* (page 24) defining classes and macroclasses. A *Band set* (page 37) must be defined before the ROI creation, and ROI polygons must be inside the area of the *Band set*.

-  : ROI Macroclass ID [int]; the corresponding *MC Info* is loaded if already defined in *Macroclasses* (page 28);
- *MC Info*  : ROI Macroclass information [text]; style and information for macroclasses are defined in *Macroclasses* (page 28);
- *C ID*  : ROI Class ID [int];
- *C Info*  : ROI Class information [text];
-  : delete the last saved ROI from the *Training input* (page 24);
-  *Autosave* : if checked, automatically save the *ROI Signature list* to the *Training input* (page 24) every time a ROI is saved;
-  *Calculate sig.* : if checked, while saving a ROI, the spectral signature thereof is calculated (from *Band set* (page 37) pixels under ROI polygon) and saved to *Training input* (page 24) (calculation time depends on the band number of the *active band set* in *Band set* (page 37));
-  : save the temporary ROI to the *Training input* (page 24) using the defined classes and macroclasses; ROI is displayed in the *ROI Signature list* (page 27);

Macroclasses

Macroclasses allows for the definition of **Macroclass names and colors** (used to display the results of *Classification preview* (page 35) and *Algorithm* (page 31)). According to *Algorithm* (page 31), classifications performed using *C ID* have the colors defined for classes in the *ROI Signature list* (page 27); classifications performed using *MC ID* have the colors defined in the *Macroclasses* (page 28).

MC IDs are automatically added to this table when a new ROI is saved to the *ROI Signature list* (page 27) (if the *MC ID* is not already in the list). Settings are stored in *Training input* (page 24).

-  *Macroclasses* :
 - *MC ID*: Macroclass ID [int]; it can be edited with a single click;
 - *MC Info*: Macroclass Information [text]; it can be edited with a single click;
 - *Color*: MC ID color; double click to select a color for the class that is used in the classification;
-  : add a new row to the table;
-  : delete the highlighted rows from the table;








ROI options

ROI options are useful for displaying pixel values or improving the creation of ROIs.

-  *Display*  : if the ROI creation pointer is active (see *Working toolbar* (page 34)), the pixel value of selected

Fig. 4: *Macroclasses*

Fig. 5: *ROI options*





- NDVI (Normalized Difference Vegetation Index); NDVI requires the near-infrared and red bands;
- EVI (Enhanced Vegetation Index); EVI requires the blue, near-infrared and red bands converted to reflectance; wavelengths must be defined in the [Band set](#) (page 37);
- Custom; use the custom expression defined in the following line;
-   : set a custom expression; expression is based on the *Band set*; bands are defined as *bandset#b + band number* (e.g. *bandset#b1* for the first band of the *Band set*); for example NDVI for a Landsat image would be $(\text{bandset\#b4} - \text{bandset\#b3}) / (\text{bandset\#b4} + \text{bandset\#b3})$;
-  *Rapid ROI b.*   : if checked, temporary ROI is created with region growing using only one *Band set* (page 37) band (i.e. region growing is rapider); the band is defined by the *Band set* number; if unchecked, ROI is the result of the intersection between ROIs calculated on every band (i.e. region growing is slower, but ROI is spectrally homogeneous in every band);
-  *Auto-refresh ROI*: calculate automatically a new temporary ROI while *Region growing parameters* in the *Working toolbar* (page 34) are being changed;
-  *Auto-plot*: calculate automatically the temporary ROI spectral signature and display it in the *Spectral Signature Plot* (page 98) (MC Info of this spectral signature is set tempo_ROI);

3.2.3 Classification

This tab allows for the classification of the *active band set* defined in [Band set](#) (page 37).





Classification is performed using the *active band set* and the spectral signatures checked in [ROI Signature list](#) (page 27). Several classification options are set in this tab which affect the classification process also during the *Classification preview* (page 35).

In particular the following options are available:

- Use  *MC ID*  *C ID*  : if *MC ID* is checked, the classification is performed using the Macroclass ID (code *MC ID* of the signature); if *C ID* is checked, the classification is performed using the Class ID (code *C ID* of the signature);
-  : open the [Algorithm band weight](#) (page 42) for the definition of band weights;

Algorithm

This tool allows for the selection of the classification algorithm and the optional definition of thresholds.

-   : available [Classification Algorithms](#) (page 118) are:
 - *Minimum Distance* (page 120);
 - *Maximum Likelihood* (page 120);
 - *Spectral Angle Mapping* (page 121);
- *Threshold*   : it allows for the definition of a classification threshold (applied to all the spectral signatures); if
 - for Minimum Distance, pixels are unclassified if distance is greater than threshold value;
 - for Maximum Likelihood, pixels are unclassified if probability is less than threshold value (max 100);

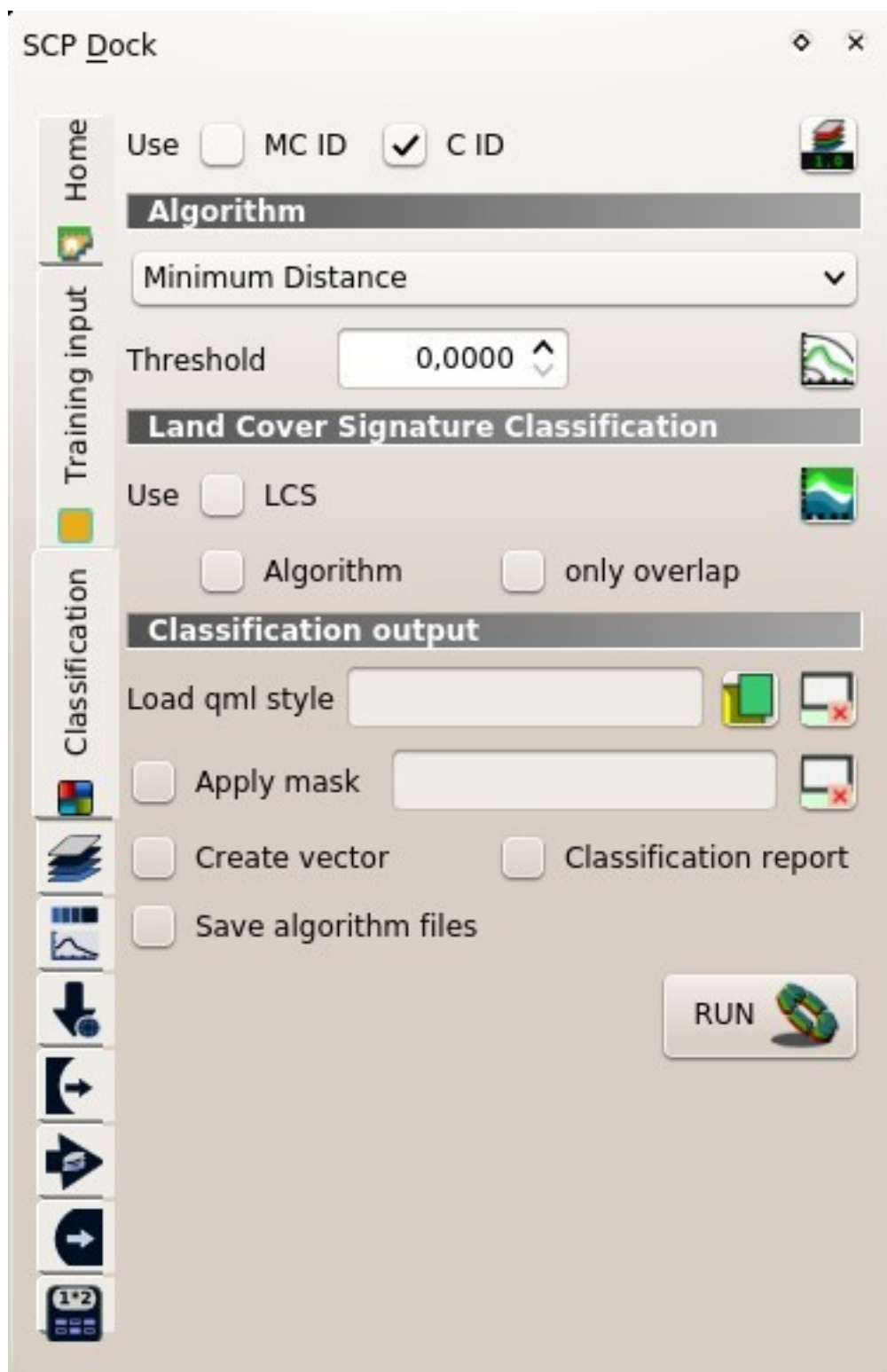







Fig. 6: Classification

- for Spectral Angle Mapping, pixels are unclassified if spectral angle distance is greater than threshold value (max 90);

- : open the *Signature threshold* (page 48) for the definition of signature thresholds;

Land Cover Signature Classification

Land Cover Signature Classification (page 122) is a classification that can be used as alternative or in combination with the *Algorithm* (page 31) (see *LCS threshold* (page 49)). Pixels belonging to two or more different classes (or macroclasses) are classified as *Class overlap* with raster value = -1000.














- Use  *LCS*  *Algorithm*  *only overlap*: if *LCS* is checked, the *Land Cover Signature Classification* is used; if *Algorithm* is checked, the selected *Algorithm* (page 31) is used for unclassified pixels of the *Land Cover Signature Classification*; if *only overlap* is checked, the selected *Algorithm* (page 31) is used only for class overlapping pixels of the *Land Cover Signature Classification*; unclassified pixels of the *Land Cover Signature Classification* are left unclassified;
- : open the *LCS threshold* (page 49);

Classification output

Classification output allows for the classification of the *Band set* (page 37) according to the parameters defined in *Algorithm* (page 31).

In addition, a previously saved *classification style* (QGIS .qml file) can be loaded and used for classification style.

Classification raster is a file .tif (a QGIS style file .qml is saved along with the classification); also other outputs can be optionally calculated. Outputs are loaded in QGIS after the calculation.

- *Load qml* : select a .qml file overriding the colors defined for *C ID* or *MC ID*;
- : reset style to default (i.e. use the colors defined for *C ID* or *MC ID*);
-  *Apply mask* : if checked, a shapefile can be selected for masking the classification output (i.e. the area outside the shapefile is not classified);
- : reset the mask shapefile;
-  *Create vector* : if checked, in addition to the classification raster, a classification shapefile is saved in the same directory and with the same name as the *Classification output*; conversion to vector can also be performed at a later time (see *Classification to vector* (page 80));
-  *Classification report* : if checked, a report about the land cover classification is calculated and saved as a .csv file in the same directory and with the same name (with the suffix _report) as the *Classification output*; report can also be performed at a later time (see *Classification report* (page 77));
-  *Save algorithm files*  : if checked, the *Algorithm raster* (page 124) is saved, in addition to the classification raster, in the same directory as the *Classification output*; a raster for each spectral signature used as input (with the suffix _sig_MC ID_C ID) and a general algorithm raster (with the suffix _alg_raster) are created;
- : choose the output destination and start the image classification;

3.3 Working toolbar

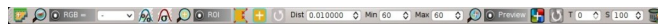




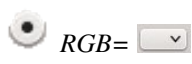


Fig. 7: Working toolbar

The *Working toolbar* allows for creating *temporary ROIs* and *classification previews*.

- *Image control* (page 34)
- *Temporary ROI* (page 34)
- *Classification preview* (page 35)

The functions are described in detail in the following paragraphs.





3.3.1 Image control

-  : show the *Main Interface Window* (page 36);
-  : zoom the map to the extent of the *active band set* in *Band set* (page 37);
-  : use the button to show/hide the *active band set* in *Band set* (page 37) in the map; from the list select a *Color Composite* (page 116) that is applied to the *Band set* (page 37); new color composites can be entered typing the band numbers separated by – or ; or , (e.g. RGB = 4-3-2 or RGB = 4;3;2 or RGB = 4,3,2);
-  : display the input image stretching the minimum and maximum values according to cumulative count of current map extent;
-  : display the input image stretching the minimum and maximum values according to standard deviation of current map extent;


http://www.youtube.com/watch?v=9jA_Rh8YfKQ

3.3.2 Temporary ROI







A *temporary ROI* is a temporary polygon displayed in the map, which can be saved permanently in the *Training input* (page 24). A *temporary ROI* can be drawn manually or using a *Region Growing Algorithm* (page 117) (i.e. the image is segmented around a pixel seed including spectrally homogeneous pixels).

-  : zoom the map to the extent of *temporary ROI*;
-  *ROI*: use the button to show/hide the *temporary ROI* and the *Training input* in the map;
-  : activate the pointer to create a *temporary ROI* by drawing a polygon in the map; left click on the map to define the ROI vertices and right click to define the last vertex closing the polygon; press the keyboard button CTRL to add a multipart polygon; press the keyboard buttons CTRL + Z for removing the last multipart polygon;
-  : activate the pointer to create a *temporary ROI* using the region growing algorithm; left click on the map for creating the ROI; right click on the map for displaying the spectral signature of a pixel of the *active*

band set in the *Spectral Signature Plot* (page 98); press the keyboard button CTRL and left click to add a multipart polygon (new parts are not created if overlapping to other parts); press the keyboard buttons CTRL + Z for removing the last multipart polygon; press the keyboard button CTRL and right click to plot spectral signatures of the same pixel for all the *band sets*;

- : create a *temporary ROI* using the region growing algorithm at the same seed pixel as the previous one; it is useful after changing the *region growing parameters*;

Region growing parameters: the following parameters are required for the ROI creation using a region growing algorithm on

- *Dist*  : set the interval which defines the maximum spectral distance between the seed pixel and the surrounding pixels (in radiometry unit);
- *Min*  : set the minimum area of a ROI (in pixel unit); this setting overrides the Range radius until the minimum ROI size is reached; if Rapid ROI on band is checked, then ROI will have at least the size defined Min ROI size; if Rapid ROI on band is unchecked, then ROI could have a size smaller than Min ROI size;
- *Max*  : set the maximum width of a ROI (i.e. the side length of a square, centred at the seed pixel, which inscribes the ROI) in pixel unit;

<http://www.youtube.com/watch?v=CQqNtlOU6mI>

3.3.3 Classification preview





Classification preview allows for displaying temporary classifications (i.e. classification previews). Classification previews are useful for testing the algorithm in a small area of the *Band set* (page 37), before classifying the entire image which can be time consuming (see *Classification output* (page 33)).





Classification preview is performed according to the parameters defined in *Algorithm* (page 31).

In addition to the classification raster, an *Algorithm raster* (page 124) can be displayed, which is useful for assessing the distance of a pixel classified as *class X* from the corresponding spectral signature *X*. In *Classification previews*, black pixels are distant from the corresponding spectral signature (i.e. probably a new ROI, or spectral signature, should be collected in that area) and white pixels are closer to the corresponding spectral signature (i.e. probably the spectral signature identifies correctly those pixels).

After the creation of a new preview, old previews are placed in QGIS Layers inside a layer group named *Class_temp_group* (custom name can be defined in *Temporary group name* (page 97)) and are deleted when the QGIS session is closed.

WARNING: Classification previews are automatically deleted from disk when the QGIS session is closed; a QGIS message (that can be ignored) could ask for the path of missing layers when opening a previously saved project.

- : zoom the map to the extent of the last *Classification preview* (page 35);
-  *Preview*: use the button to show/hide the last *Classification preview* (page 35) in the map;
- : activate the pointer for the creation of a *Classification preview* (page 35); left click the map to start the classification process and display the classification preview; right click to start the classification process and show the *Algorithm raster* (page 124) of the preview;
- : create a new *Classification preview* (page 35) centred at the same pixel as the previous one;

-  *T*: change dynamically the classification preview transparency, which is useful for comparing the classification to other layers;
-  *S* : size of the preview in pixel unit (i.e. the side length of a square, centred at the clicked pixel);
- : remove from QGIS the *classification previews* that are archived in the *Class_temp_group*;

3.4 Main Interface Window

The Main Interface Window is composed of several tabs described in detail in the following paragraphs. Tabs can be selected through the menu at the left side.

- *Band set* (page 37)
 - *Multiband image list* (page 38)
 - *Single band list* (page 38)
 - *Band set definition* (page 38)
 - *Band set tools* (page 40)
- *Basic tools* (page 40)
 - *RGB list* (page 40)
 - *Algorithm band weight* (page 42)
 - *Multiple ROI Creation* (page 43)
 - *Import signatures* (page 44)
 - *Export signatures* (page 46)
 - *Signature threshold* (page 48)
 - *LCS threshold* (page 49)
- *Download products* (page 51)
 - *Login data* (page 51)
 - *Search* (page 52)
 - *Download options* (page 55)
- *Preprocessing* (page 56)
 - *Landsat* (page 56)
 - *Sentinel-2* (page 58)
 - *Sentinel-3* (page 59)
 - *ASTER* (page 61)
 - *MODIS* (page 62)
 - *Vector to raster* (page 64)
 - *Clip multiple rasters* (page 65)
 - *Split raster bands* (page 66)
 - *Stack raster bands* (page 67)
 - *Mosaic band sets* (page 67)

- *Cloud masking* (page 69)
- *Band processing* (page 70)
 - *Band combination* (page 70)
 - *PCA* (page 71)
 - *Clustering* (page 72)
 - *Spectral distance* (page 73)
- *Postprocessing* (page 75)
 - *Accuracy* (page 75)
 - *Land cover change* (page 76)
 - *Classification report* (page 77)
 - *Cross classification* (page 78)
 - *Class signature* (page 79)
 - *Classification to vector* (page 80)
 - *Reclassification* (page 81)
 - *Edit raster* (page 82)
 - *Classification sieve* (page 84)
 - *Classification erosion* (page 85)
 - *Classification dilation* (page 86)
- *Band calc* (page 87)
 - *Band list* (page 87)
 - *Expression* (page 87)
 - *Index calculation* (page 89)
 - *Decision rules* (page 89)
 - *Output raster* (page 90)
- *Batch* (page 91)
 - *Batch* (page 91)
 - *Run* (page 94)
- *Settings* (page 94)
 - *Processing* (page 94)
 - *Interface* (page 96)
 - *Debug* (page 97)

3.4.1 Band set

Image input in *SCP* is named *band set*. This tab allows for the definition of one or more *band sets* used as input for classification and other tools.

Band sets are identified by numbers. The *active band set* (i.e. the tab selected in *Band set definition* (page 38) with bold green name) is used as input for the tools in *SCP dock* (page 23) and *Working toolbar* (page 34). Other *SCP* tools allow for the selection of *band set* numbers.

The *Band set* definition is saved with the QGIS project.

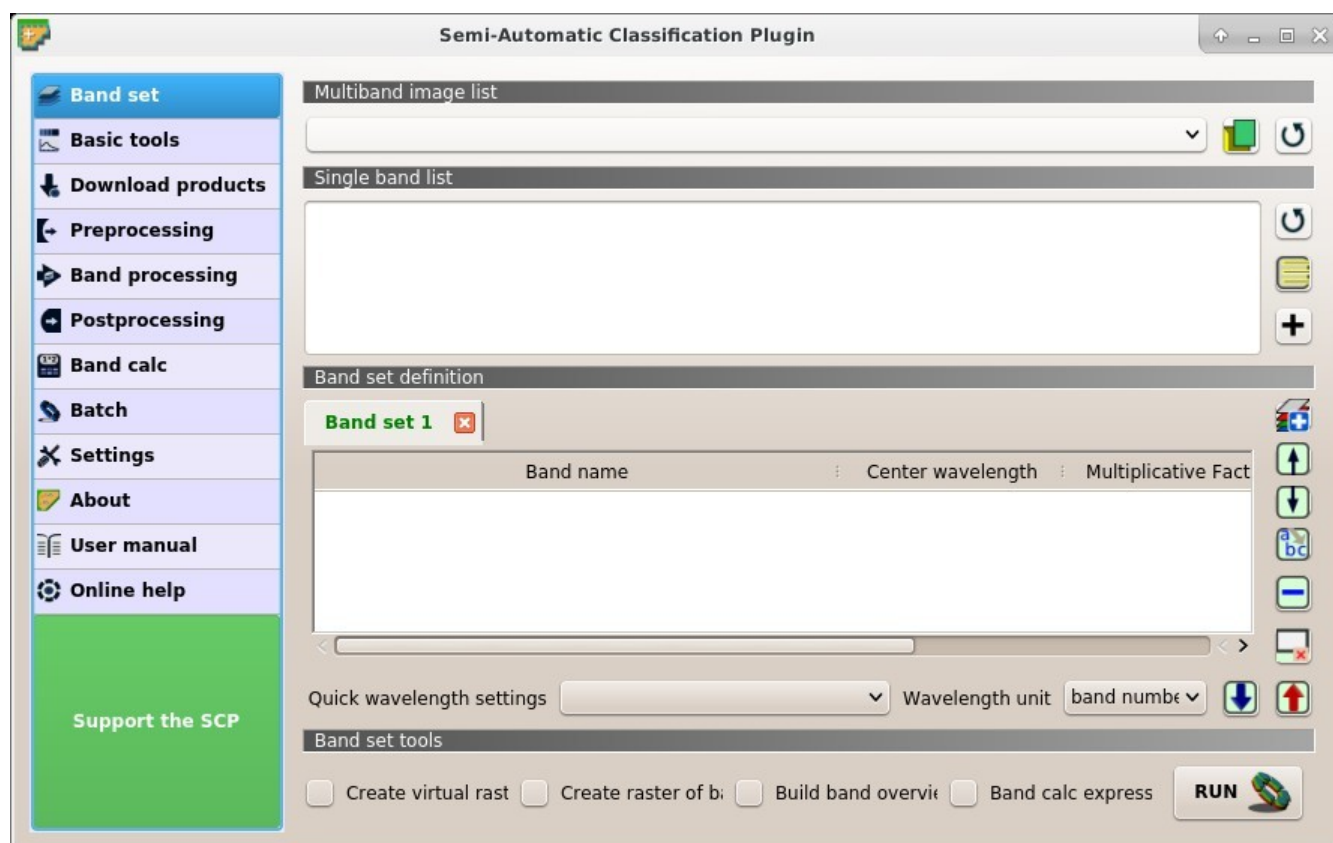





Fig. 8:  *Band set*




Multiband image list

This section allows for the selection of a multiband raster. If selected, raster bands are listed in the *active band set*.

-  : select the input image from a list of multispectral images loaded in QGIS;
-  : open one or more raster files that are added to the *active band set* and loaded in QGIS;
-  : refresh layer list;


Single band list


List of single band rasters already loaded in QGIS. It is possible to select one or more bands to be added to the *active band set*.

-  : refresh list of raster bands loaded in QGIS;
-  : select all raster bands;
-  : add selected rasters to the *active band set*.

Band set definition

Definition of bands composing the *band sets*. The *active band set* is the tab selected with bold green name. It is possible to add new *band sets* clicking the following button:















- : add a new empty *band set*;





Click the  in the tab to remove the corresponding *band set*. *Band sets* can be reordered dragging the tabs.

The *Center wavelength* of bands should be defined in order to use several functions of *SCP*. If the *Center wavelength* of bands is not defined, the band number is used and some *SCP* tools will be disabled.

It is possible to define a multiplicative rescaling factor and additive rescaling factor for each band (for instance using the values in Landsat metadata), which are used on the fly (i.e. $\text{pixel value} = \text{original pixel value} * \text{multiplicative rescaling factor} + \text{additive rescaling factor}$) during the processing.

Every *band set* is defined with the following table:






-  **Band set #:** table containing the following fields;
 - *Band name*  : name of the band; name cannot be edited;
 - *Center wavelength*  : center of the wavelength of the band;
 - *Multiplicative Factor*  : multiplicative rescaling factor;
 - *Additive Factor*  : additive rescaling factor;
 - *Wavelength unit*  : wavelength unit;
 - *Image name*  : image name for multiband rasters;
- : move highlighted bands upward;
- : move highlighted bands downward;
- : sort automatically bands by name, giving priority to the ending numbers of name;
- : remove highlighted bands from the *active band set*;
- : clear all bands from *active band set*;
- *Quick wavelength settings*   : rapid definition of band center wavelength for the following satellite sensors:
 - ASTER;
 - GeoEye-1;
 - Landsat 8 OLI;
 - Landsat 7 ETM+;
 - Landsat 5 TM;
 - Landsat 4 TM;
 - Landsat 1, 2, and 3 MSS;
 - MODIS;

- Pleiades;
 - QuickBird;
 - RapidEye;
 - Sentinel-2;
 - Sentinel-3;
 - SPOT 4;
 - SPOT 5;
 - SPOT 6;
 - WorldView-2 and WorldView-3;
- **Wavelength unit**   : select the wavelength unit among:
 - *Band number*: no unit, only band number;
 - *μm*: micrometres;
 - *nm*: nanometres;
-  : import a previously saved *active band set* from file;
-  : export the *active band set* to a file;


<http://www.youtube.com/watch?v=1PclAtPjyZE>

Band set tools

It is possible to perform several processes directly on *active band set*.

-  *Create virtual raster of band set*: if checked, create a virtual raster of bands;
-  *Create raster of band set (stack bands)*: if checked, stack all the bands and create a unique .tif raster;
-  *Build band overviews*: if checked, build raster overviews (i.e. pyramids) for improving display performance; overview files are created in the same directory as bands;
-  *Band calc expression*: if checked, calculate the *Expression* (page 87) entered in *Band calc* (page 87); it is recommended the use of *Band set* variables in the expression (e.g. `bandset #b1`);
- *RUN*  : choose the output destination and start the process;

3.4.2 Basic tools

The tab  `Basic tools` includes several tools for manipulating input data.

RGB list

This tab allows for managing the RGB *Color Composite* (page 116) used in the list *RGB=* of the *Image control* (page 34).

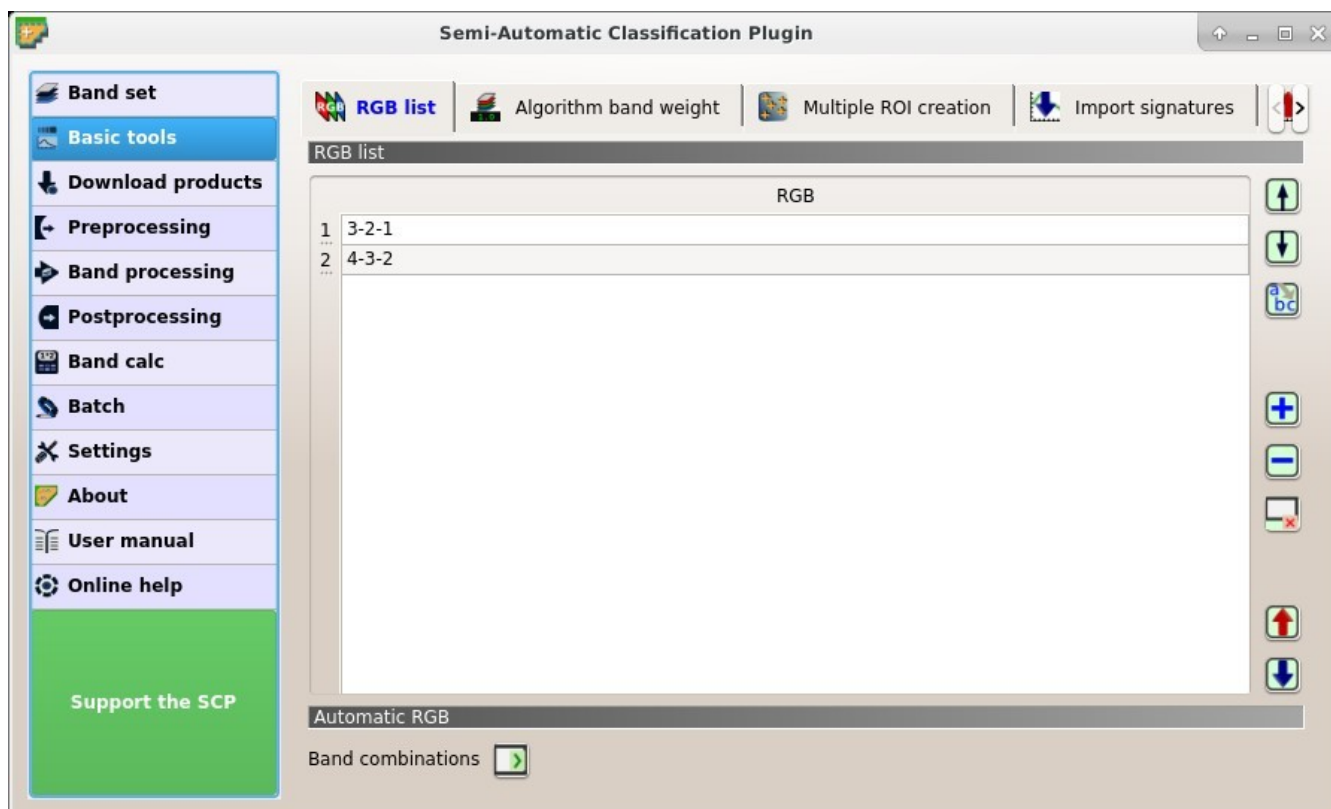












Fig. 9:  *RGB list*

RGB list

-  ***RGB list***: table containing the following fields;
 - *RGB*: RGB combination; this field can be manually edited;
- : move highlighted RGB combination upward;
- : move highlighted RGB combination downward;
- : automatically sort RGB combinations by name;
- : add a row to the table;
- : remove highlighted rows from the table;
- : clear all RGB combinations from *RGB list*;
- : export the *RGB list* to a file (i.e. `.csv`);
- : import a previously saved *RGB list* from file (i.e. `.csv`);

Automatic RGB

- **Band combinations** : add the combinations of all bands (i.e. permutation) to the *RGB list* (page 41) (e.g. 1-2-3, 1-2-4, ..., 3-2-1);

Algorithm band weight

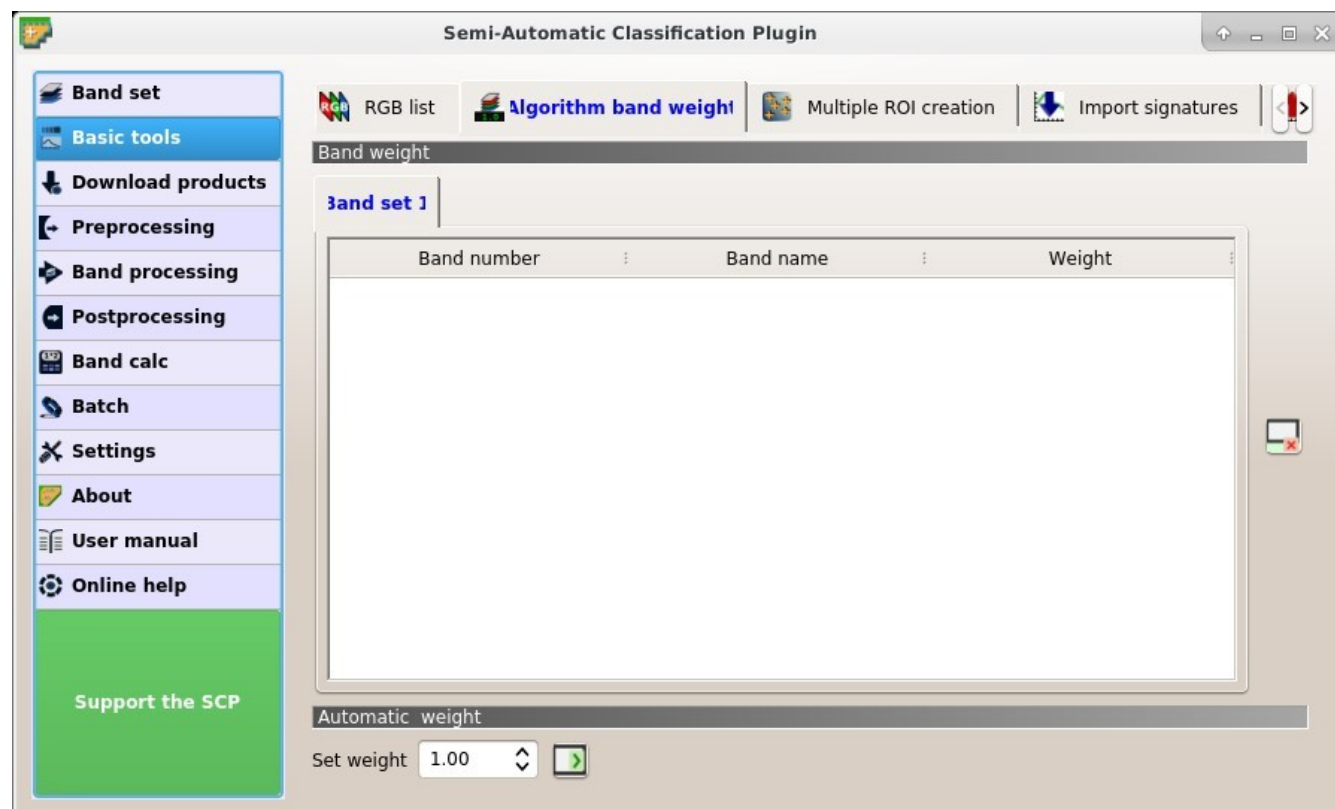






Fig. 10:  *Algorithm band weight*

This tab allows for the definition of band weights that are useful for improving the spectral separability of materials at certain wavelengths (bands). During the classification process, band values and spectral signature values are multiplied by the corresponding band weights, thus modifying the spectral distances. A tab is displayed for every *Band set* (page 37).

Band weight

-  **Band weight**: table containing the following fields;
 - *Band number* : number of the band in the *Band set*;
 - *Band name* : name of the band;
 - *Weight* : weight of the band; this value can be edited;

Automatic weight

- : reset all band weights to 1;
- Set weight  : set the defined value as weight for all the highlighted bands in the table;

Multiple ROI Creation

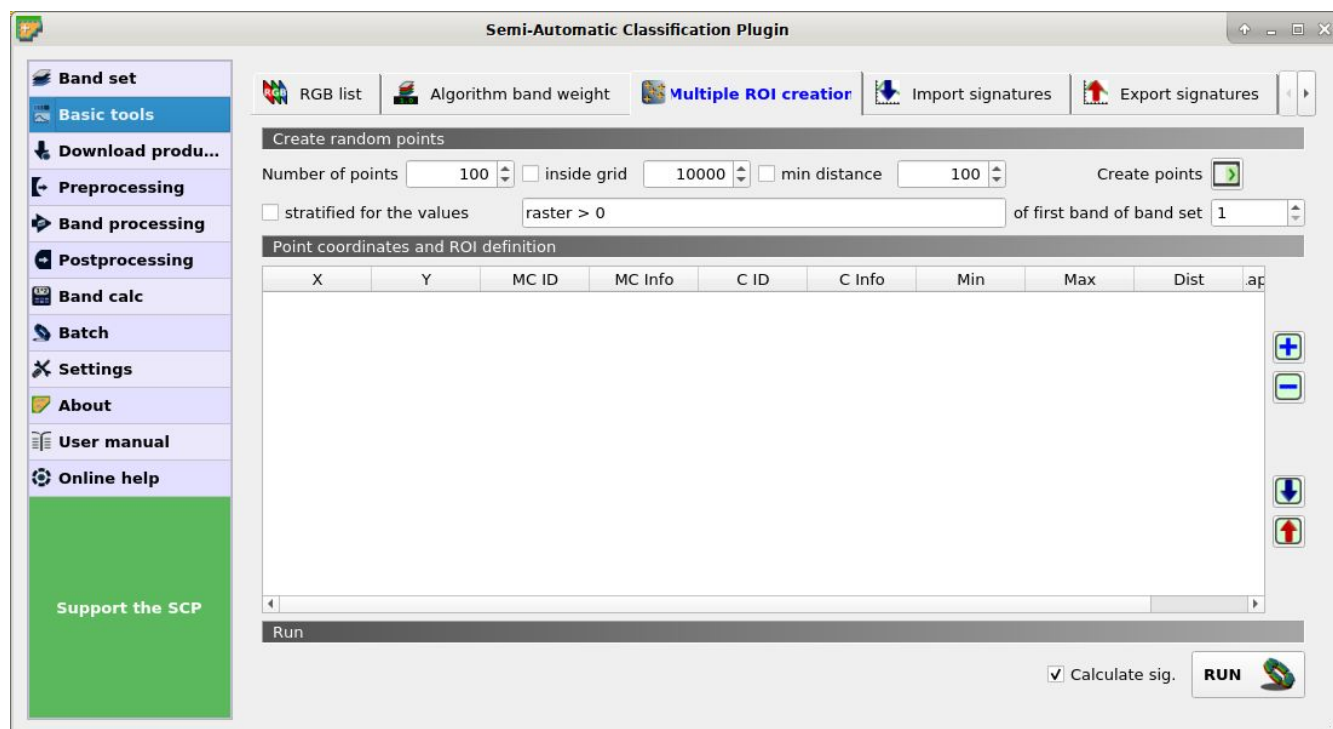










Fig. 11:  Multiple ROI Creation






This tab allows for the automatic creation of ROIs, useful for the rapid classification of multi-temporal images, or for accuracy assessment. Given a list of point coordinates and ROI options, this tool performs the region growing of ROIs. Created ROIs are automatically saved to the *Training input* (page 24). The *active band set* in *Band set* (page 37) is used for calculations.

Create random points



- Number of points : set a number of points that will be created when *Create points*  is clicked;
- ☒ inside grid : if checked, the *band set* area is divided in cells where the size thereof is defined in the combobox (image unit, usually meters); points defined in *Number of random points* are created randomly within each cell;
- ☒ min distance : if checked, random points have a minimum distance defined in the combobox (image unit, usually meters); setting a minimum distance can result in fewer points than the number defined in *Number of points*;
- Create points : create random points inside the *band set* area;

-  *stratified for the values*  of the first band of the band set *min distance* : if checked, create random points inside the values defined in the expression calculated for the first band of the defined band set; the expression must include the variable `raster`; multiple expressions can be entered separated by semicolon (;) but the total number of stratified points is the same as the defined *Number of points*;

Point coordinates and ROI definition

-  **Point coordinates and ROI definition: table containing the following fields;**
 - *X* : point X coordinate (float);
 - *Y* : point Y coordinate (float);
 - *MC ID*: ROI Macroclass ID (int);
 - *MC Info*: ROI Macroclass information (text);
 - *C ID*: ROI Class ID (int);
 - *C Info*: ROI Class information (text);
 - *Min* : the minimum area of a ROI (in pixel unit);
 - *Max* : the maximum width of a ROI (in pixel unit);
 - *Dist* : the interval which defines the maximum spectral distance between the seed pixel and the surrounding pixels (in radiometry unit);
 - *Rapid ROI band* : if a band number is defined, ROI is created only using the selected band, similarly to *Rapid ROI band* in [ROI Signature list](#) (page 27) ;
-  : add a new row to the table; all the table fields must be filled for the ROI creation;
-  : delete the highlighted rows from the table;
-  : import a point list from text file or a point shapefile to the table; in case of text file, every line must contain values separated by tabs of X, Y, MC ID, MC Info, Class ID, C Info, Min, Max, Dist, and optionally the *Rapid ROI band*; in case of shapefile, only point coordinates are imported;
-  : export the point list to text file;

Run

-  *Calculate sig.*: if checked, the spectral signature is calculated while the ROI is saved to *Training input* (page 24);
- *RUN*  : start the ROI creation process for all the points and save ROIs to the *Training input* (page 24);

Import signatures

The tab  *Import signatures* allows for importing spectral signatures from various sources.

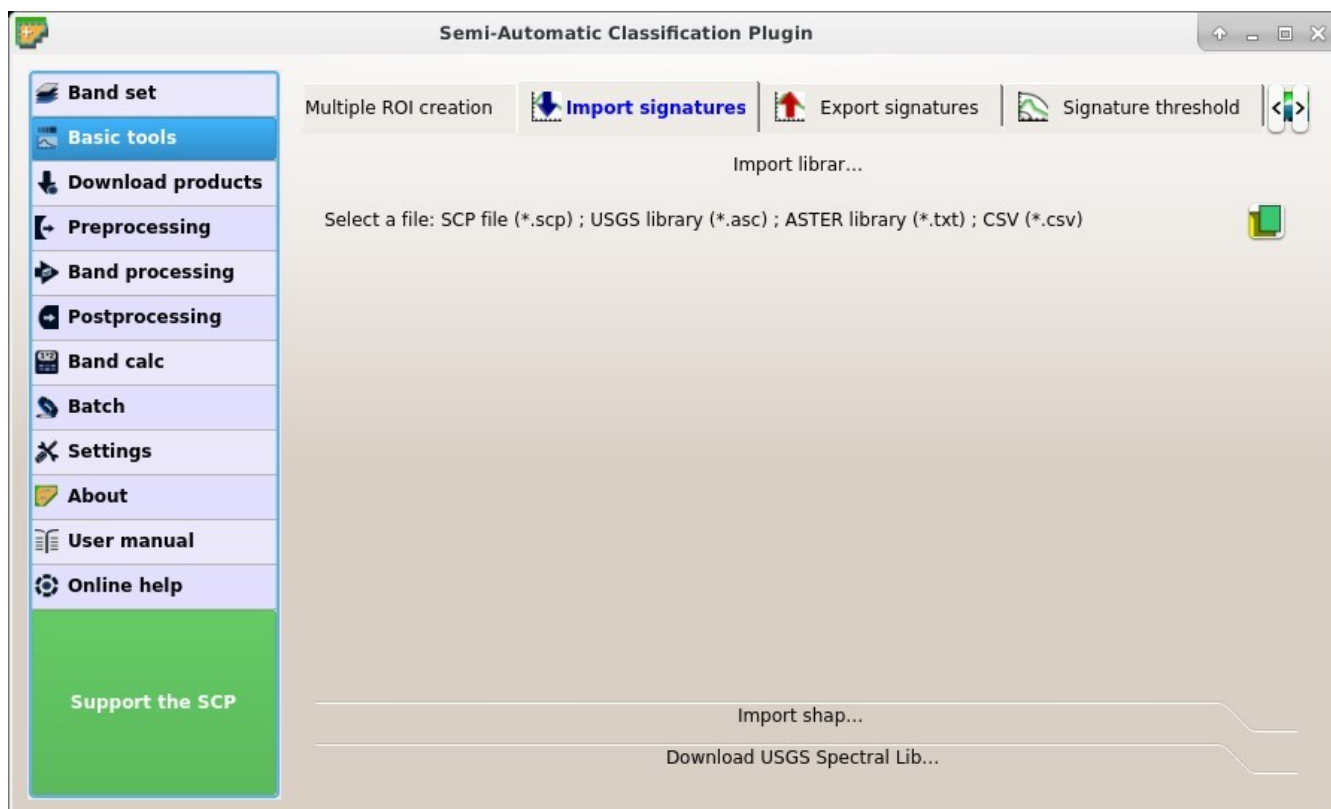



Fig. 12: Import library file







Import library file

This tool allows for importing spectral signatures from various sources: a previously saved *Training input* (page 24) (.scp file); a USGS Spectral Library (.asc file); a previously exported CSV file. In case of USGS Spectral Library, the library is automatically sampled according to the image band wavelengths defined in the *Band set* (page 37), and added to the *ROI Signature list* (page 27);

- *Select a file* : open a file to be imported in the *Training input* (page 24);

Import shapefile

This tool allows for importing a shapefile, selecting the corresponding fields of the *Training input* (page 24).

- *Select a shapefile* : open a shapefile;
- *MC ID field* : select the shapefile field corresponding to MC ID;
- *MC Info field* : select the shapefile field corresponding to MC Info;
- *C ID field* : select the shapefile field corresponding to C ID;
- *C Info field* : select the shapefile field corresponding to C Info;
- ☒ *Calculate sig.*: if checked, the spectral signature is calculated while the ROI is saved to *Training input* (page 24);
- *Import shapefile* : import all the shapefile polygons as ROIs in the *Training input* (page 24);

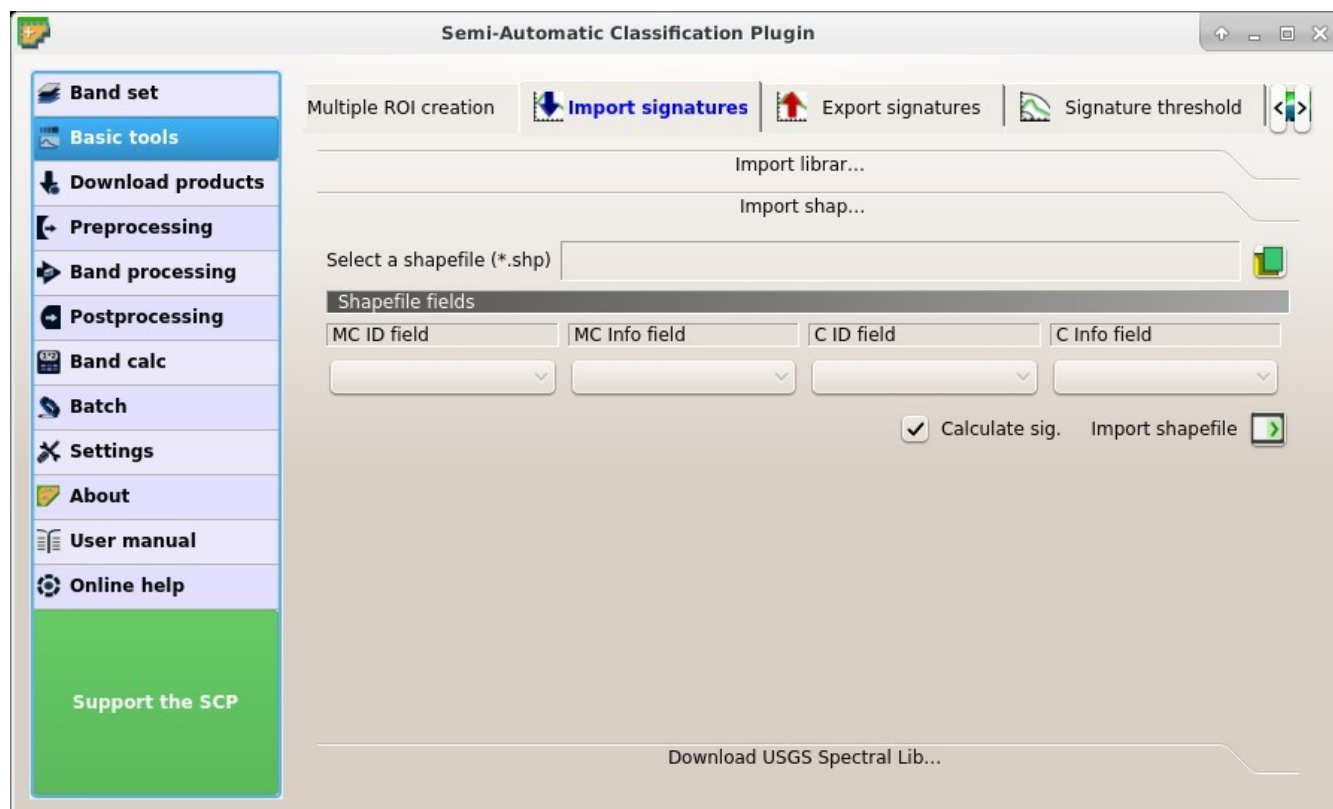





Fig. 13: Import shapefile

Download USGS Spectral Library

The tab *Download USGS Spectral Library* allows for the download of the [USGS spectral library](#) (Clark, R.N., Swayze, G.A., Wise, R., Livo, E., Hoefen, T., Kokaly, R., Sutley, S.J., 2007, USGS digital spectral library splib06a: U.S. Geological Survey, Digital Data Series 231).


The libraries are grouped in chapters including Minerals, Mixtures, Coatings, Volatiles, Man-Made, Plants, Vegetation Communities, Mixtures with Vegetation, and Microorganisms. An internet connection is required.

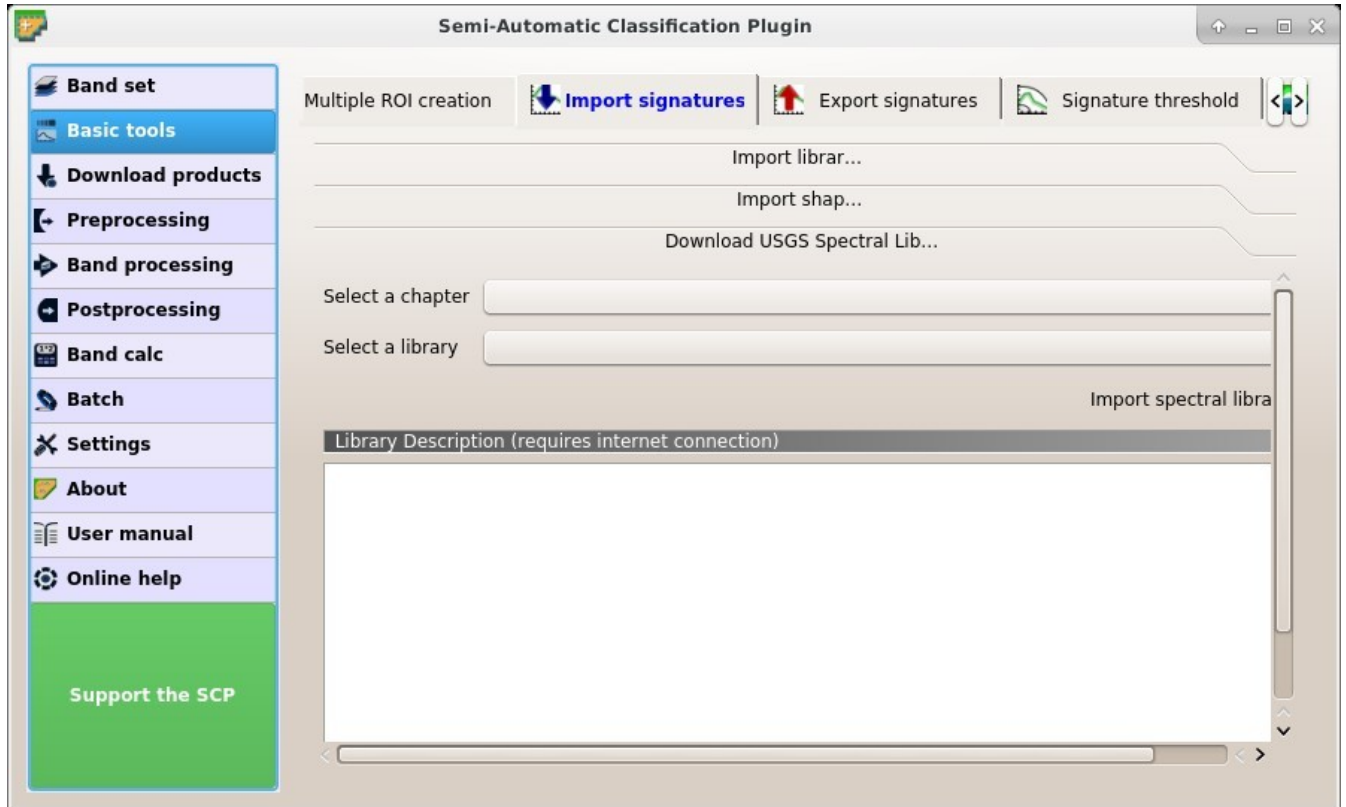
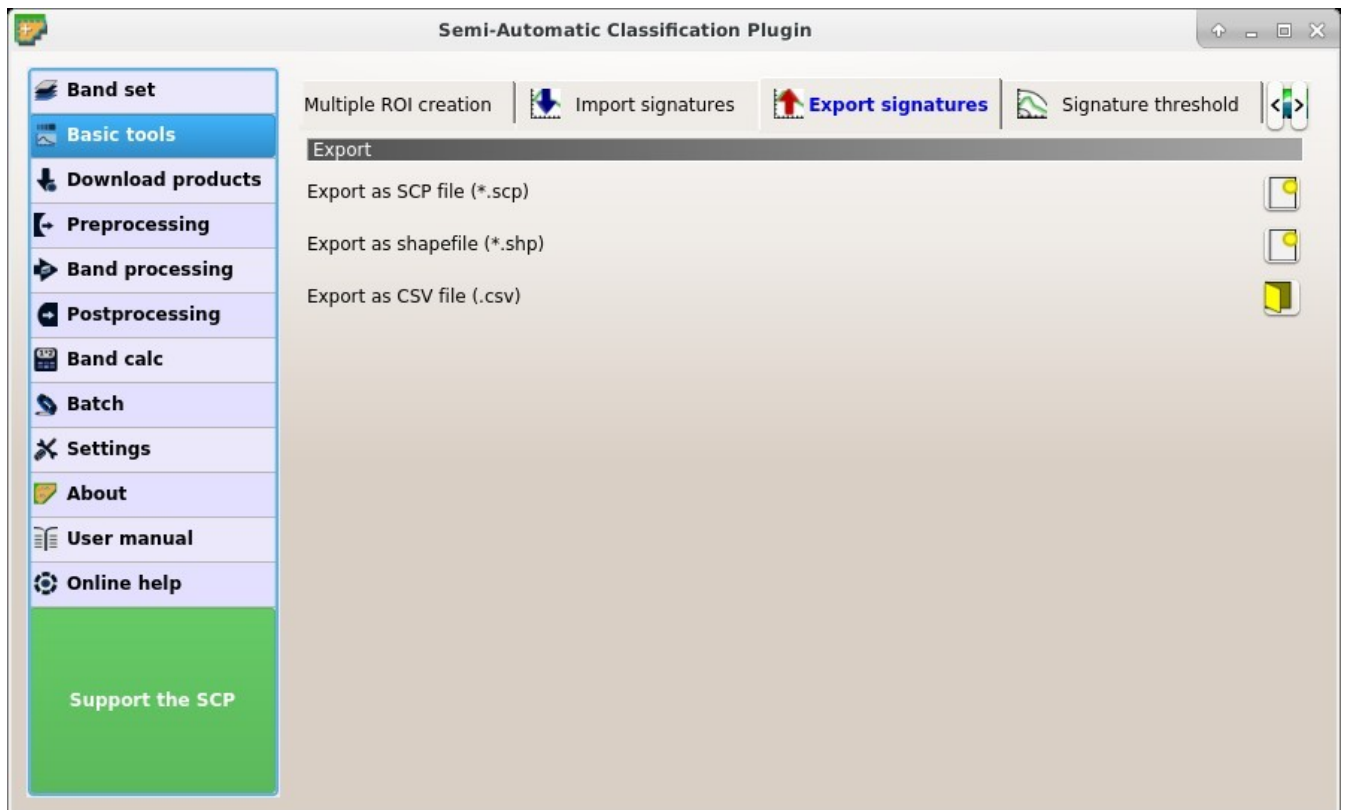
- *Select a chapter* : select one of the library chapters; after the selection, chapter libraries are shown in *Select a library*;
- *Select a library* : select one of the libraries; the library description is displayed in the frame *Library description*;
- *Import spectral library* : download the library and add the sampled spectral signature to the *ROI Signature list* (page 27) using the parameters defined for class and macroclass; the library is automatically sampled according to the image band wavelengths defined in the *active band set* in *Band set* (page 37), and added to the *ROI Signature list* (page 27);

Tip: Spectral libraries downloaded from the USGS Spectral Library can be used with Minimum Distance or Spectral Angle Mapping algorithms, but not Maximum Likelihood because this algorithm needs the covariance matrix that is not included in the spectral libraries.



Export signatures

This tool allows for exporting the signatures highlighted in the *ROI Signature list* (page 27).

- *Export as SCP file* : create a new .scp file and export highlighted ROIs and spectral signatures as *SCP*

Fig. 14: *Download USGS Spectral Library*Fig. 15:  *Export signatures*

file (*.scp);

- *Export as shapefile* : export highlighted ROIs (spectral signature data excluded) as a new shapefile (*.shp);
- *Export as CSV file* : open a directory, and export highlighted spectral signatures as individual CSV files (*.csv) separated by semicolon (;);

Signature threshold

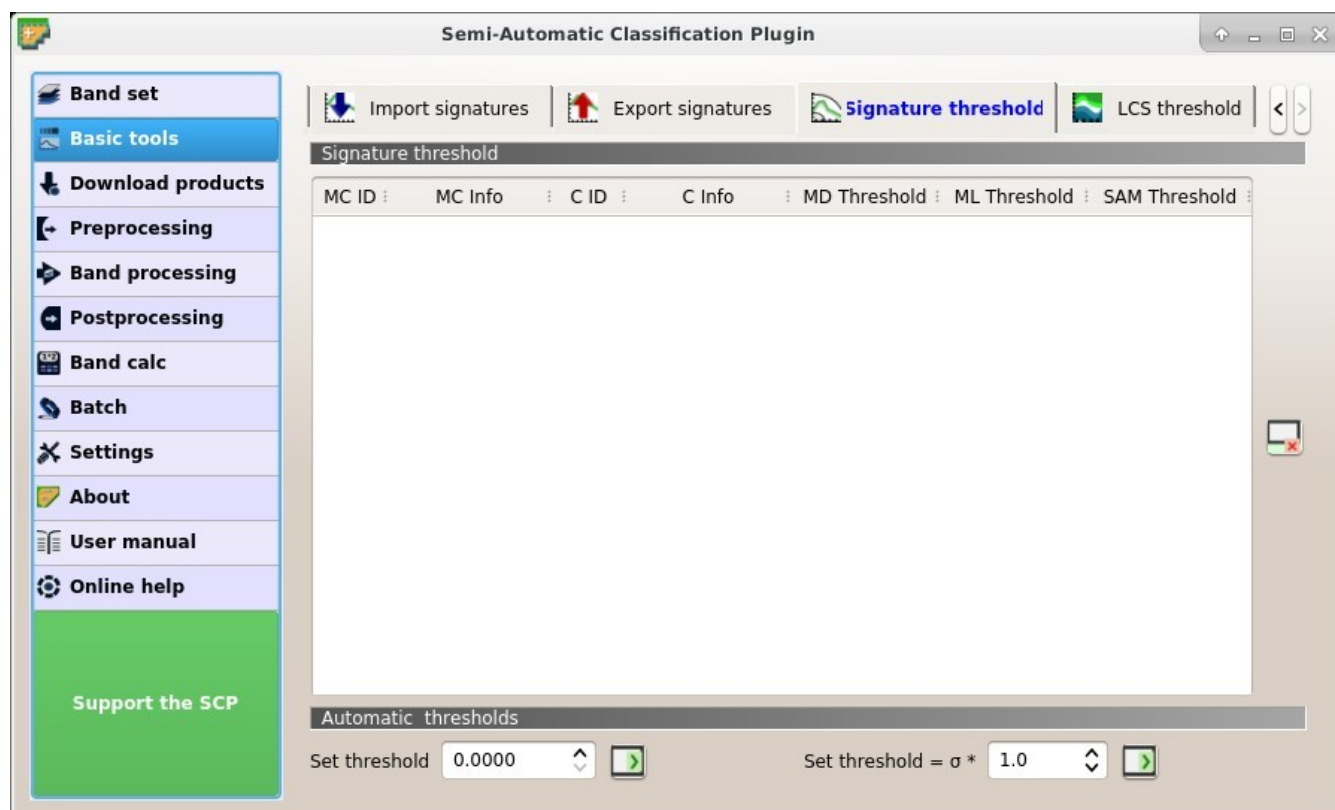


Fig. 16:  *Signature threshold*



This tab allows for the definition of a classification threshold for each spectral signature. All the signatures contained in the *Training input* (page 24) are listed. Thresholds defined in this tool are applied to classification only if *Threshold* value in *Algorithm* (page 31) is 0.

This is useful for improving the classification results, especially when spectral signatures are similar. Thresholds of signatures are saved in the *Training input* (page 24).





If threshold is 0 then no threshold is applied and all the image pixels are classified. Depending on the selected *Algorithm* (page 31) the threshold value is evaluated differently:

- for Minimum Distance, pixels are unclassified if distance is greater than threshold value;
- for Maximum Likelihood, pixels are unclassified if probability is less than threshold value (max 100);
- for Spectral Angle Mapping, pixels are unclassified if spectral angle distance is greater than threshold value (max 90).

Signature threshold

-  **Signature threshold:** table containing the following fields;
 - *MC ID*: signature Macroclass ID;
 - *MC Info*: signature Macroclass Information;
 - *C ID*: signature Class ID;
 - *C Info*: signature Class Information;
 - *MD Threshold*: Minimum Distance threshold; this value can be edited;
 - *ML Threshold*: Maximum Likelihood threshold; this value can be edited;
 - *SAM Threshold*: Spectral Angle Mapping threshold; this value can be edited;
- : reset all signatures thresholds to 0 (i.e. no threshold used);

Automatic thresholds

- Set threshold  : set the defined value as threshold for all the highlighted signatures in the table;
- Set threshold = $\sigma * \text{value}$  : for all the highlighted signatures, set an automatic threshold calculated as the distance (or angle) between mean signature and (mean signature + ($\sigma * v$)), where σ is the standard deviation and v is the defined value; currently works for Minimum Distance and Spectral Angle Mapping;


LCS threshold

This tab allows for setting the signature thresholds used by *Land Cover Signature Classification* (page 122). All the signatures contained in the *Training input* (page 24) are listed; also, signature thresholds are saved in the *Training input* (page 24).

Overlapping signatures (belonging to different classes or macroclasses) are highlighted in orange in the table *LC Signature threshold*; the overlapping check is performed considering *MC ID* or *C ID* according to the setting *Use*

☒ *MC ID* ☒ *C ID* in *Algorithm* (page 31). Overlapping signatures sharing the same *ID* are not highlighted.

LC Signature threshold

-  **LC Signature threshold:** table containing the following fields;
 - *MC ID*: signature Macroclass ID;
 - *MC Info*: signature Macroclass Information;
 - *C ID*: signature Class ID;
 - *C Info*: signature Class Information;
 - *Color [overlap MC_ID-C_ID]*: signature color; also, the combination *MC ID-C ID* is displayed in case of overlap with other signatures (see *Land Cover Signature Classification* (page 122));
 - *Min B X*: minimum value of band X; this value can be edited;
 - *Max B X*: maximum value of band X; this value can be edited;

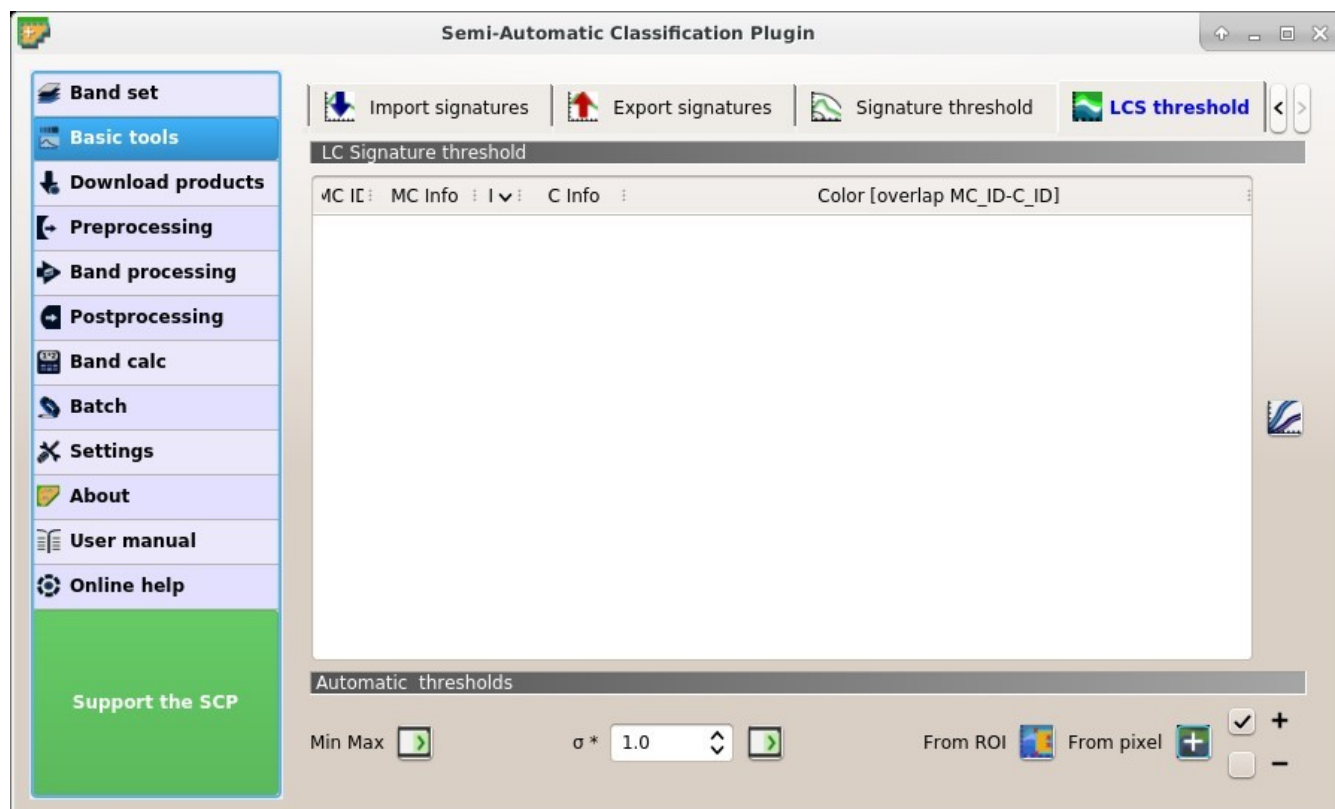






Fig. 17:  *LCS threshold*

- : show the ROI spectral signature in the *Spectral Signature Plot* (page 98); spectral signature is calculated from the *Band set* (page 37);


Automatic thresholds

Set thresholds automatically for highlighted signatures in the table *LC Signature threshold*; if no signature is highlighted, then the threshold is applied to all the signatures.

- *Min Max* : set the threshold based on the minimum and maximum of each band;
- $\sigma * 1.0$ : set an automatic threshold calculated as $(\text{band value} + (\sigma * v))$, where σ is the standard deviation of each band and v is the defined value;
- *From ROI* : set the threshold using the temporary ROI pixel values, according to the following checkboxes:
 - ☒ +: if checked, signature threshold is extended to include pixel signature;
 - ☒ -: if checked, signature threshold is reduced to exclude pixel signature;
- *From pixel* : set the threshold by clicking on a pixel, according to the following checkboxes:
 - ☒ +: if checked, signature threshold is extended to include pixel signature;

-  –: if checked, signature threshold is reduced to exclude pixel signature;

3.4.3 Download products

The tab  *Download products* includes the tools for searching and downloading free remote sensing images. Also, automatic conversion to reflectance of downloaded bands is available.

An internet connection is required and free registration could be required depending on the download service.

This tool allows for searching and downloading:

- *Landsat Satellites* (page 113) images (from 1 MSS to 8 OLI) acquired from the 80s to present days;
- *Sentinel-2 Satellite* (page 114) images (Level-1C and Level-2A) acquired from 2015 to present days;
- *Sentinel-3 Satellite* (page 114) images (OLCI Level-1B OL_1_EFR) acquired from 2016 to present days;
- *ASTER Satellite* (page 115) images (Level 1T) acquired from 2000 to present days;
- *MODIS Products* (page 115) images (MOD09GQ, MYD09GQ, MOD09GA, MYD09GA, MOD09Q1, MYD09Q1, MOD09A1, MYD09A1) acquired from 2000 to present days;

For Landsat, ASTER, and MODIS the search is performed through the [CMR Search API](#) developed by NASA. Landsat images are freely available through the services: [EarthExplorer](#), [Google Earth Engine](#), and the [Amazon Web Services \(AWS\)](#) (only for Landsat 8). The ASTER L1T and MODIS products are retrieved from the online Data Pool, courtesy of the NASA Land Processes Distributed Active Archive Center (LP DAAC), USGS/Earth Resources Observation and Science (EROS) Center, Sioux Falls, South Dakota, https://lpdaac.usgs.gov/data_access/data_pool.




For Sentinel-2 and Sentinel-3 the search is performed through the [Copernicus Open Access Hub](#) (using the [Data Hub API](#)); images are mainly downloaded from the [Amazon S3 AWS](#) if available.

This tool attempts to download images first from *Amazon Web Services* and *Google Earth Engine*; only if images are not available, the download is performed through the services that require to login.

Login data


Login <https://ers.cr.usgs.gov>

For Landsat images *USGS EROS* credentials (<https://ers.cr.usgs.gov>) are required for downloads from [EarthExplorer](#). Login using your *USGS EROS* credentials or register for free at <https://ers.cr.usgs.gov/register>.

- User  : enter the user name;
- Password  : enter the password;
-  *remember*: remember user name and password in QGIS;

Login <https://urs.earthdata.nasa.gov>

For ASTER and MODIS images *EOSDIS Earthdata* credentials (<https://urs.earthdata.nasa.gov>) are required for download. Login using your *EOSDIS Earthdata* credentials or register for free at <https://urs.earthdata.nasa.gov/users/new>. Before downloading ASTER and MODIS images, you must approve LP DAAC Data Pool clicking the following link https://urs.earthdata.nasa.gov/approve_app?client_id=ijpRZvb9qeKCK5ctsn75Tg

- User  : enter the user name;

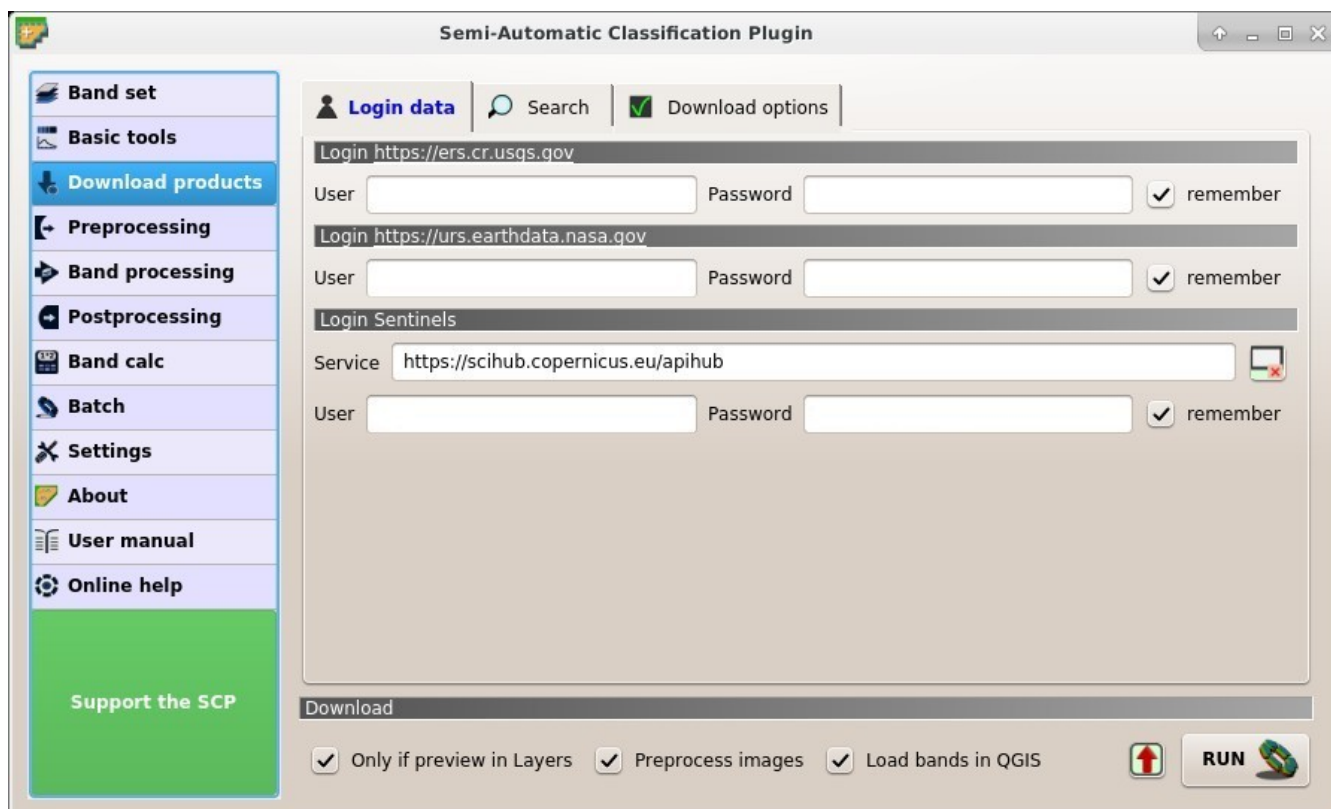









Fig. 18:  Login data

- Password  : enter the password;
-  *remember*: remember user name and password in QGIS;

Login Sentinel

In order to access to Sentinel data a free registration is required at <https://scihub.copernicus.eu/userguide/1SelfRegistration> (other services may require different registrations). After the registration, enter the user name and password for accessing data.

- Service  : enter the service URL (default is <https://scihub.copernicus.eu/apihub>); other mirror services that share the same infrastructure can be used (such as <https://scihub.copernicus.eu/dhus> , <https://finhub.nsd.c.fmi.fi> , <https://data.sentinel.zamg.ac.at>);
-  : reset the default service;
- User  : enter the user name;
- Password  : enter the password;
-  *remember*: remember user name and password in QGIS;

Search

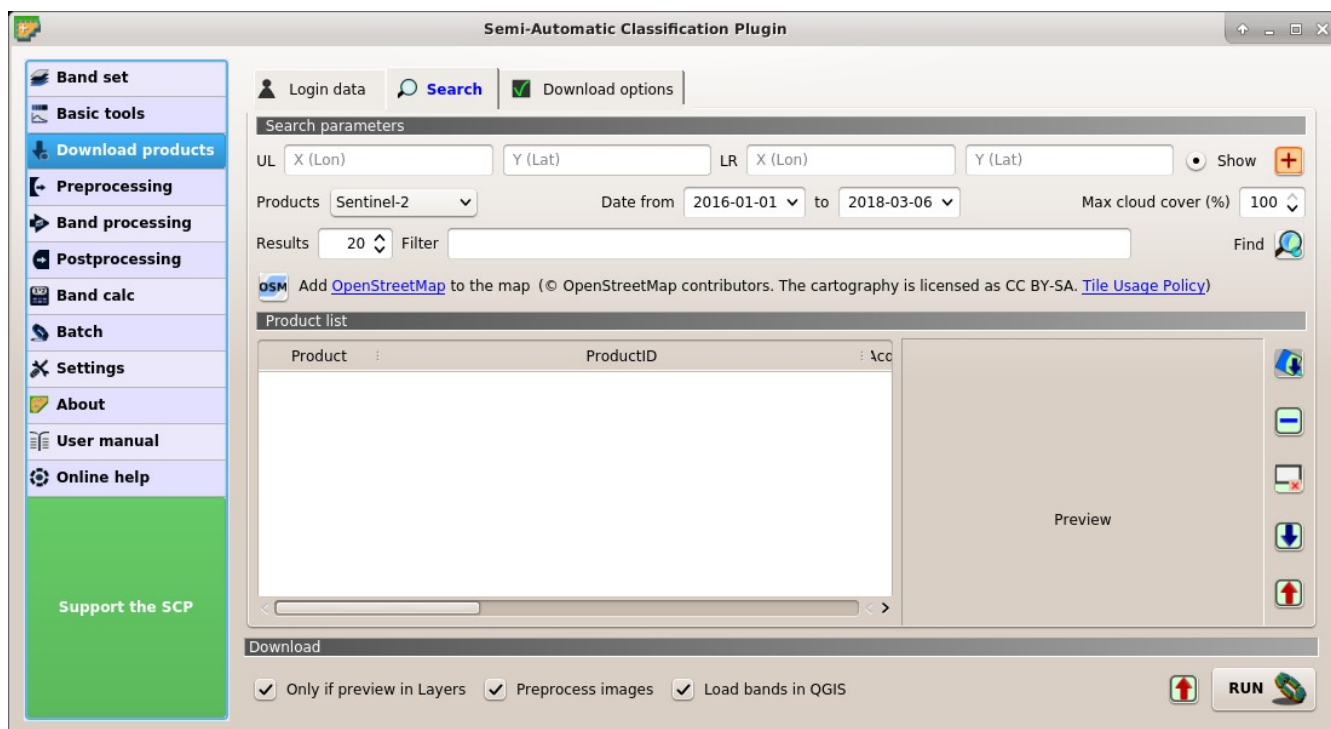
















Fig. 19:  Search

Search parameters

Define the search area by entering the coordinates (longitude and latitude) of an Upper Left (UL) point and Lower Right (LR) point and select a product to search. Optional settings are date of acquisition, maximum cloud cover, number of results (the less the results, the faster is the query).

The definition of a search area is required before searching the images.








- **UL**  : set the UL longitude X (Lon) and the UL latitude Y (Lat);
- **LR**  : set the LR longitude X (Lon) and the LR latitude Y (Lat);
-  **Show**: show or hide the search area in the map;
- : define a search area by left click to set the UL point and right click to set the LR point; the search area is displayed in the map;
- **Products** : set the search product;
- **Date from** : set the starting date of acquisition;
- **to** : set the ending date of acquisition;
- **Max cloud cover (%)** : maximum cloud cover in the product;
- **Results** : maximum number of products returned by the search;
- **Filter** : set a filter such as the Product ID (e.g. LC81910312015006LGN00); it is possible to enter multiple Product IDs separated by comma or semicolon (e.g. LC81910312015006LGN00, LC81910312013224LGN00); filter is applied to resulting products in the search area;

-  *Find*: find the products in the search area; results are displayed inside the table in *Product list* (page 54); results are added to previous results;
-  Add OpenStreetMap to the map: this button allows for the display of OpenStreetMap tiles (© OpenStreetMap contributors) in the QGIS map as described in <https://wiki.openstreetmap.org/wiki/QGIS> . The cartography is licensed as CC BY-SA ([Tile Usage Policy](#));

Tip: Search results (and the number thereof) depend on the defined area extent and the range of dates. In order to get more results, perform multiple searches defining smaller area extent and narrow acquisition dates (from and to).






Product list

The table *Product list* contains the results of the search. Click on any item (highlight) to display the image preview thereof. Results are saved with the QGIS project.

-  *Product list*  : found products are displayed in this table, which includes the following fields;
 - *Product*: the product name;
 - *ProductID*: the product ID;
 - *AcquisitionDate*: date of acquisition of product;
 - *CloudCover*: percentage of cloud cover in the product;
 - *Zone/Path*: the zone or WRS path depending on the product type;
 - *Row/DayNightFlag*: the WRS row or acquisition flag(day or night) depending on the product type;
 - *min_lat*: minimum latitude of the product;
 - *min_lon*: minimum longitude of the product;
 - *max_lat*: maximum latitude of the product;
 - *max_lon*: maximum longitude of the product;
 - *Collection/Size*: collection code or size depending on the product type;
 - *Preview*: URL of the product preview;
 - *Collection/ID*: collection or image ID depending on the product type;
 - *Collection/Image*: collection or image ID depending on the product type;
-  : display preview of highlighted images in the map; preview is roughly georeferenced on the fly;
-  : remove highlighted images from the list;
-  : remove all images from the list;
-  : import the product list from a text file (i.e. .txt);
-  : export the product list to a text file (i.e. .txt);

Download

Download the products in the *Product list* (page 54). During the download it is recommended not to interact with QGIS.

-  *Only if preview in Layers*: if checked, download only those images listed in *Product list* (page 54) which are also listed in the QGIS layer panel;
-  *Preprocess images*: if checked, bands are automatically converted after the download, according to the settings defined in *Landsat* (page 56);
-  *Load bands in QGIS*: if checked, bands are loaded in QGIS after the download;
- : export the download links to a text file;
- *RUN* : start the download process of all the products listed in *Product list* (page 54);

Download options

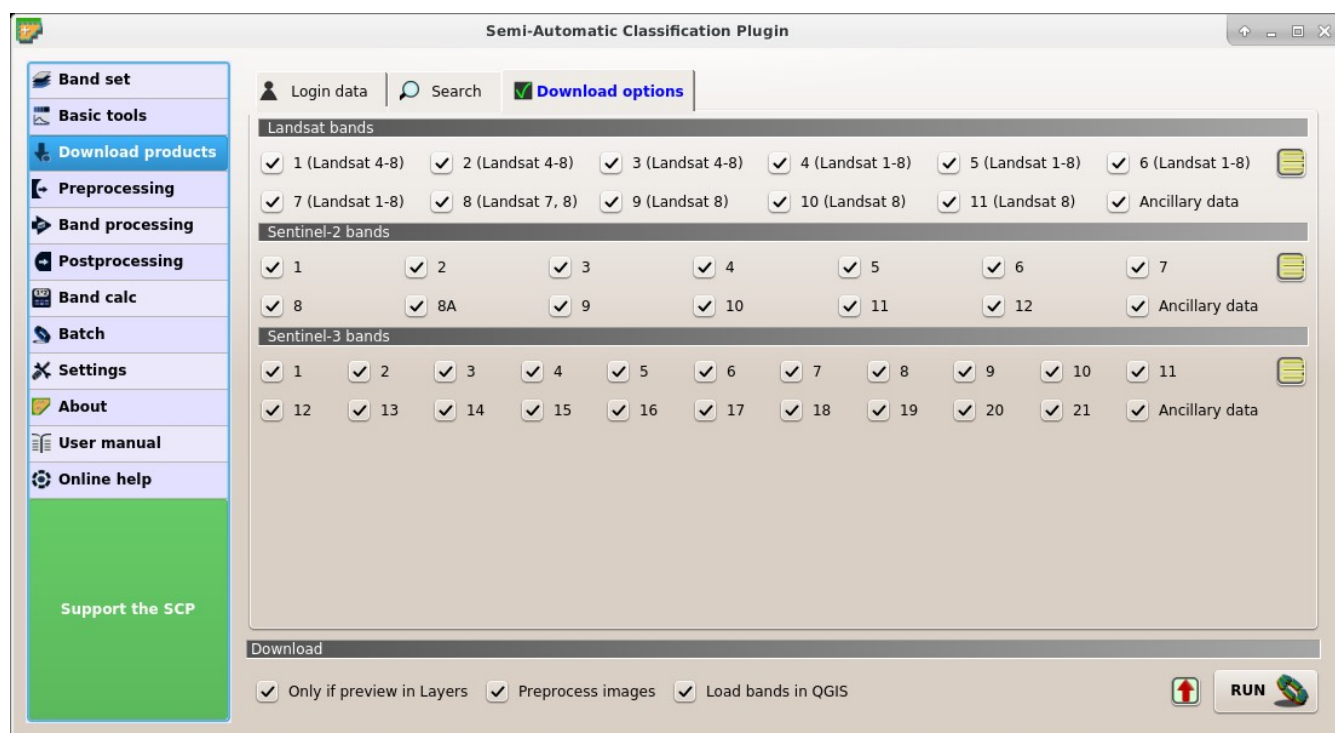






Fig. 20:  *Download options*

This tab allows for the selection of single bands for Landsat, Sentinel-2, and Sentinel-3 images. Depending on the download service, single band download could be unavailable.

-  *Band X*: select bands for download;
-  *Ancillary data*: if checked, the metadata files are selected for download;
- : select or deselect all bands;

3.4.4 Preprocessing

The tab  *Preprocessing* provides several tools for data manipulation which are useful before the actual classification process.

Landsat

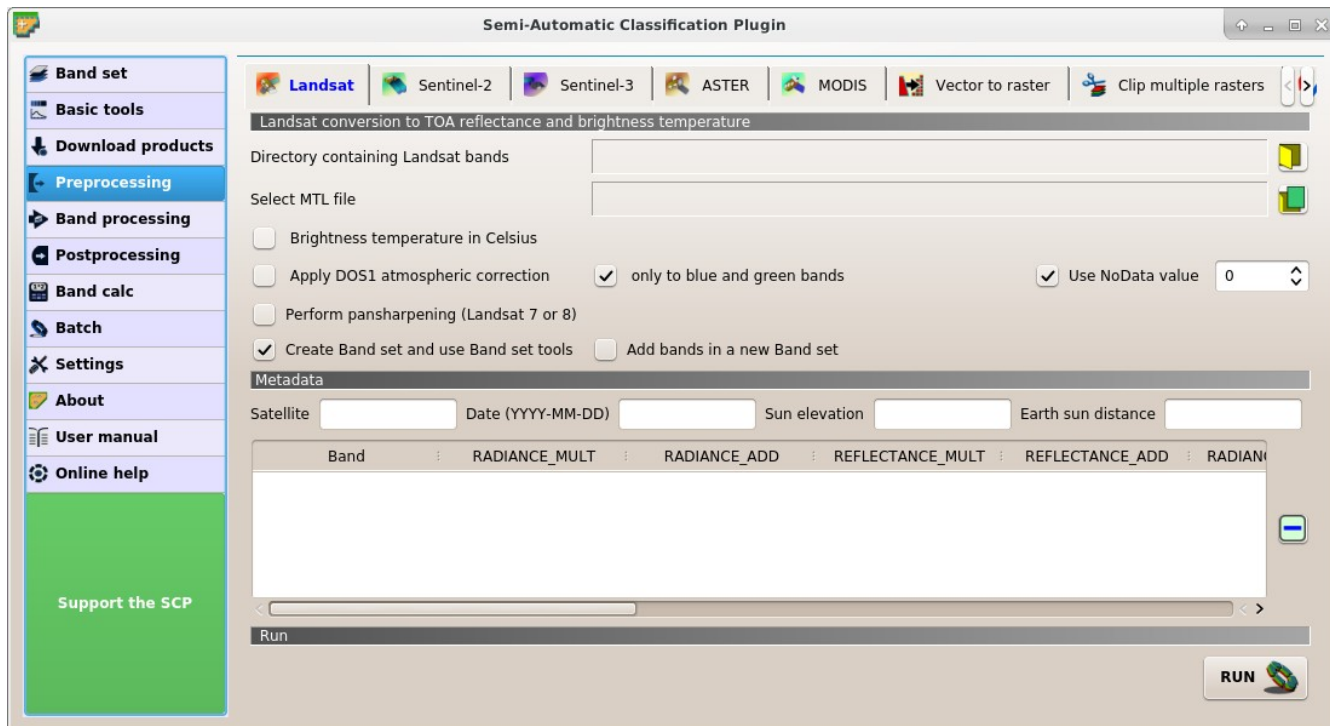




Fig. 21:  *Landsat*








This tab allows for the conversion of **Landsat 1, 2, and 3** MSS and **Landsat 4, 5, 7, and 8** images from DN (i.e. Digital Numbers) to the physical measure of Top Of Atmosphere reflectance (TOA), or the application of a simple atmospheric correction using the DOS1 method (Dark Object Subtraction 1), which is an image-based technique (for more information about the Landsat conversion to TOA and DOS1 correction, see [Image conversion to reflectance](#) (page 131)). Pan-sharpening is also available; for more information read [Pan-sharpening](#) (page 128).

Once the input is selected, available bands are listed in the metadata table.

WARNING: For the best spectral precision you should download the Landsat Level-2 Data Products (Surface Reflectance) from <https://earthexplorer.usgs.gov>.







Landsat conversion to TOA reflectance and brightness temperature

- *Directory containing Landsat bands*  : open a directory containing Landsat bands; names of Landsat bands must end with the corresponding number; if the metadata file is included in this directory then *Metadata* (page 57) are automatically filled;
- *Select MTL file*  : if the metadata file is not included in the *Directory containing Landsat bands*, select the path of the metadata file in order to fill the *Metadata* (page 57) automatically;


-  *Brightness temperature in Celsius*: if checked, convert brightness temperature to Celsius (if a Landsat thermal band is listed in [Metadata](#) (page 57)); if unchecked temperature is in Kelvin;
-  *Apply DOS1 atmospheric correction*: if checked, the [DOS1 Correction](#) (page 132) is applied to all the bands (thermal bands excluded);
-  *only to blue and green bands*: if checked (with *Apply DOS1 atmospheric correction* also checked), the [DOS1 Correction](#) (page 132) is applied only to blue and green bands;
-  *Use NoData value (image has black border)* : if checked, pixels having NoData value are not counted during conversion and the DOS1 calculation of DNmin; it is useful when image has a black border (usually pixel value = 0);
-  *Perform pan-sharpening*: if checked, a Brovey Transform is applied for the [Pan-sharpening](#) (page 128) of Landsat bands;
-  *Create Band set and use Band set tools*: if checked, the *Band set* is created after the conversion; also, the *Band set* is processed according to the tools checked in the [Band set](#) (page 37);

Metadata

All the bands found in the *Directory containing Landsat bands* are listed in the table *Metadata*. If the Landsat metadata file (a .txt or .met file with the suffix MTL) is provided, then *Metadata* are automatically filled. For information about *Metadata* fields read [this page](#) and [this one](#).

- *Satellite* : satellite name (e.g. Landsat8);
- *Date* : date acquired (e.g. 2013-04-15);
- *Sun elevation* : Sun elevation in degrees;
- *Earth sun distance* : Earth Sun distance in astronomical units (automatically calculated if *Date* is filled);
- : remove highlighted bands from the table *Metadata*;
-  **Metadata: table containing the following fields;**
 - *Band*: band name;
 - *RADIANCE_MULT*: multiplicative rescaling factor;
 - *RADIANCE_ADD*: additive rescaling factor;
 - *REFLECTANCE_MULT*: multiplicative rescaling factor;
 - *REFLECTANCE_ADD*: additive rescaling factor;
 - *RADIANCE_MAXIMUM*: radiance maximum;
 - *REFLECTANCE_MAXIMUM*: reflectance maximum;
 - *K1_CONSTANT*: thermal conversion constant;
 - *K2_CONSTANT*: thermal conversion constant;
 - *LMAX*: spectral radiance that is scaled to QCALMAX;
 - *LMIN*: spectral radiance that is scaled to QCALMIN;
 - *QCALMAX*: minimum quantized calibrated pixel value;
 - *QCALMIN*: maximum quantized calibrated pixel value;

Run

-  **RUN**: select an output directory and start the conversion process; only bands listed in the table *Metadata* are converted; converted bands are saved in the output directory with the prefix *RT_* and automatically loaded in QGIS;

Sentinel-2

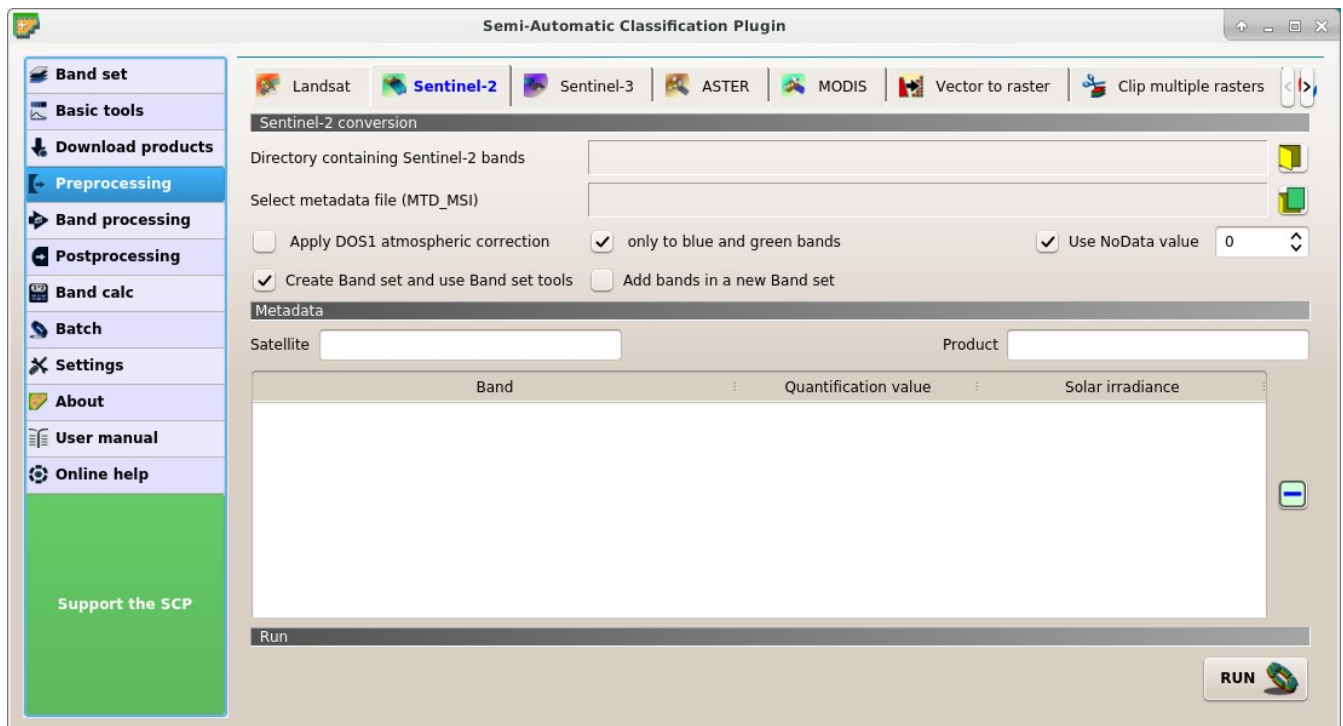



Fig. 22:  Sentinel-2



This tab allows for the conversion of **Sentinel-2** images Level-1C to the physical measure of Top Of Atmosphere reflectance (TOA), or the application of a simple atmospheric correction using the DOS1 method (Dark Object Subtraction 1), which is an image-based technique (for more information about conversion to TOA and DOS1 correction, see [Image conversion to reflectance](#) (page 131)). This tool can also convert **Sentinel-2** images Level-2A from DN to reflectance values.

Once the input is selected, available bands are listed in the metadata table. Bands with 20m spatial resolution are resampled to 10m resolution without changing the original pixel value (i.e. one 20m pixel is divided in four 10m pixels with the same value).

WARNING: For the best spectral precision you should download the Sentinel-2 Level-2A Products (Surface Reflectance) or use the official SNAP tool for atmospheric correction (see <http://step.esa.int>).




Sentinel-2 conversion

-  **Directory containing Sentinel-2 bands**: open a directory containing Sentinel-2 bands; names of Sentinel-2 bands must end with the corresponding number; if the metadata file is included in this directory then *Metadata* (page 59) are automatically filled;


- **Select metadata file**  : select the metadata file which is a .xml file whose name contains MTD_MSIL1C);
- ☒ **Apply DOS1 atmospheric correction**: if checked, the [DOS1 Correction](#) (page 132) is applied to all the bands;
- ☒ **only to blue and green bands**: if checked (with *Apply DOS1 atmospheric correction* also checked), the [DOS1 Correction](#) (page 132) is applied only to blue and green bands;
- ☒ **Use NoData value (image has black border)** : if checked, pixels having NoData value are not counted during conversion and the DOS1 calculation of DNmin; it is useful when image has a black border (usually pixel value = 0);
- ☒ **Create Band set and use Band set tools**: if checked, the active *Band set* is created after the conversion; also, the *Band set* is processed according to the tools checked in the [Band set](#) (page 37);
- ☒ **Add bands in a new Band set**: if checked, bands are added to a new empty *Band set*;

Metadata

All the bands found in the *Directory containing Sentinel-2 bands* are listed in the table *Metadata*. If the Sentinel-2 metadata file (a .xml file whose name contains MTD_MSIL1C) is provided, then *Metadata* are automatically filled. For information about *Metadata* fields read [this informative page](#).

- **Satellite** : satellite name (e.g. Sentinel-2A);
- : remove highlighted bands from the table *Metadata*;
-  **Metadata: table containing the following fields;**
 - *Band*: band name;
 - *Quantification value*: value for conversion to TOA reflectance;
 - *Solar irradiance*: solar irradiance of band;

Run

- **RUN** : select an output directory and start the conversion process; only bands listed in the table *Metadata* are converted; converted bands are saved in the output directory with the prefix RT_ and automatically loaded in QGIS;

Sentinel-3

This tab allows for the conversion of **Sentinel-3** images (OL_1_EFR) to the physical measure of Top Of Atmosphere reflectance (TOA), or the application of a simple atmospheric correction using the DOS1 method (Dark Object Subtraction 1), which is an image-based technique (for more information about conversion to TOA and DOS1 correction, see [Image conversion to reflectance](#) (page 131)). The following ancillary data are required for conversion: `instrument_data.nc`, `geo_coordinates.nc`, `tie_geometries.nc`.

Once the input is selected, available bands are listed in the metadata table.

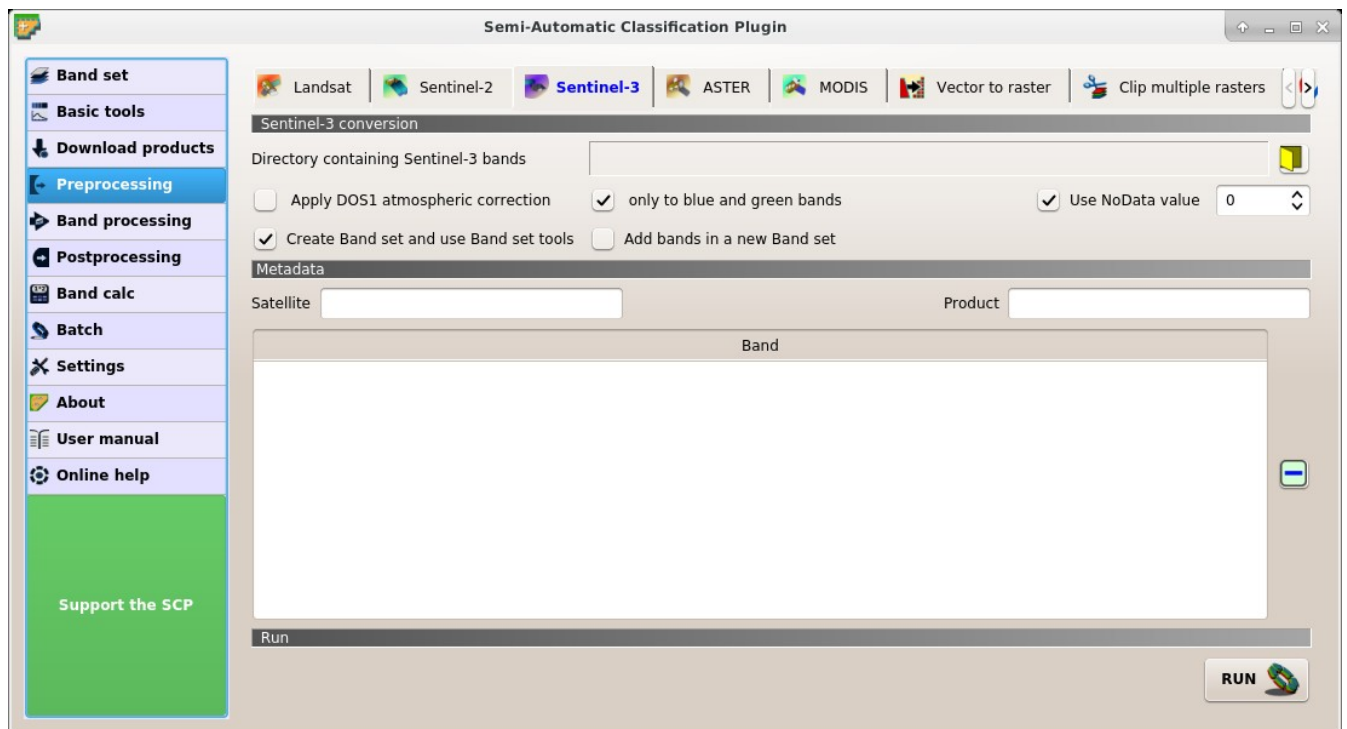




Fig. 23:  Sentinel-3





WARNING: Sentinel-3 bands are reprojected to WGS 84 coordinate system using a sample of pixels from the file `geo_coordinates.nc`. For the best precision you should use the official SNAP tool (see <http://step.esa.int>).

Sentinel-3 conversion


- *Directory containing Sentinel-3 bands*  : open a directory containing Sentinel-3 bands; names of Sentinel-2 bands must end with the corresponding number; ancillary data required for conversion must be in the same directory;
- ☒ *Apply DOS1 atmospheric correction*: if checked, the *DOS1 Correction* (page 132) is applied to all the bands;
- ☒ *only to blue and green bands*: if checked (with *Apply DOS1 atmospheric correction* also checked), the *DOS1 Correction* (page 132) is applied only to blue and green bands;
- ☒ *Use NoData value (image has black border)* : if checked, pixels having NoData value are not counted during conversion and the DOS1 calculation of DNmin; it is useful when image has a black border (usually pixel value = 0);
- ☒ *Create Band set and use Band set tools*: if checked, the *Band set* is created after the conversion; also, the *Band set* is processed according to the tools checked in the *Band set* (page 37);

Metadata

All the bands found in the *Directory containing Sentinel-3 bands* are listed in the table *Metadata*.

- *Satellite* : satellite name (e.g. Sentinel-3A);
- *Product* : product name (e.g. OLCI);
- : remove highlighted bands from the table *Metadata*;
-  **Metadata**: table containing the following fields;
 - *Band*: band name;

Run

- *RUN* : select an output directory and start the conversion process; only bands listed in the table *Metadata* are converted; converted bands are saved in the output directory with the prefix RT_ and automatically loaded in QGIS;

ASTER

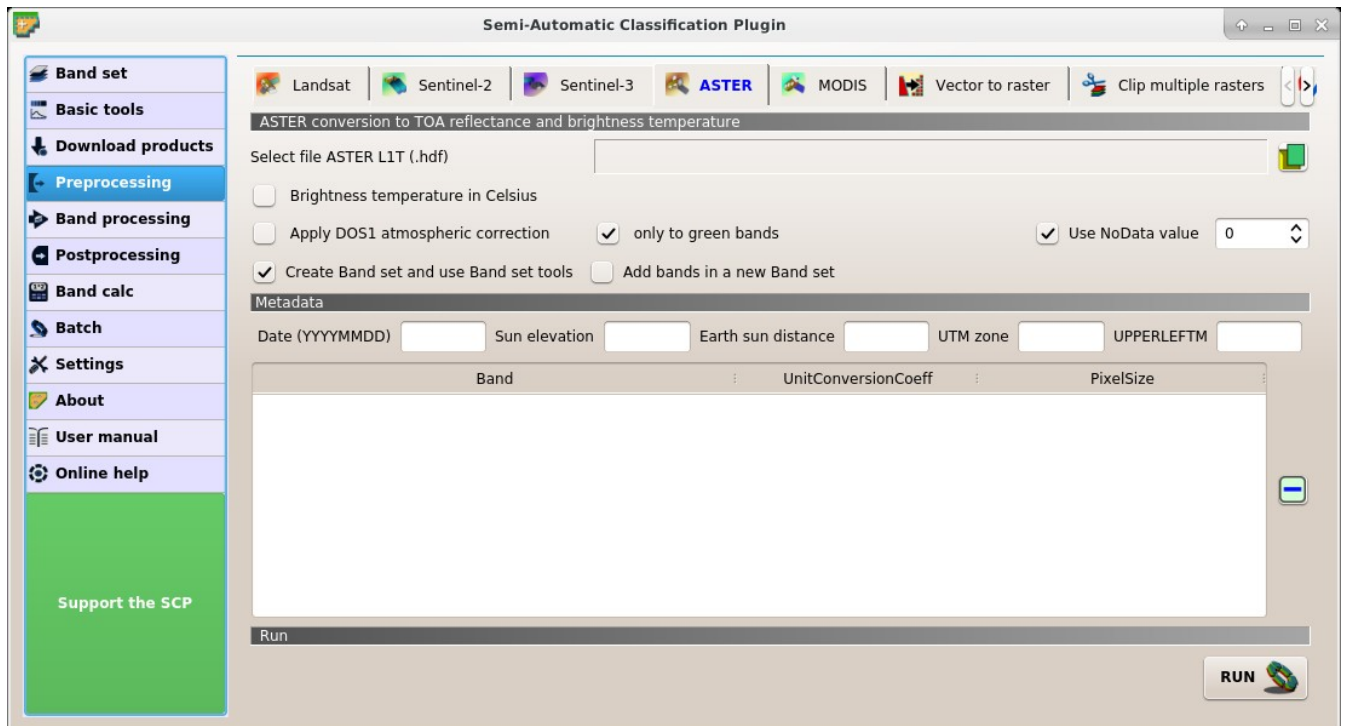




Fig. 24:  ASTER

This tab allows for the conversion of **ASTER L1T** images to the physical measure of Top Of Atmosphere reflectance (TOA), or the application of a simple atmospheric correction using the DOS1 method (Dark Object Subtraction 1), which is an image-based technique (for more information about conversion to TOA and DOS1 correction, see [Image conversion to reflectance](#) (page 131)).








Once the input is selected, available bands are listed in the metadata table.

ASTER conversion


-  **Select file ASTER LIT**: select an ASTER image (file .hdf);
- ☒ **Apply DOS1 atmospheric correction**: if checked, the [DOS1 Correction](#) (page 132) is applied to all the bands;
- ☒ **only to green band**: if checked (with *Apply DOS1 atmospheric correction* also checked), the [DOS1 Correction](#) (page 132) is applied only to green band;
- ☒ **Use NoData value (image has black border)** : if checked, pixels having NoData value are not counted during conversion and the DOS1 calculation of DNmin; it is useful when image has a black border (usually pixel value = 0);
- ☒ **Create Band set and use Band set tools**: if checked, the *Band set* is created after the conversion; also, the *Band set* is processed according to the tools checked in the [Band set](#) (page 37);

Metadata

All the bands found in the *Select file ASTER LIT* are listed in the table *Metadata*. For information about *Metadata* fields visit [the ASTER page](#).

- **Date** : date acquired (e.g. 20130415);
- **Sun elevation** : Sun elevation in degrees;
- **Earth sun distance** : Earth Sun distance in astronomical units (automatically calculated if *Date* is filled);
- **UTM zone** : UTM zone code of the image;
- **UPPERLEFTM** : coordinates of the upper left corner of the image;
- : remove highlighted bands from the table *Metadata*;
-  **Metadata: table containing the following fields;**
 - *Band*: band name;
 - *UnitConversionCoeff*: value for radiance conversion;
 - *PixelSize*: solar irradiance of band;

Run

-  **RUN**: select an output directory and start the conversion process; only bands listed in the table *Metadata* are converted; converted bands are saved in the output directory with the prefix RT_ and automatically loaded in QGIS;

MODIS

This tab allows for the conversion of **MODIS** images to .tif format, and the reprojection to WGS 84.

Once the input is selected, available bands are listed in the metadata table.

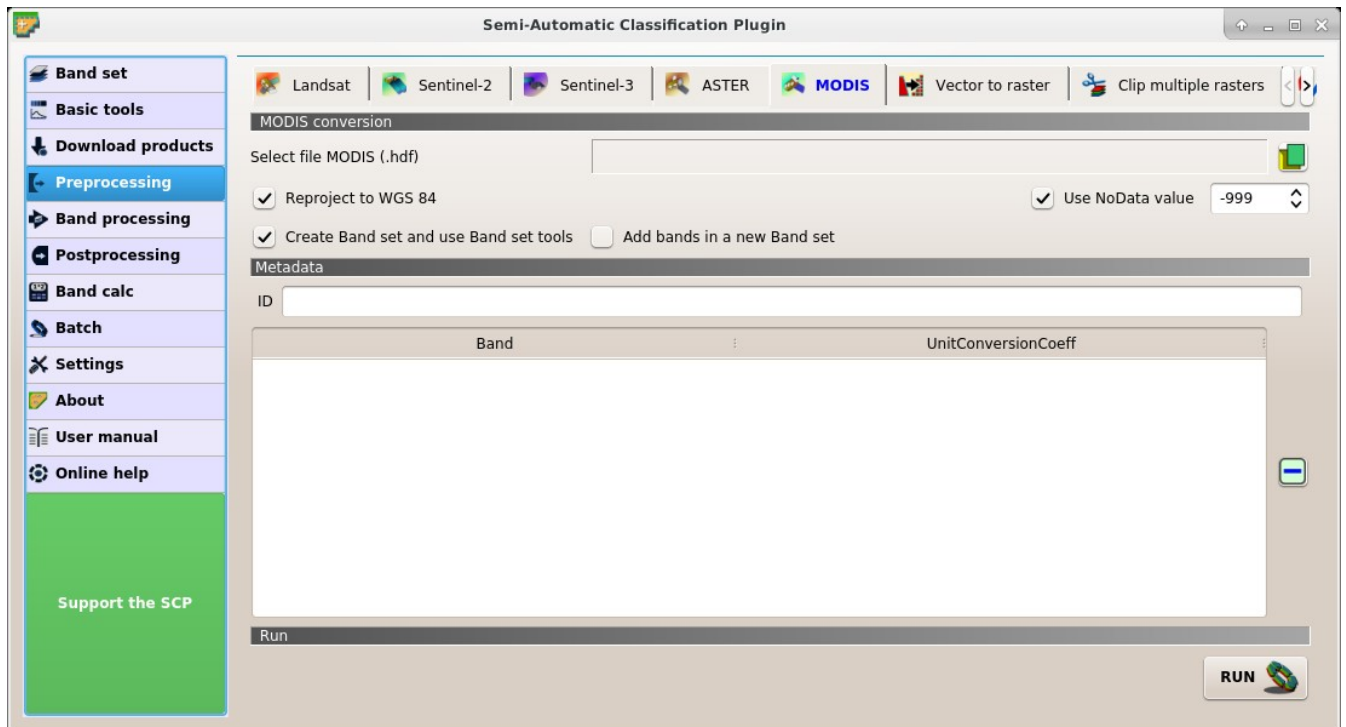










Fig. 25:  MODIS

MODIS conversion


- *Select file MODIS* : select a MODIS image (file .hdf);
-  *Reproject to WGS 84*: if checked, reproject bands to WGS 84, required for use in SCP;
-  *Use NoData value (image has black border)* : if checked, pixels having NoData value are not counted during conversion and the DOS1 calculation of DNmin; it is useful when image has a black border (usually pixel value = 0);
-  *Create Band set and use Band set tools*: if checked, the *Band set* is created after the conversion; also, the *Band set* is processed according to the tools checked in the [Band set](#) (page 37);

Metadata

All the bands found in the *Select file MODIS* are listed in the table *Metadata*. For information about *Metadata* fields visit [the MODIS page](#).

- *ID* : ID of the image;
- : remove highlighted bands from the table *Metadata*;
-  **Metadata: table containing the following fields;**
 - *Band*: band name;
 - *UnitConversionCoeff*: value for conversion;

Run

-  **RUN**: select an output directory and start the conversion process; only bands listed in the table *Meta-data* are converted; converted bands are saved in the output directory with the prefix *RT_* and automatically loaded in QGIS;

Vector to raster

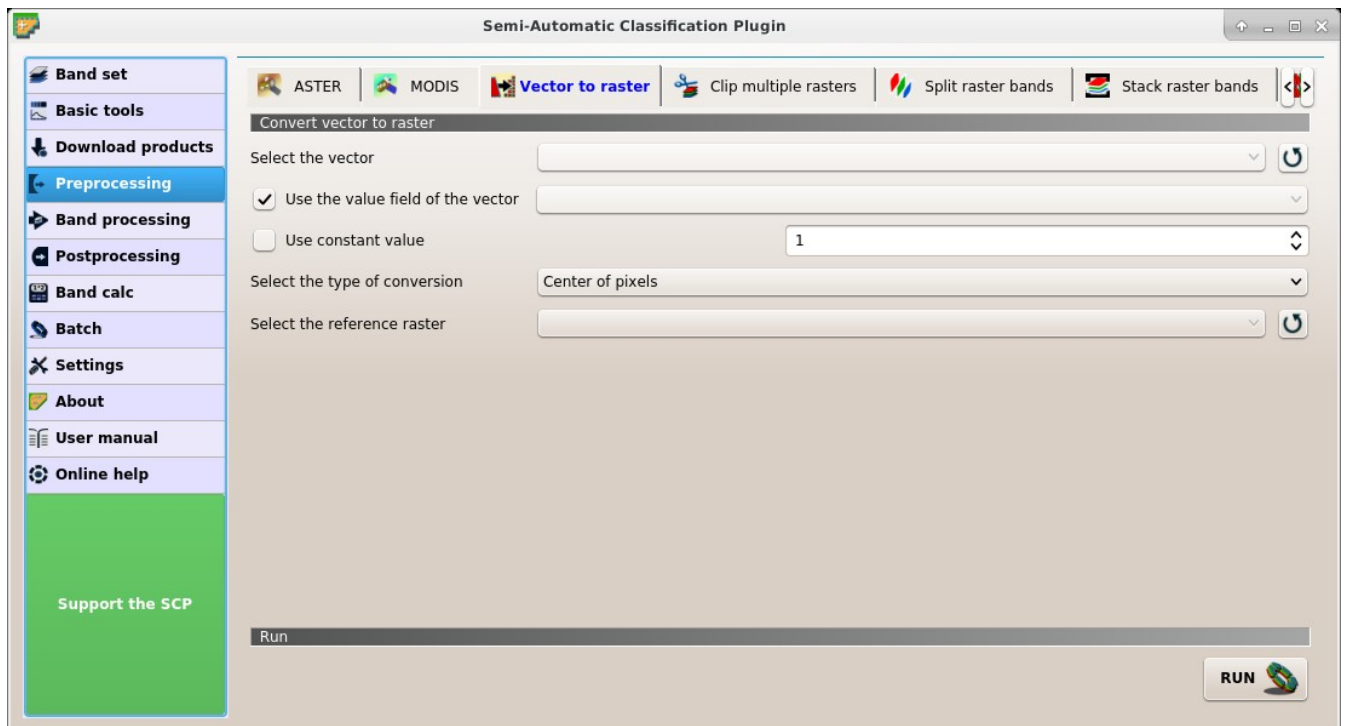












Fig. 26:  *Vector to raster*

This tab allows for the conversion of a vector to raster format.

- *Select the vector* : select a vector already loaded in QGIS;
- : refresh layer list;
-  *Use the value field of the vector* : if checked, the selected field is used as attribute for the conversion; pixels of the output raster have the same values as the vector attribute;
-  *Use constant value* : if checked, the polygons are converted to raster using the selected constant value;
- *Select the type of conversion* : select the type of conversion between *Center of pixels* and *All pixels touched*:
 - *Center of pixels*: during the conversion, vector is compared to the reference raster; output raster pixels are attributed to a polygon if pixel center is within that polygon;
 - *All pixels touched*: during the conversion, vector is compared to the reference raster; output raster pixels are attributed to a polygon if pixel touches that polygon;

- *Select the reference raster* : select a reference raster; pixels of the output raster have the same size and alignment as the reference raster;
- : refresh layer list;

Run

- *RUN* : choose the output destination and start the conversion to raster;

Clip multiple rasters

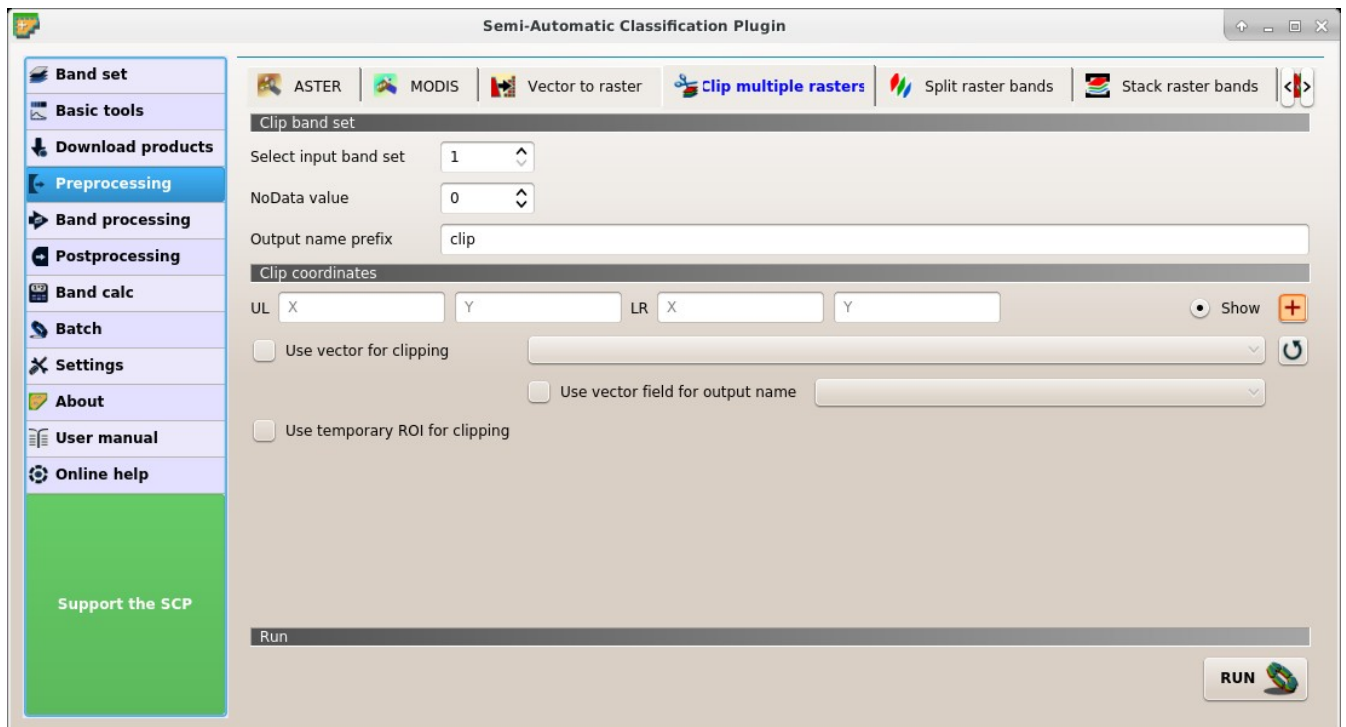




Fig. 27:  *Clip multiple rasters*
















This tab allows for cutting several image bands at once, using a rectangle defined with point coordinates or a boundary defined with a vector.

Raster list


- : refresh layer list;
- : select all the rasters;

Clip coordinates

Set the Upper Left (UL) and Lower Right (LR) point coordinates of the rectangle used for clipping; it is possible to enter the coordinates manually. Alternatively use a vector.

- *UL X* : set the UL X coordinate;
- *UL Y* : set the UL Y coordinate;
- *LR X* : set the LR X coordinate;
- *LR Y* : set the LR Y coordinate;
-  *Show*: show or hide the clip area drawn in the map;
- : define a clip area by drawing a rectangle in the map; left click to set the UL point and right click to set the LR point; the area is displayed in the map;
-  *Use vector for clipping* : if checked, use the selected vector (already loaded in QGIS) for clipping; UL and LR coordinates are ignored;
-  *Use vector field for output name* : if checked, a vector field is selected for clipping while iterating through each vector polygon and the corresponding field value is added to the output name;
-  *Use temporary ROI for clipping*: if checked, use a temporary ROI (see [ROI Signature list](#) (page 27)) for clipping; UL and LR coordinates are ignored;
- : refresh layer list;
-  *NoData value* : if checked, set the value for NoData pixels (e.g. pixels outside the clipped area);
- *Output name prefix* : set the prefix for output file names (default is `clip`);




Run

- *RUN* : choose an output destination and clip selected rasters; only rasters selected in the [Raster list](#) (page 65) are clipped and automatically loaded in QGIS;


Split raster bands

Split a multiband raster to single bands.

Raster input

- *Select a multiband raster* : select a multiband raster already loaded in QGIS;
- : refresh layer list;
- *Output name prefix* : set the prefix for output file names (default is `split`);

Run

- *RUN* : choose the output destination and split selected raster; output bands are automatically loaded in QGIS;

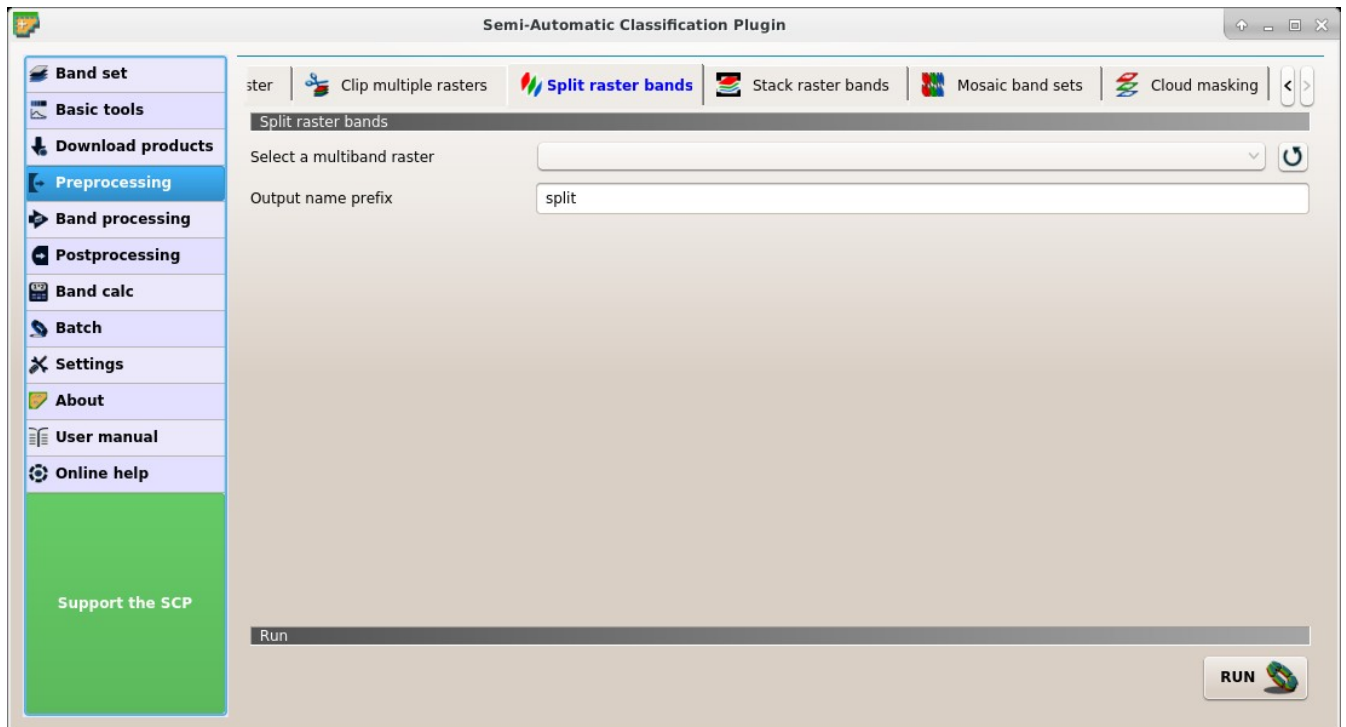




Fig. 28:  *Split raster bands*


Stack raster bands

Stack raster bands into a single file.

Raster list

-  : refresh layer list;
-  : select all the rasters;

Run

-  **RUN** : choose the output destination and stack selected rasters; output is automatically loaded in QGIS;

Mosaic band sets

This tool allows for the mosaic of band sets, merging the corresponding bands of two or more band sets defined in the [Band set](#) (page 37). An output band is created for every corresponding set of bands in the band sets.

NoData values of one band set are replaced by the values of the other band sets.

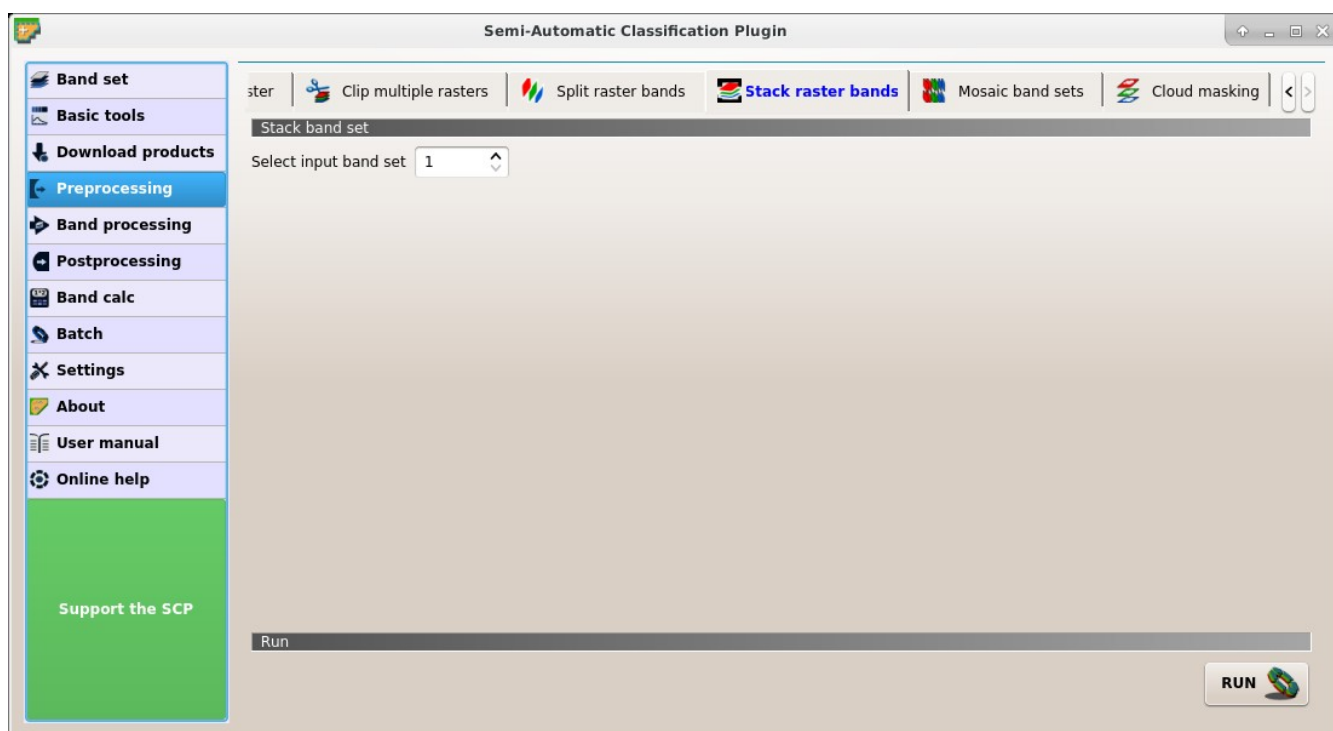


Fig. 29:  *Stack raster bands*

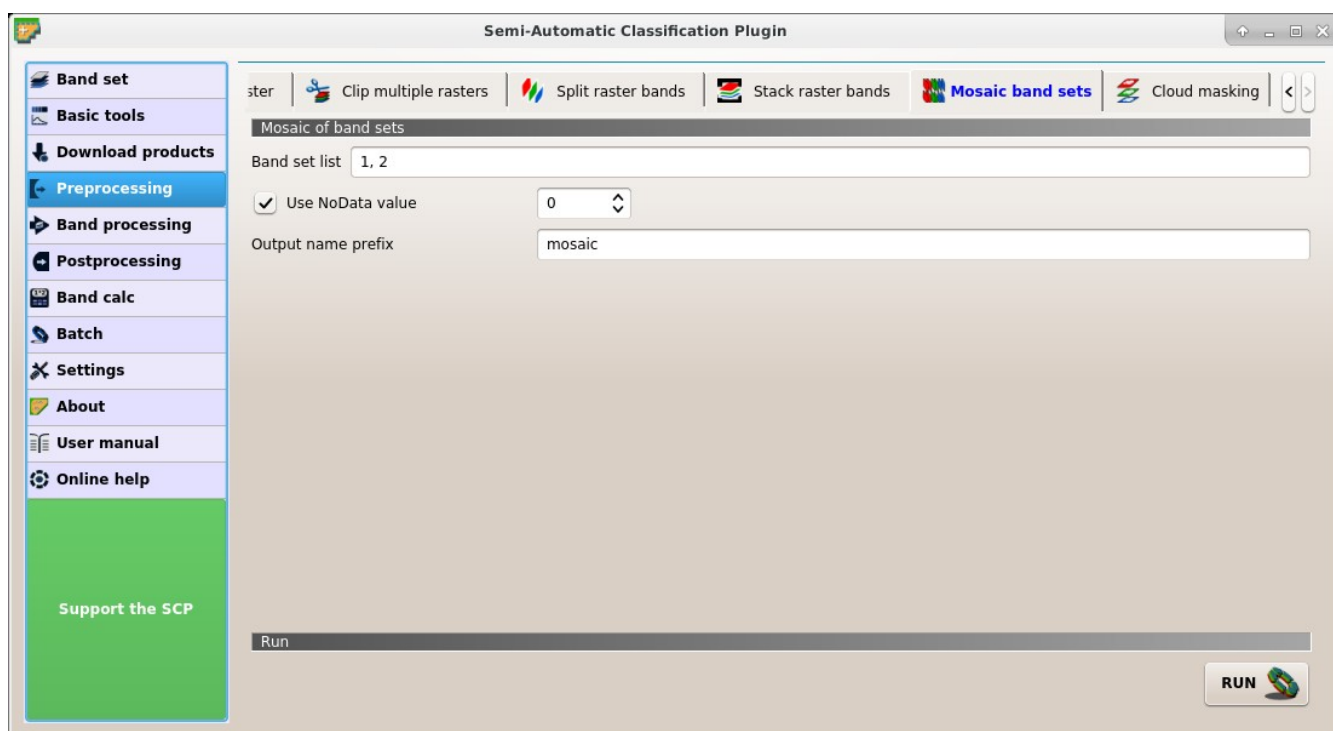



Fig. 30:  *Mosaic band sets*

Mosaic of band sets

- *Band set list* : list if band sets defined in the [Band set](#) (page 37); in case of overlapping images, the pixel values of the first band set in the list are assigned.
- ☒ *Use NoData value* : if checked, set the value of NoData pixels, ignored during the calculation;
- *Output name prefix* : set the prefix for output file names (default is mosaic);

Run

- *RUN* : select an output directory and start the mosaic process;

Cloud masking

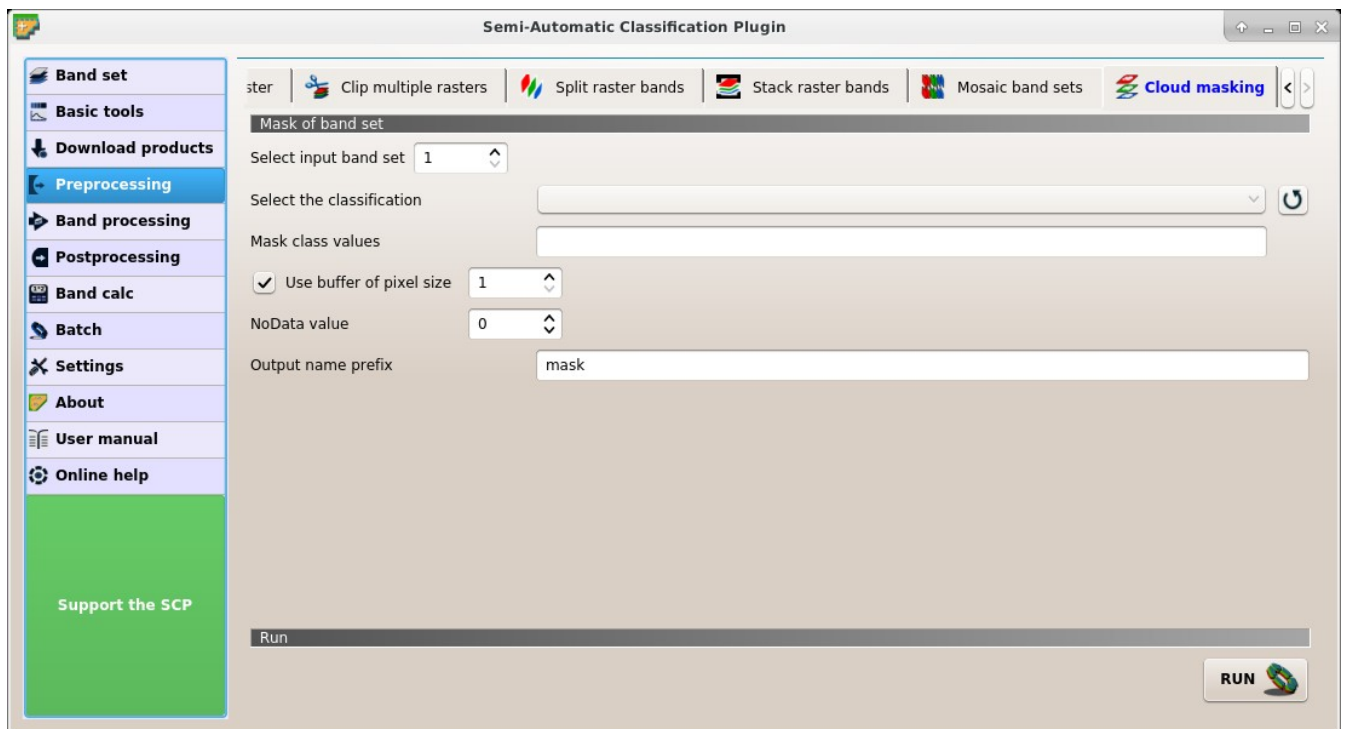







Fig. 31:  Cloud masking


This tool allows for cloud masking, based on the values of a raster mask, creating an output masked band for each band of the [Band set](#) (page 37). NoData is set in all the bands of the [Band set](#) (page 37) for pixels corresponding to clouds.

Mask of band set


- *Select input band set* : select the input [Band set](#) (page 37) to be masked;
- *Select the classification* : select a classification raster (already loaded in QGIS) which contains a cloud class;

-  : refresh layer list;
- *Mask class values*  : set the class values to be masked; class values must be separated by , and – can be used to define a range of values (e.g. 1, 3–5, 8 will select classes 1, 3, 4, 5, 8); if the text is red then the expression contains errors;
-  *Use buffer of pixel size*  : if checked, a buffer is created for masked area, corresponding to the defined number of pixels; this can be useful to dilate masked area in case the mask doesn't cover the thinner border of clouds;
- *NoData value*: set the value of NoData pixels, corresponding to clouds;
- *Output name prefix*  : set the prefix for output file names (default is mask);

Run

- *RUN*  : select an output directory and start the mask process;

3.4.5 Band processing

The tab  *Band processing* provides several functions that can be applied to the *Band set* (page 37).

Band combination

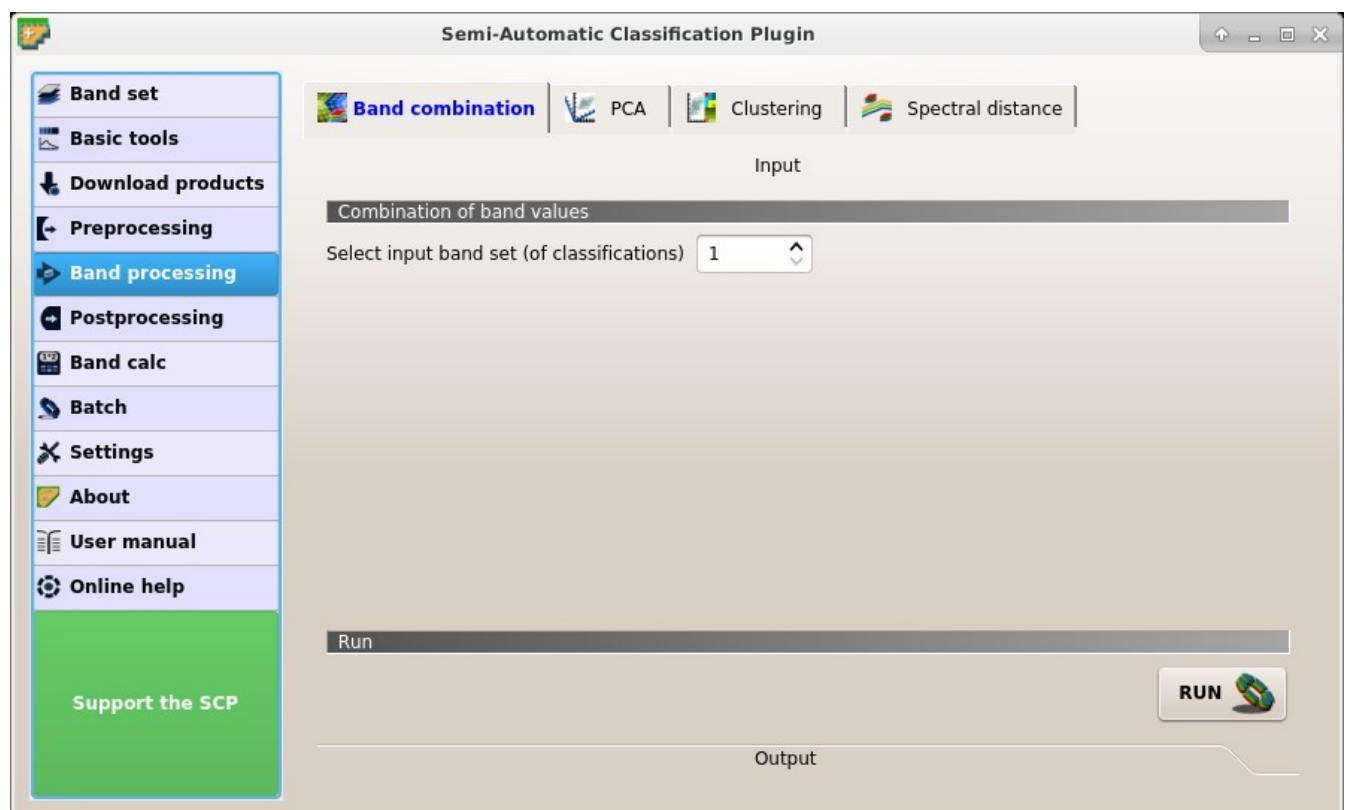




Fig. 32:  *Band combination*

This tab allows for the combination of bands loaded in a *Band set* (page 37). This tool is intended for combining classifications in order to get a raster where each value corresponds to a combination of class values. A combination raster is produced as output and the area of each combination is reported in a text file.

Combination of band values

- *Select input band set (of classifications)* : select the input *Band set* (page 37);

Run

- *RUN* : choose the output destination and start the calculation; also, the details about the combinations are displayed in the tab *Output* and saved in a .txt file in the output directory;

PCA

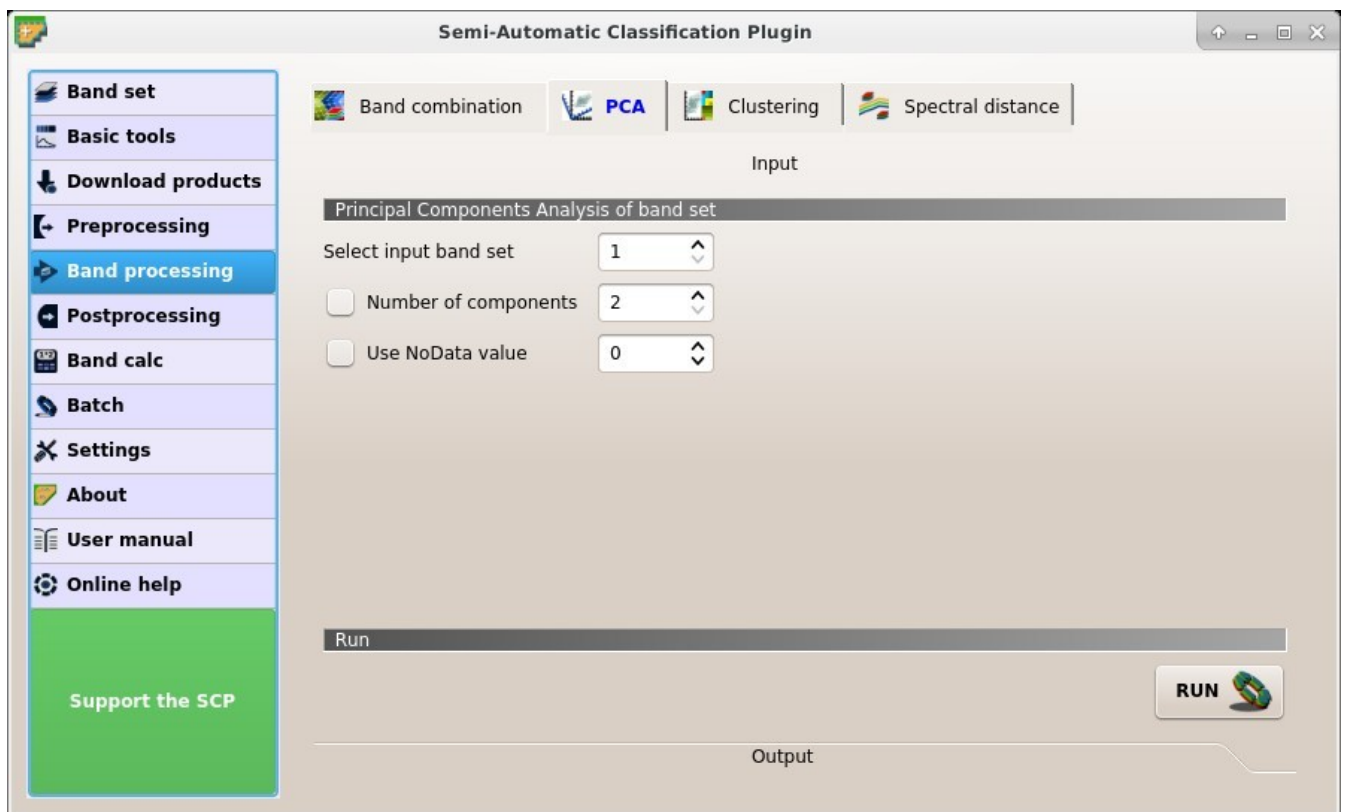





Fig. 33:  PCA


This tab allows for the PCA (*Principal Component Analysis* (page 127)) of bands loaded in the *Band set*.

Principal Component Analysis of Band set

- *Select input band set* : select the input *Band set* (page 37);
- ☒ *Number of components* : if checked, set the number of calculated components; if unchecked, all the components are calculated;

- ☒ *Use NoData value* : if checked, set the value of NoData pixels, ignored during the calculation;

Run

- *RUN* : select an output directory and start the calculation process; principal components are calculated and saved as raster files; also, the details about the PCA are displayed in the tab *Output* and saved in a .txt file in the output directory;

Clustering

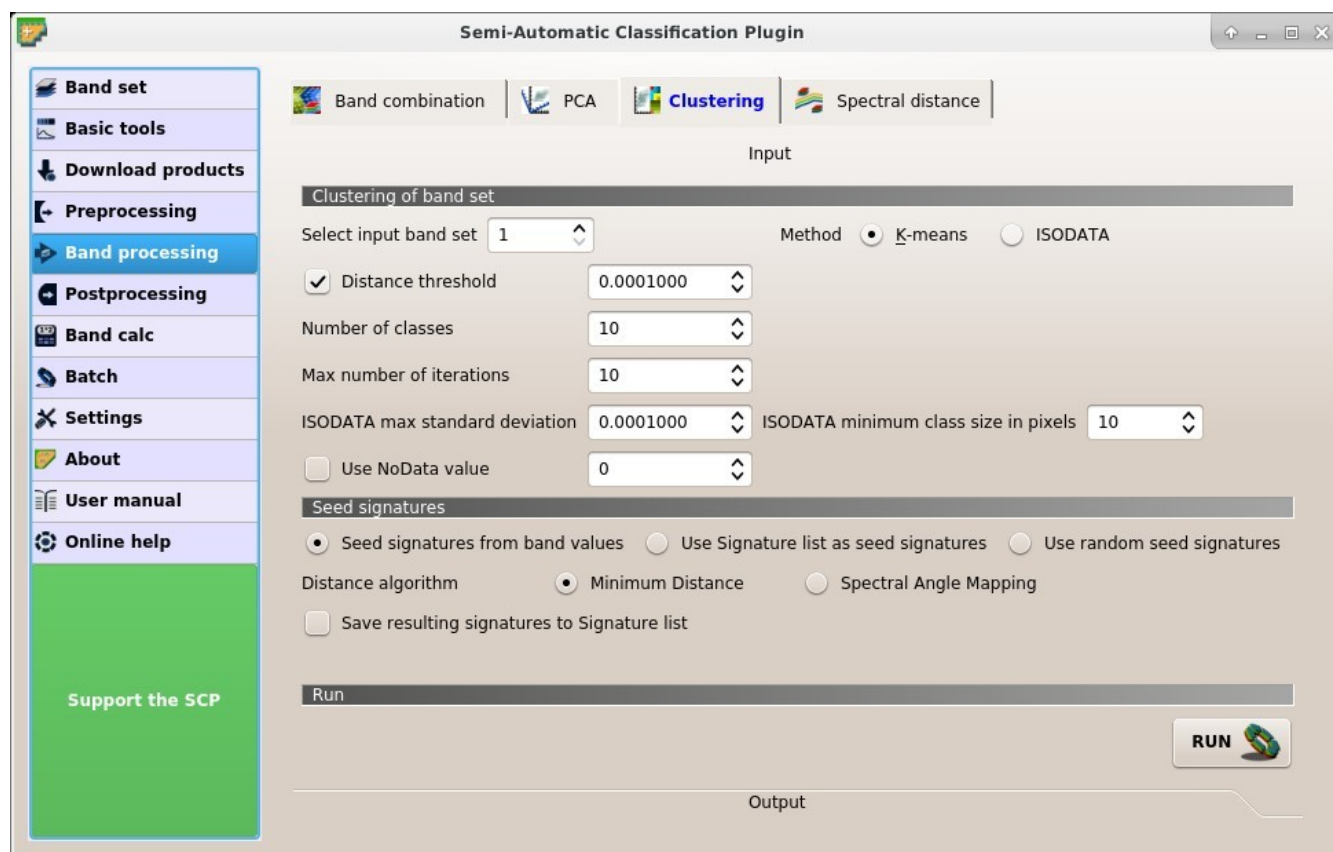







Fig. 34:  Clustering






This tab allows for the *Clustering* (page 129) of a *Band set* (page 37). In particular, *K-means* (page 129) and *ISODATA* (page 130) methods are available.

Clustering of band set


- *Select input band set* : select the input *Band set* (page 37);
- *Method* ☐ *K-means* ☐ *ISODATA*: select the clustering method *K-means* (page 129) or *ISODATA* (page 130);
- ☒ *Distance threshold* : if checked, for K-means: iteration is terminated if distance is lower than threshold; for ISODATA: signatures are merged if distance is greater than threshold;

- *Number of classes* : number of desired output classes;
- *Max number of iterations* : maximum number of iterations if *Distance threshold* is not reached;
- *ISODATA max standard deviation* : maximum standard deviation considered for splitting a class, for *ISODATA* algorithm only;
- *ISODATA minimum class size in pixels* : desired minimum class size in pixels, for *ISODATA* algorithm only;
- ☒ *Use NoData value* : if checked, set the value of NoData pixels, ignored during the calculation;

Seed signatures

-  *Seed signatures from band values*  *Use Signature list as seed signatures*  *Use random seed signatures*: select one options for seed signatures that start the iteration; the option *Seed signatures from band values* divides the spectral space of the *Band set* (page 37) to get spectral signatures; the option *Use Signature list as seed signatures* uses the spectral signatures checked in *ROI Signature list* (page 27); the option *Use random seed signatures* randomly selects the spectral signatures of pixels in the *Band set* (page 37);
- *Distance algorithm*  *Minimum Distance*  *Spectral Angle Mapping*: select *Minimum Distance* (page 120) or * *Spectral Angle Mapping* (page 121) for spectral distance calculation;
- ☒ *Save resulting signatures to Signature list*: if checked, save the resulting spectral signatures in the *ROI Signature list* (page 27);






Run

- *RUN* : choose the output destination and start the calculation;

Spectral distance

This tab allows for calculating the spectral distance between every corresponding pixel of two *band sets*. The output is a raster containing the spectral distance of each pixel. Optionally, a threshold can be defined for creating a binary raster of values below and above the threshold.

Spectral distance of band sets

- *Select first input band set* : select the first input *Band set* (page 37);
- *Select second input band set* : select the second input *Band set* (page 37);
- *Distance algorithm*  *Minimum Distance*  *Spectral Angle Mapping*: select *Minimum Distance* (page 120) or * *Spectral Angle Mapping* (page 121) for spectral distance calculation;
- ☒ *Distance threshold* : if checked, a binary raster of values below and above the threshold is created;

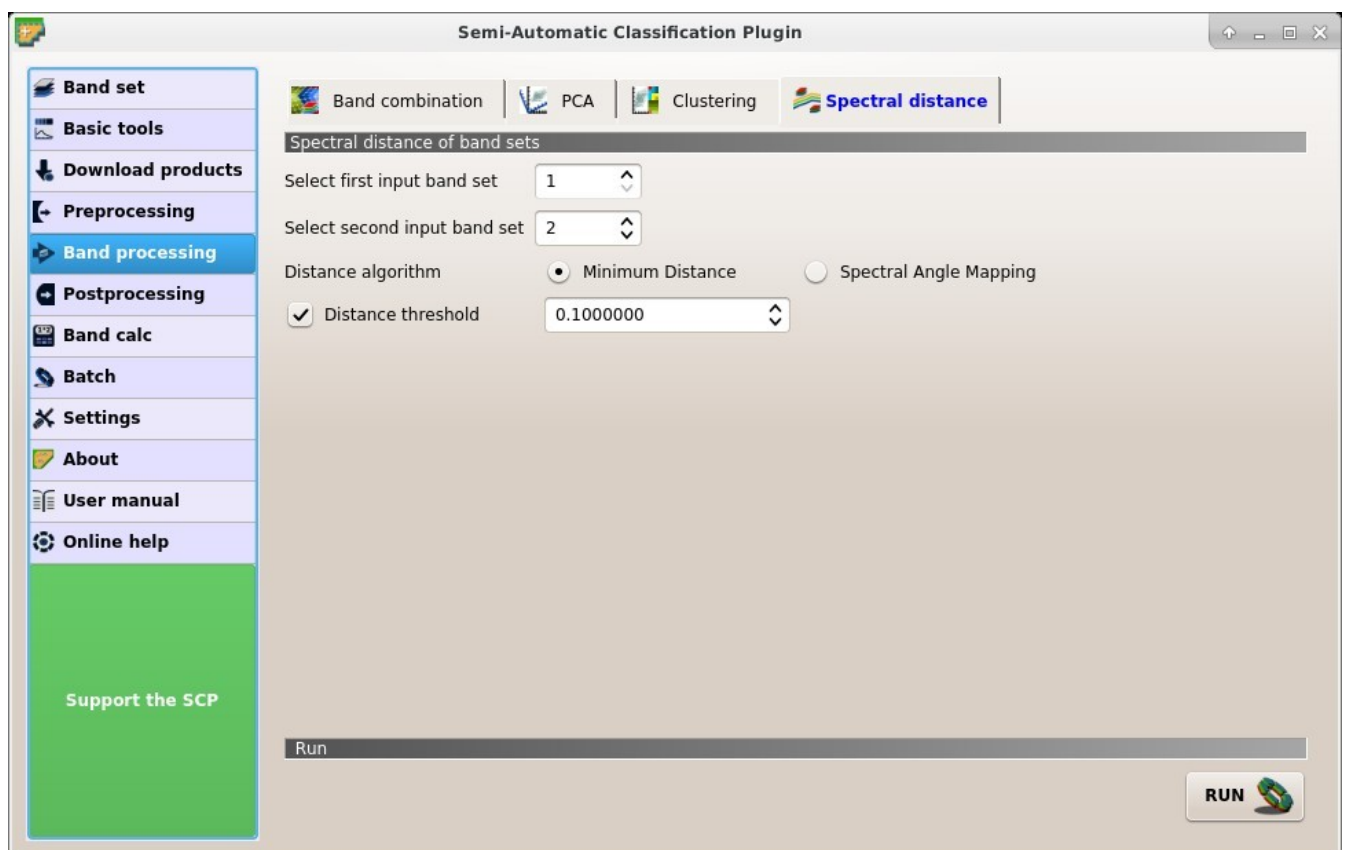




Fig. 35:  *Spectral distance*

Run

- **RUN**  : choose the output destination and start the calculation;

3.4.6 Postprocessing

The tab  *Postprocessing* provides several functions that can be applied to the classification output.

Accuracy

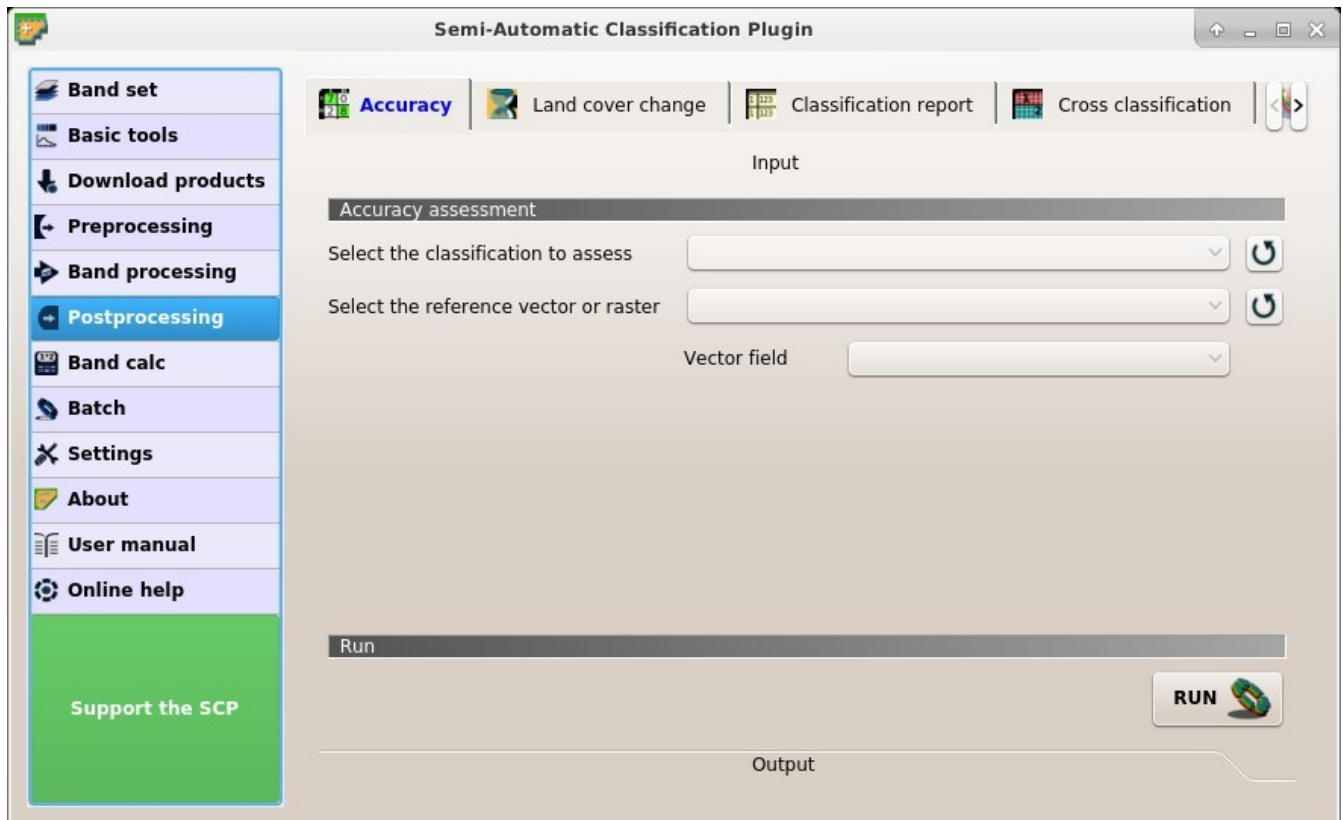







Fig. 36:  Accuracy

This tab allows for the validation of a classification (read [Accuracy Assessment](#) (page 126)). Classification is compared to a reference raster or reference vector (which is automatically converted to raster). If a vector is selected as reference, it is possible to choose a field describing class values.


Several statistics are calculated such as overall accuracy, user's accuracy, producer's accuracy, and Kappa hat. In particular, these statistics are calculated according to the area based error matrix where each element represents the estimated area proportion of each class. This allows for estimating the unbiased user's accuracy and producer's accuracy, the unbiased area of classes according to reference data, and the standard error of area estimates.

The output is an `error raster` that is a `.tif` file showing the errors in the map, where pixel values represent the categories of comparison (i.e. combinations identified by the `ErrorMatrixCode` in the error matrix) between the classification and reference. Also, a text file containing the error matrix (i.e. a `.csv` file separated by tab) is created with the same name defined for the `.tif` file.

Input

- *Select the classification to assess* : select a classification raster (already loaded in QGIS);
- : refresh layer list;
- *Select the reference vector or raster* : select a raster or a vector (already loaded in QGIS), used as reference layer (ground truth) for the accuracy assessment;
- : refresh layer list;
- *Vector field* : if a vector is selected as reference, select a vector field containing numeric class values;

Run

- *RUN* : choose the output destination and start the calculation; the error matrix is displayed in the tab *Output* and the error raster is loaded in QGIS;

Land cover change

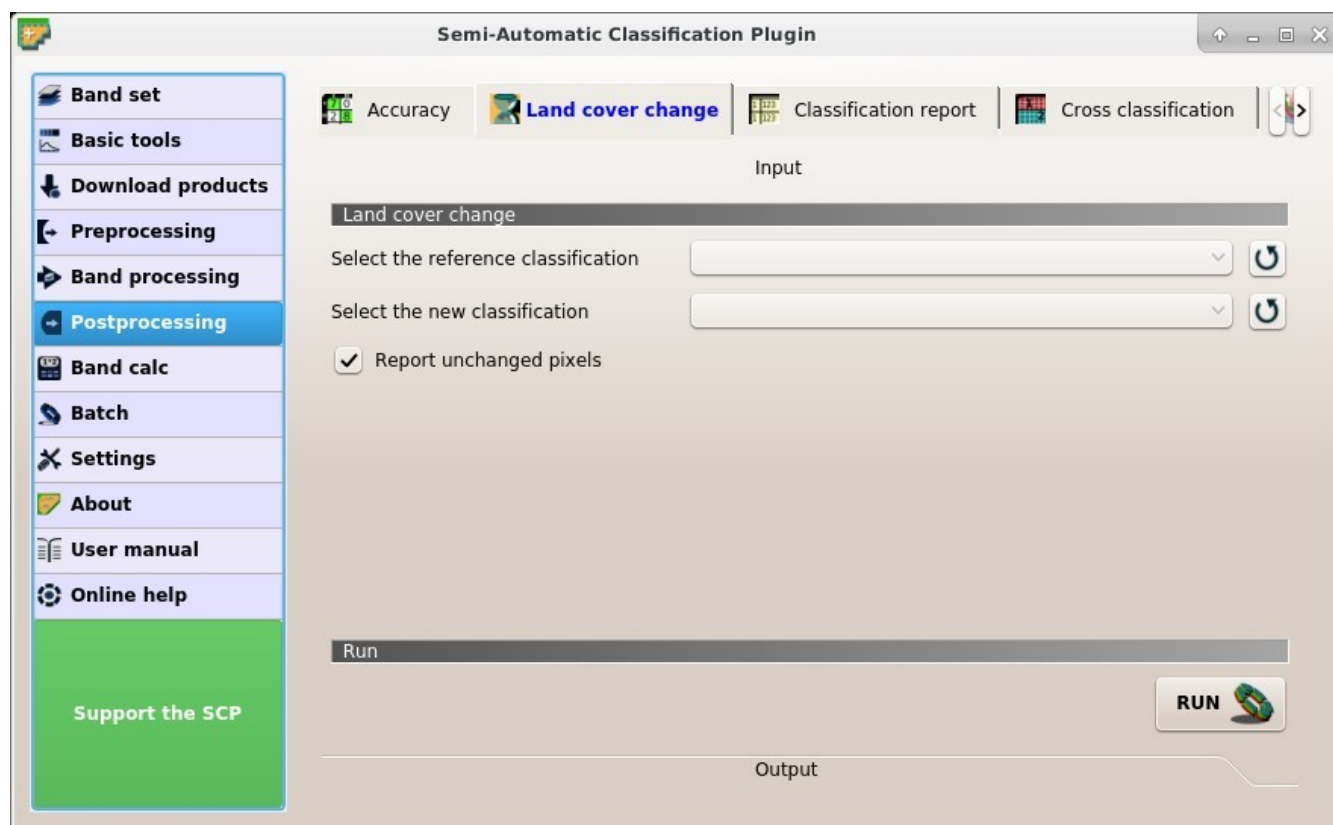







Fig. 37:  Land cover change

The tab *Land cover change* allows for the comparison between two classifications in order to assess land cover changes. Output is a land cover change raster (i.e. a file .tif showing the changes in the map, where each pixel represents a category of comparison (i.e. combinations) between the two classifications, which is the *ChangeCode* in the land cover change statistics) and a text file containing the land cover change statistics (i.e. a file .csv separated by tab, with the same name defined for the .tif file).

Input

- *Select the reference classification* : select a reference classification raster (already loaded in QGIS);
- : refresh layer list;
- *Select the new classification* : select a new classification raster (already loaded in QGIS), to be compared with the reference classification;
- : refresh layer list;
- ☒ *Report unchanged pixels*: if checked, report also unchanged pixels (having the same value in both classifications);

Run

- *RUN* : choose the output destination and start the calculation; the land cover change statistics are displayed in the tab *Output* (and saved in a text file) and the `land cover change` raster is loaded in QGIS;

Classification report

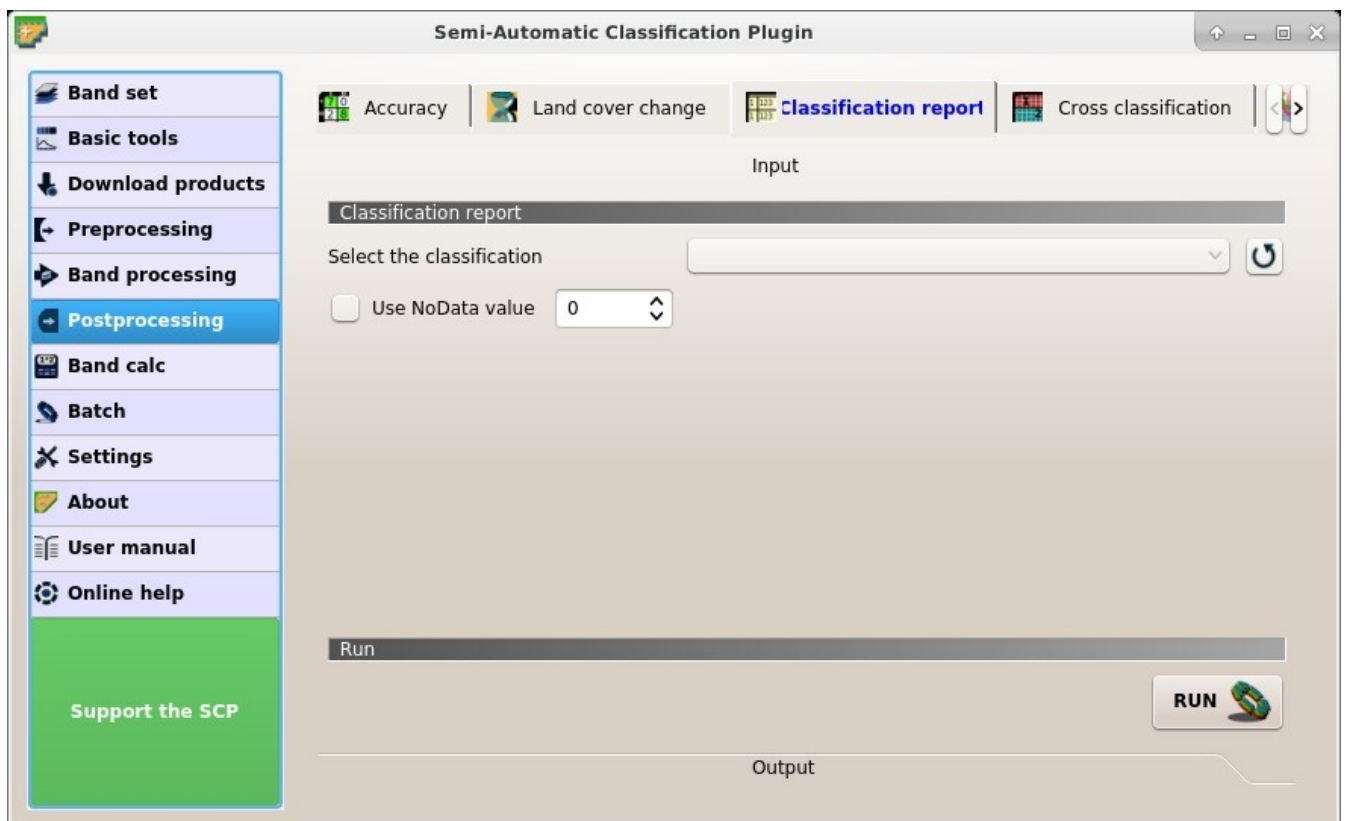







Fig. 38:  *Classification report*

This tab allows for the calculation of class statistics such as number of pixels, percentage and area (area unit is defined from the image itself).

Input

- *Select the classification* : select a classification raster (already loaded in QGIS);
- : refresh layer list;
-  *Use NoData value* : if checked, NoData value will be excluded from the report;

Run

- *RUN* : choose the output destination and start the calculation; the report is saved in a text file and displayed in the tab *Output*;

Cross classification

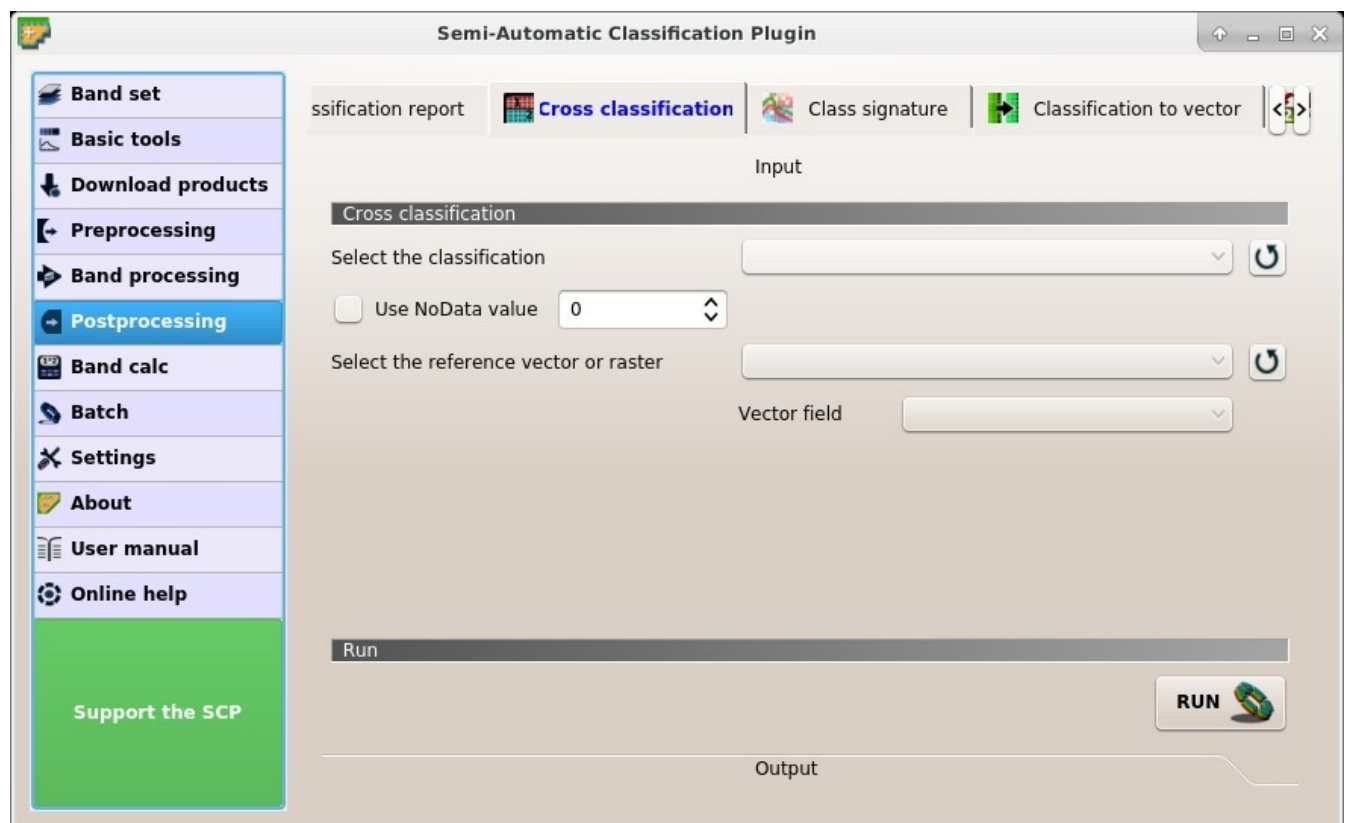








Fig. 39:  *Cross classification*


This tab allows for the calculation of a cross classification raster and matrix. Classification is compared to a reference raster or reference vector (which is automatically converted to raster). This is useful for calculating the area for every combination between reference classes and classification values. If a vector is selected as reference, it is possible to choose a field describing class values.

The output is a `cross_raster` that is a `.tif` file where pixel values represent the categories of comparison (i.e. combinations identified by the `CrossMatrixCode`) between the classification and reference. Also, a text file containing the cross matrix (i.e. a `.csv` file separated by tab) is created with the same name defined for the `.tif` file.

Input

- *Select the classification* : select a classification raster (already loaded in QGIS);
- : refresh layer list;
- ☒ *Use NoData value* : if checked, NoData value will be excluded from the calculation;
- *Select the reference vector or raster* : select a raster or a vector (already loaded in QGIS), used as reference layer;
- : refresh layer list;
- *Vector field* : if a vector is selected as reference, select a vector field containing numeric class values;

Run

- *RUN* : choose the output destination and start the calculation; the cross matrix is displayed in the tab *Output* and the `cross` raster is loaded in QGIS;

Class signature

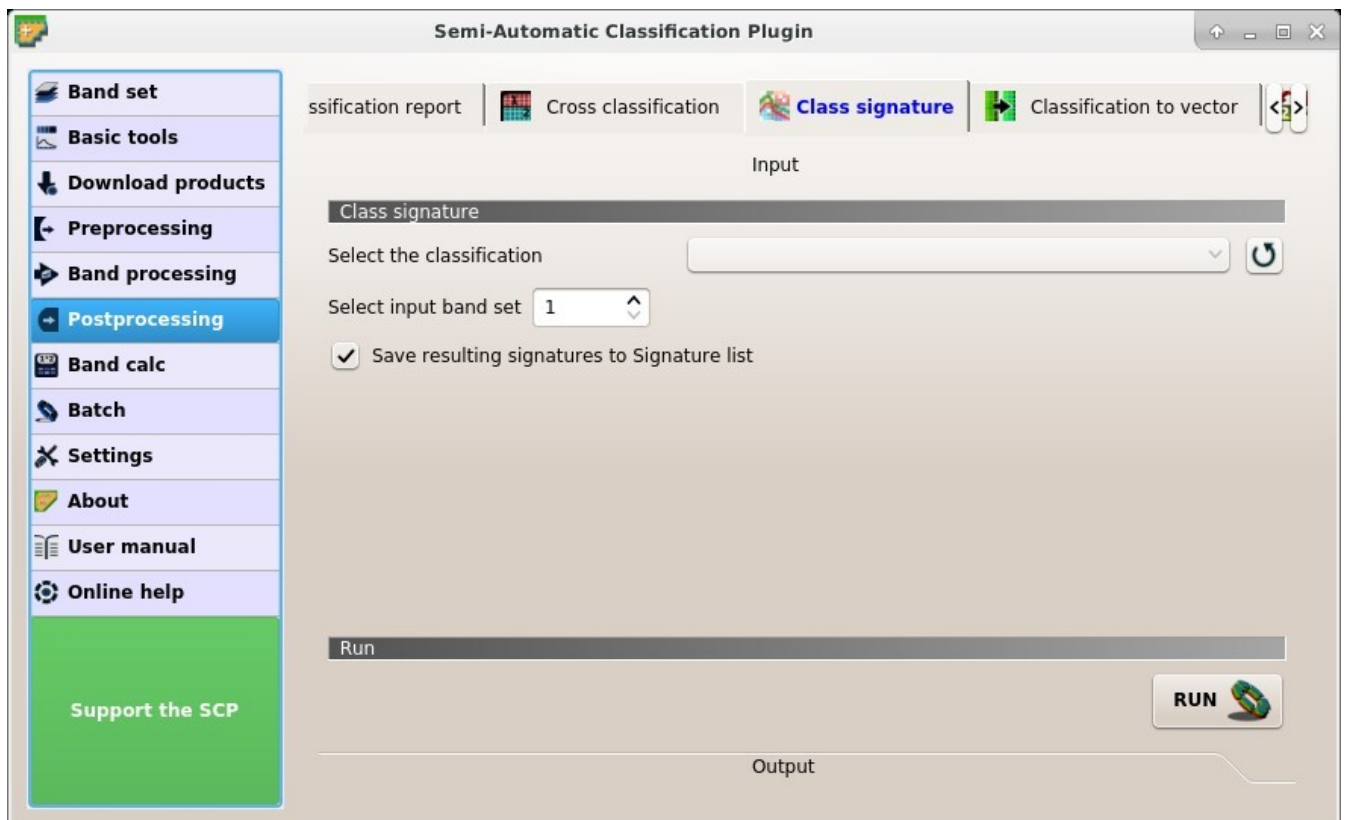







Fig. 40:  *Class signature*

This tab allows for the calculation of the mean spectral signature of each class in a classification using a *Band set* (page 37).

- *Select the classification* : select a classification raster (already loaded in QGIS);
- : refresh layer list;
- *Select input band set* : select the input *Band set* (page 37) for spectral signature calculation;
-  *Save resulting signatures to Signature list*: if checked, save the resulting spectral signatures to *ROI Signature list* (page 27);

Run

- *RUN* : choose the output destination and start the conversion;

Classification to vector

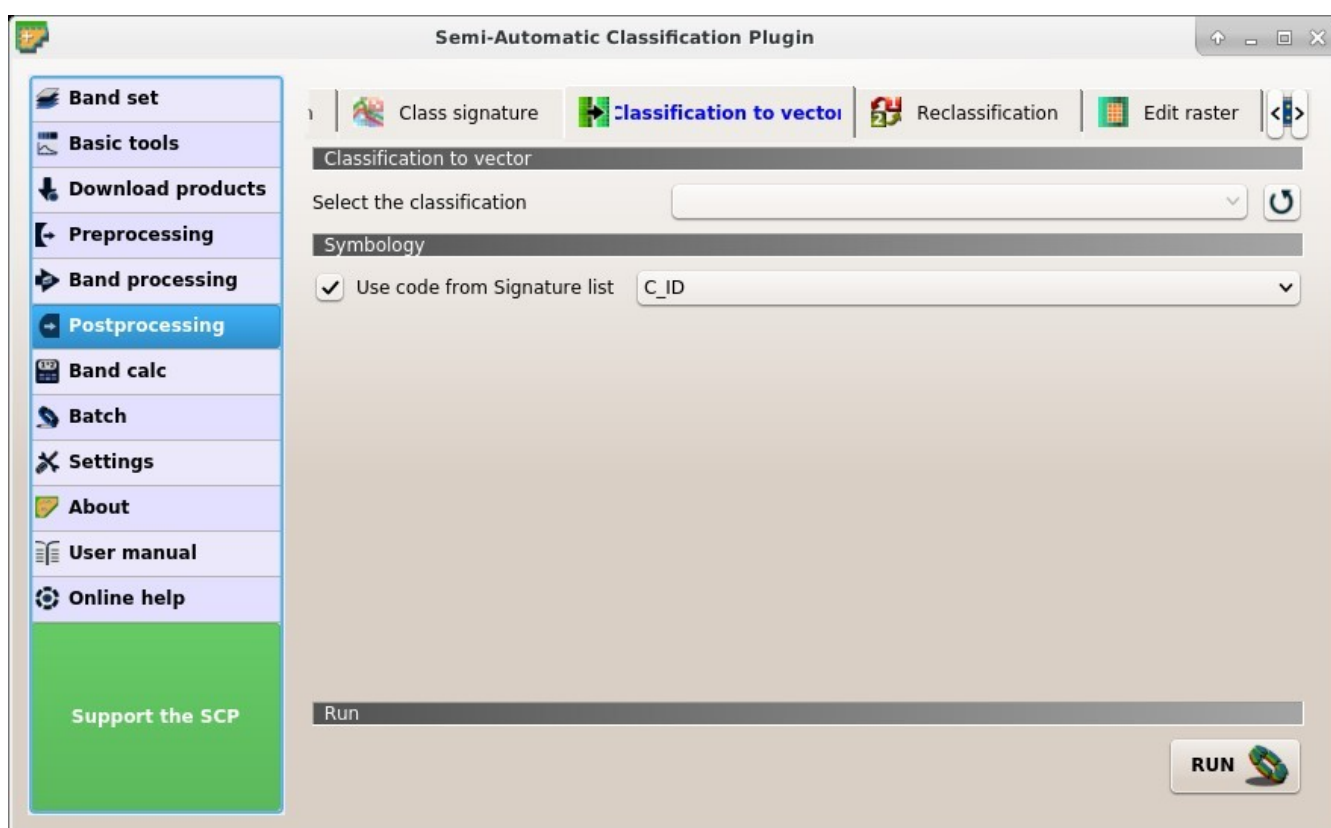






Fig. 41:  *Classification to vector*


This tab allows for the conversion of a classification raster to vector shapefile.

- *Select the classification* : select a classification raster (already loaded in QGIS);
- : refresh layer list;

Symbology

-  *Use code from Signature list* : if checked, color and class information are defined from *ROI Signature list* (page 79)
 - MC ID: use the ID of macroclasses;
 - C ID: use the ID of classes;

Run

- *RUN* : choose the output destination and start the conversion;

Reclassification

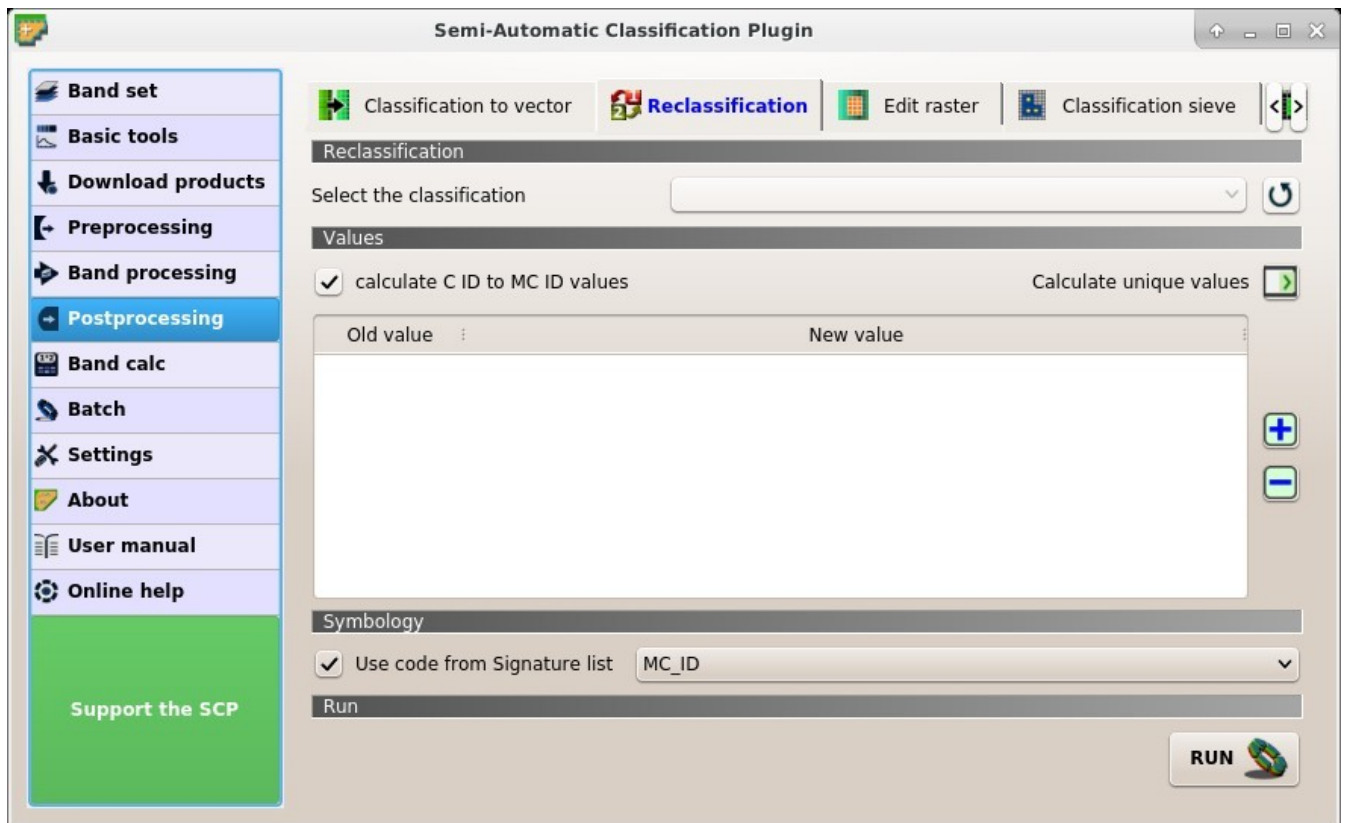










Fig. 42:  *Reclassification*



This tab allows for the reclassification (i.e. assigning a new class code to raster pixels). In particular, it eases the conversion from C ID to MC ID values.

- *Select the classification* : select a classification raster (already loaded in QGIS);
- : refresh layer list;


Values

-  *calculate C ID to MC ID values*: if checked, the reclassification table is filled according to the *ROI Signature list* (page 27) when *Calculate unique values*  is clicked;
- *Calculate unique values* : calculate unique values in the classification and fill the reclassification table;
-  **Values: table containing the following fields;**
 - *Old value*: set the expression defining old values to be reclassified; Old value can be a value or an expressions defined using the variable name `raster` (custom names can be defined in *Variable name for expressions* (page 97)), following Python operators (e.g. `raster > 3` select all pixels having value `> 3` ; `raster > 5 | raster < 2` select all pixels having value `> 5` or `< 2` ; `raster >= 2 & raster <= 5` select all pixel values between 2 and 5);
 - *New value*: set the new value for the old values defined in Old value;
- : add a row to the table;
- : remove highlighted rows from the table;

Symbology

-  *Use code from Signature list* : if checked, color and class information are defined from *ROI Signature list* (page 27)
 - MC ID: use the ID of macroclasses;
 - C ID: use the ID of classes;

Run



- *RUN* : choose the output destination and start the calculation; reclassified raster is loaded in QGIS;

Edit raster

This tab allows for the direct editing of pixel values in a raster. Only pixels beneath ROI polygons or vector polygons are edited.

Attention: the input raster is directly edited; it is recommended to create a **backup copy** of the input raster before using this tool in order to prevent data loss.

This tool can rapidly edit large rasters, especially when editing polygons are small, because pixel values are edited directly. In addition, the *SCP Edit Toolbar* (page 107) is available for easing the raster editing using multiple values.

- *Select the input raster* : select a raster (already loaded in QGIS);
- : refresh layer list;

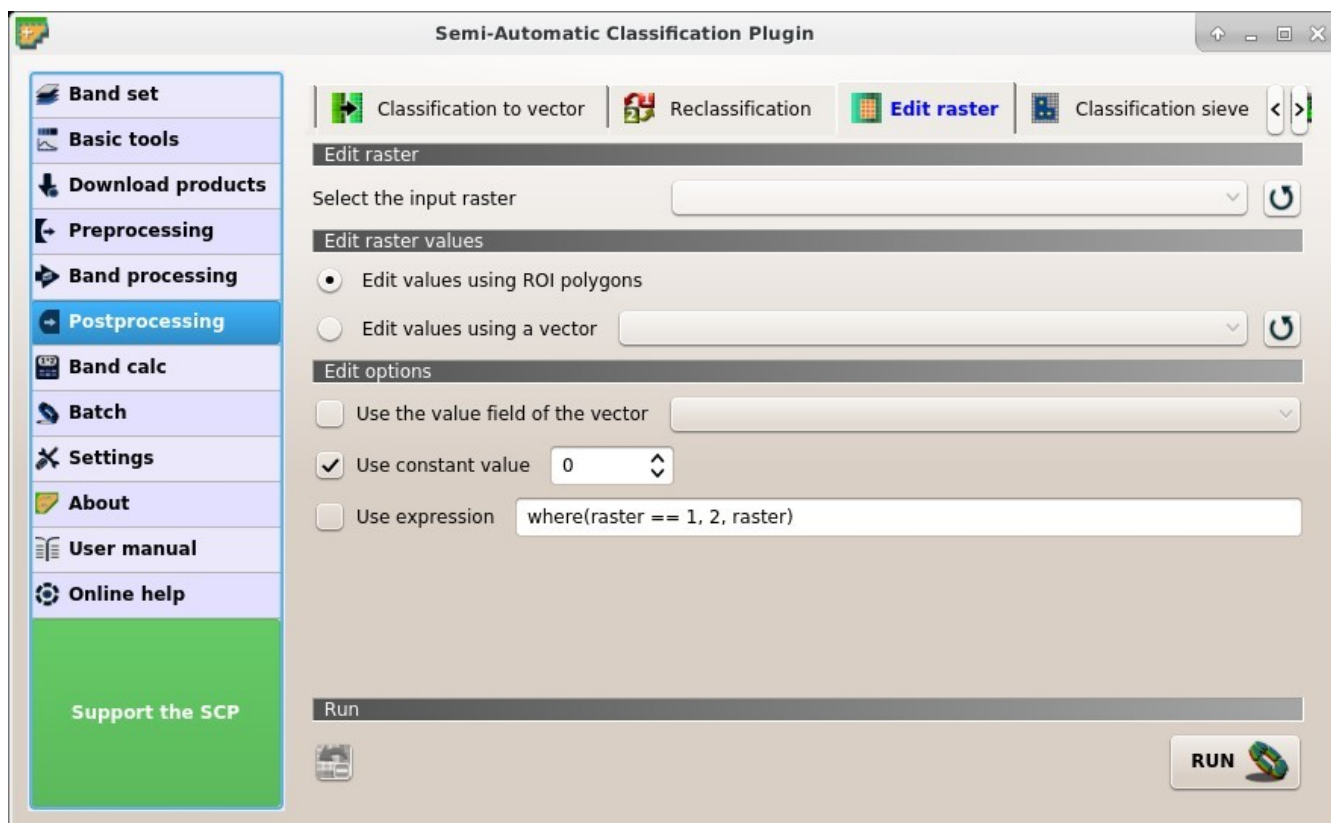












Fig. 43:  *Edit raster*



Edit raster values

-  *Edit values using ROI polygons*: if checked, raster is edited using temporary ROI polygons in the map;
-  *Edit values using a vector* : if checked, raster is edited using all the polygons of selected vector;
- : refresh layer list;

Edit options

-  *Use the value field of the vector* : if checked, raster is edited using the selected vector (in *Edit values using a vector*) and the polygon values of selected vector field;
-  *Use constant value* : if checked, raster is edited using the selected constant value;
-  *Use expression* : if checked, raster is edited according to the entered expression; the expression must contain one or more `where`; accepted variable are `raster` representing the input raster value and `vector` representing the vector value if selected; the following example expression `where(raster == 1, 2, raster)` is already entered, which sets 2 where `raster` equals 1, and leaves unchanged the values where `raster` is not equal to 1;

Run

- : undo the last raster edit (available only when using ROI polygons);
- *RUN* : edit the raster;

Classification sieve

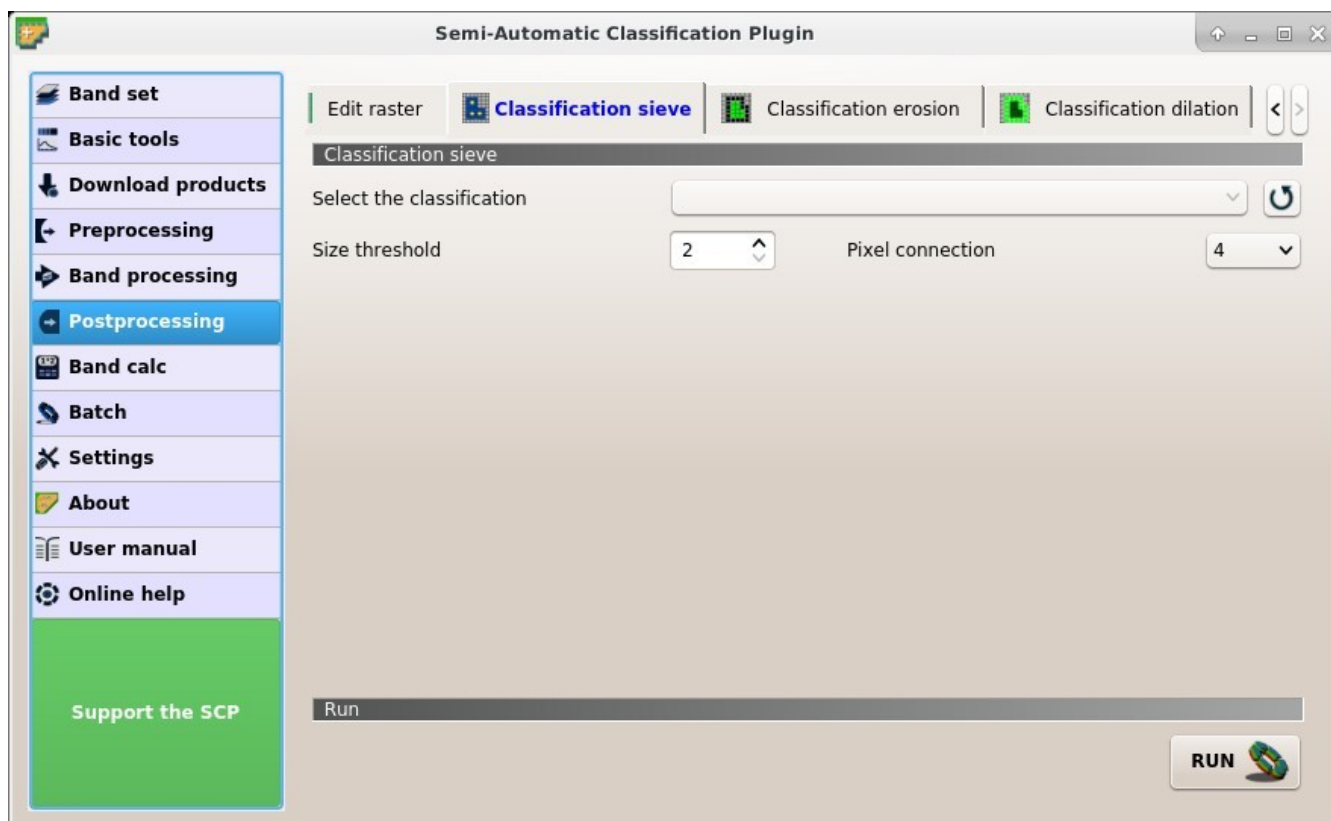







Fig. 44:  *Classification sieve*

This tab allows for the replacement of isolated pixel values with the value of the largest neighbour patch (based on [GDAL Sieve](#)). It is useful for removing small patches from a classification.

- *Select the classification* : select a raster (already loaded in QGIS);
- : refresh layer list;
- *Size threshold* : size of the patch to be replaced (in pixel unit); all patches smaller the the selected number of pixels will be replaced by the value of the largest neighbour patch;
- *Pixel connection* : select the type of pixel connection:
 - 4: in a 3x3 window, diagonal pixels are not considered connected;
 - 8: in a 3x3 window, diagonal pixels are considered connected;

Run

- **RUN** : choose the output destination and start the calculation;

Classification erosion

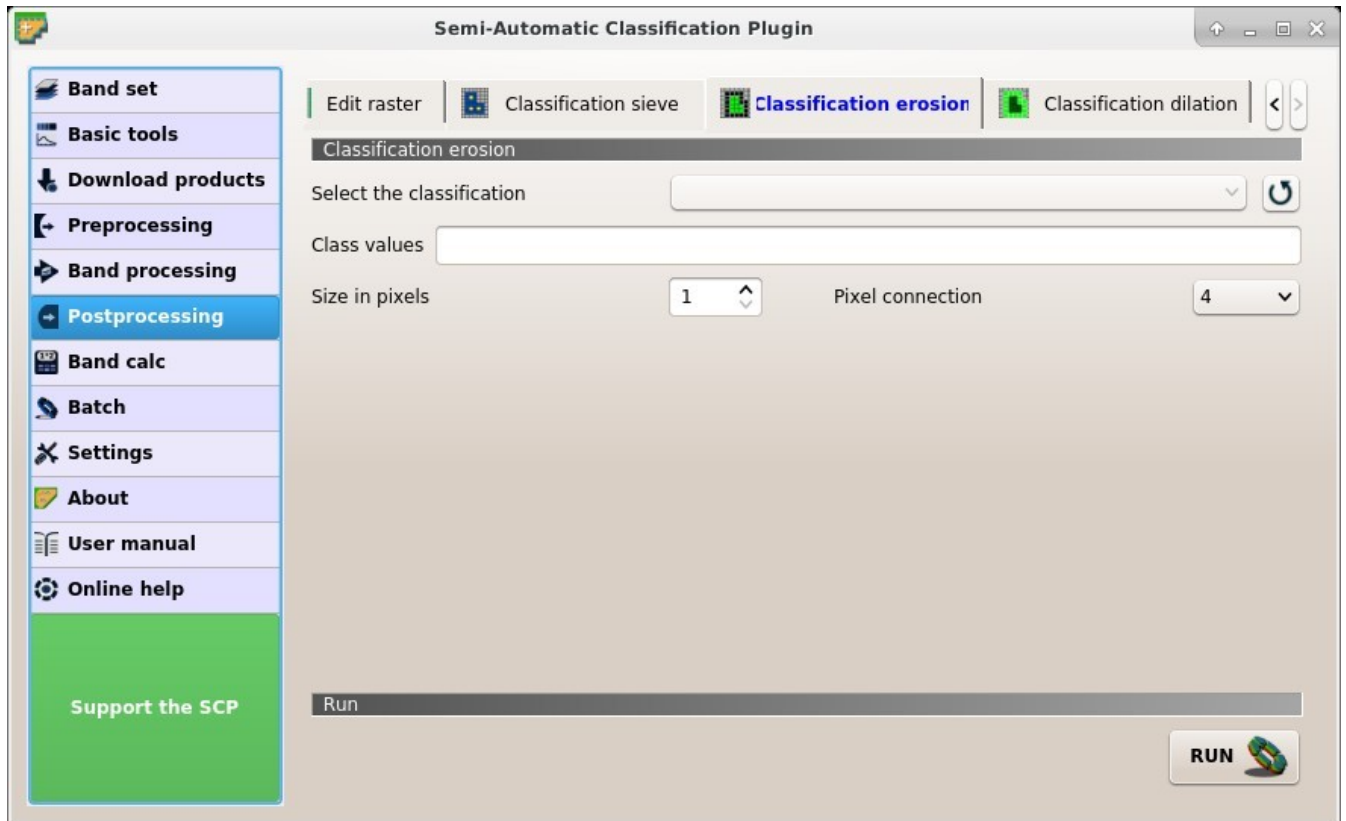








Fig. 45:  *Classification erosion*

This tab allows for removing the border of a class patch (erosion), defining the class values to be eroded and the number of pixels from the border. It is useful for classification refinement.

- *Select the classification* : select a raster (already loaded in QGIS);
- : refresh layer list;
- *Class values* : set the class values to be eroded; class values must be separated by , and – can be used to define a range of values (e.g. 1, 3–5, 8 will select classes 1, 3, 4, 5, 8); if the text is red then the expression contains errors;
- *Size in pixels* : number of pixels to be eroded from the border;
- *Pixel connection* : **select the type of pixel connection:**
 - 4: in a 3x3 window, diagonal pixels are not considered connected;
 - 8: in a 3x3 window, diagonal pixels are considered connected;

Run

- **RUN** : choose the output destination and start the calculation;

Classification dilation

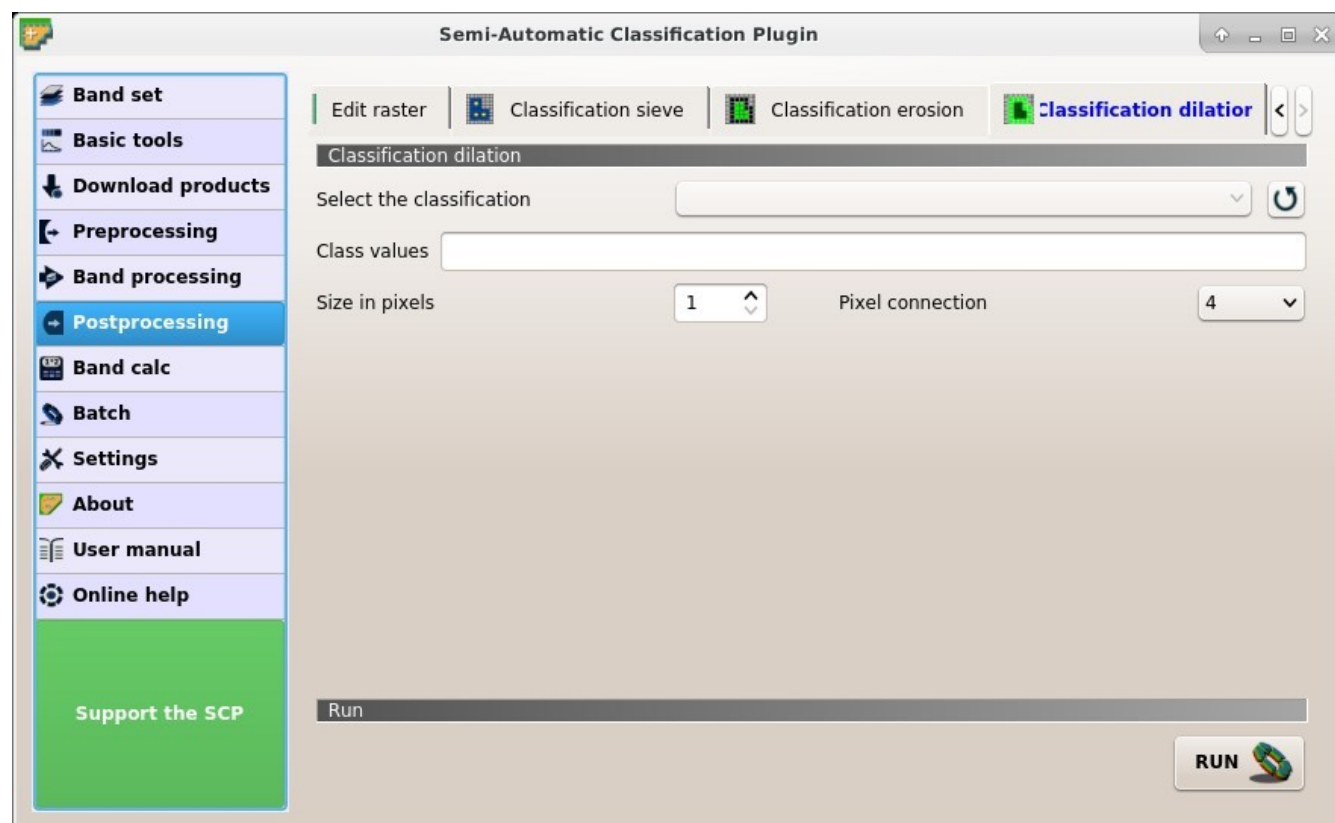








Fig. 46:  *Classification dilation*

This tab allows for dilating the border of a class patch, defining the class values to be dilated and the number of pixels from the border. It is useful for classification refinement.

- *Select the classification* : select a raster (already loaded in QGIS);
- : refresh layer list;
- *Class values* : set the class values to be dilated; class values must be separated by , and – can be used to define a range of values (e.g. 1, 3–5, 8 will select classes 1, 3, 4, 5, 8); if the text is red then the expression contains errors;
- *Size in pixels* : number of pixels to be dilated from the border;
- *Pixel connection* : **select the type of pixel connection:**
 - 4: in a 3x3 window, diagonal pixels are not considered connected;
 - 8: in a 3x3 window, diagonal pixels are considered connected;

Run

-  **RUN**: choose the output destination and start the calculation;

3.4.7 Band calc

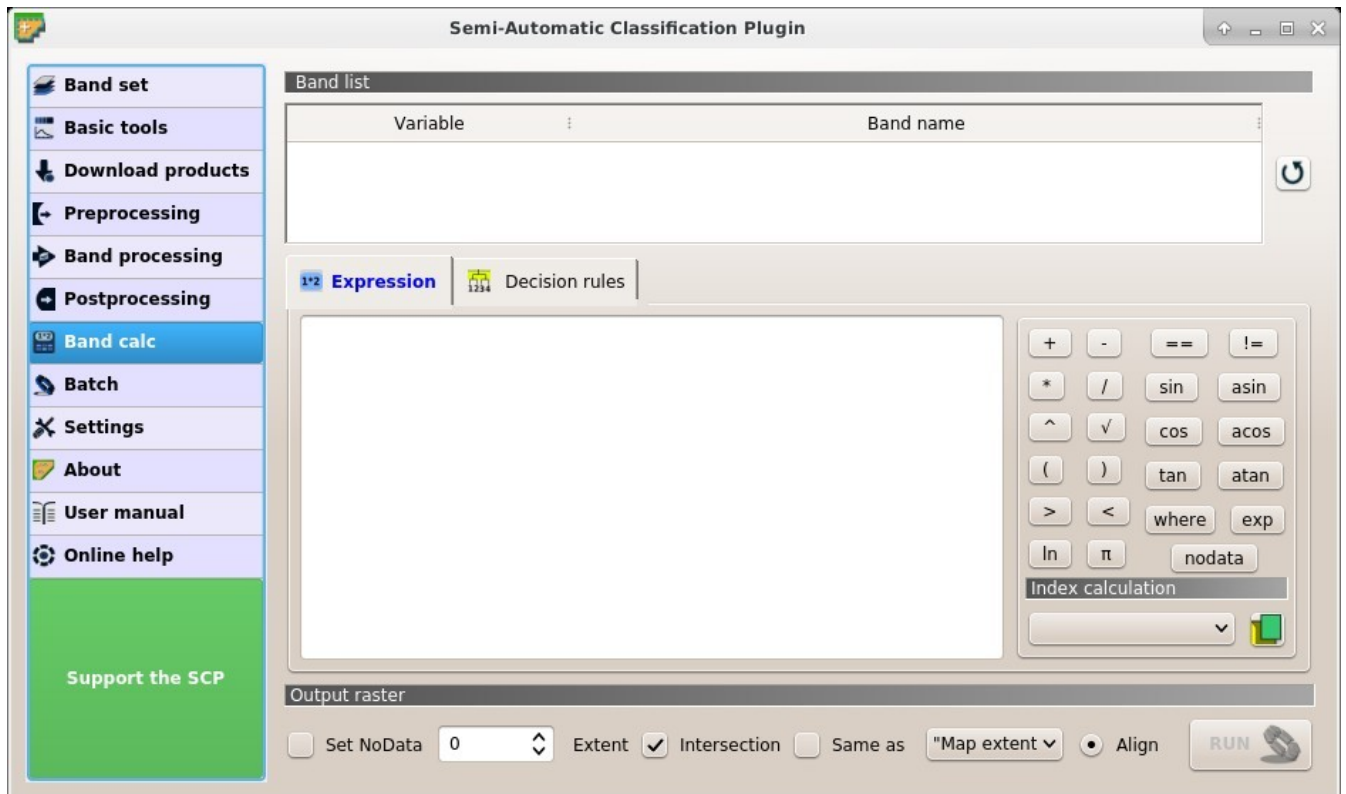




Fig. 47:  **Band calc**

The **Band calc** allows for the **raster calculation for bands** (i.e. calculation of pixel values) using [NumPy functions](#). Raster bands must be already loaded in QGIS. Input rasters must be in the same projection.

In addition, it is possible to calculate a raster using **decision rules**.

Band list

-  **Band list**: table containing a list of single band rasters (already loaded in QGIS);
 - *Variable*: variable name defined automatically for every band (e.g. raster1, raster2);
 - *Band name*: band name (i.e. the layer name in QGIS);
- : refresh image list;

Expression

Enter a mathematical expression for raster bands. In particular, NumPy functions can be used with the prefix *np.* (e.g. `np.log10(raster1)`). For a list of NumPy functions see [the NumPy page](#).

The expression can work with both *Variable* and *Band name* (between double quotes). Also, bands in the *Band set* (page 37) can be referenced directly; for example `bandset#b1` refers to band 1 of the *Band set*. Double click on any item in the *Band list* (page 87) for adding its name to the expression. In addition, the following variables related to *Band set* (page 37) the are available:

- “#BLUE#”: the band with the center wavelength closest to 0.475 μm ;
- “#GREEN#”: the band with the center wavelength closest to 0.56 μm ;
- “#RED#”: the band with the center wavelength closest to 0.65 μm ;
- “#NIR#”: the band with the center wavelength closest to 0.85 μm ;

Variables for output name are available:

- #BANDSET#: the name of the first band in the *Band set* (page 37);
- #DATE#: the current date and time (e.g. 20161110_113846527764);

If text in the *Expression* is green, then the syntax is correct; if text is red, then the syntax is incorrect and it is not possible to execute the calculation.

It is possible to enter multiple expressions separated by newlines such as the following example:

```
"raster1" + "raster2"  
"raster3" - "raster4"
```

The above example calculates two new rasters in the output directory with the suffix `_1` (e.g. `calc_raster_1`) for the first expression and `_2` (e.g. `calc_raster_2`) for the second expression. Also, it is possible to define the output name using the symbol `@` followed by the name, such as the following example:

```
"raster1" + "raster2" @ calc_1  
"raster3" - "raster4" @ calc_2
```



The following buttons are available:

- +: plus;
- -: minus;
- *: product;
- /: ratio;
- ^: power;
- V: square-root;
- (: open parenthesis;
-): close parenthesis;
- >: greater then;
- <: less then;
- *ln*: natural logarithm;
- π : pi;
- ==: equal;
- !=: not equal;
- *sin*: sine;
- *asin*: inverse sine;
- *cos*: cosine;
- *acos*: inverse cosine;
- *tan*: tangent;

- *atan*: inverse tangent;
- *where*: conditional expression according to the syntax `where(condition , value if true, value if false)` (e.g. `where("raster1" == 1, 2, "raster1")`);
- *exp*: natural exponential;
- *nodata*: NoData value of raster (e.g. `nodata("raster1")`); it can be used as value in the expression (e.g. `where("raster1" == nodata("raster1"), 0, "raster1")`);

Index calculation

Index calculation allows for entering a spectral index expression (see [Spectral Indices](#) (page 128)).






- **Index calculation** : **list of spectral indices:**
 - *NDVI*: if selected, the NDVI calculation is entered in the *Expression* ((("#NIR#" - "#RED#") / ("#NIR#" + "#RED#") @ NDVI));
 - *EVI*: if selected, the EVI calculation is entered in the *Expression* (2.5 * ("#NIR#" - "#RED#") / ("#NIR#" + 6 * "#RED#" - 7.5 * "#BLUE#" + 1) @ EVI);
- : open a text file (.txt) containing custom expressions to be listed in *Index calculation*; the text file must contain an expression for each line; each line must be in the form `expression_name; expression` (separated by ;) where the `expression_name` is the expression name that is displayed in the *Index calculation*; if you open an empty text file, the default values are restored; following an example of text content:

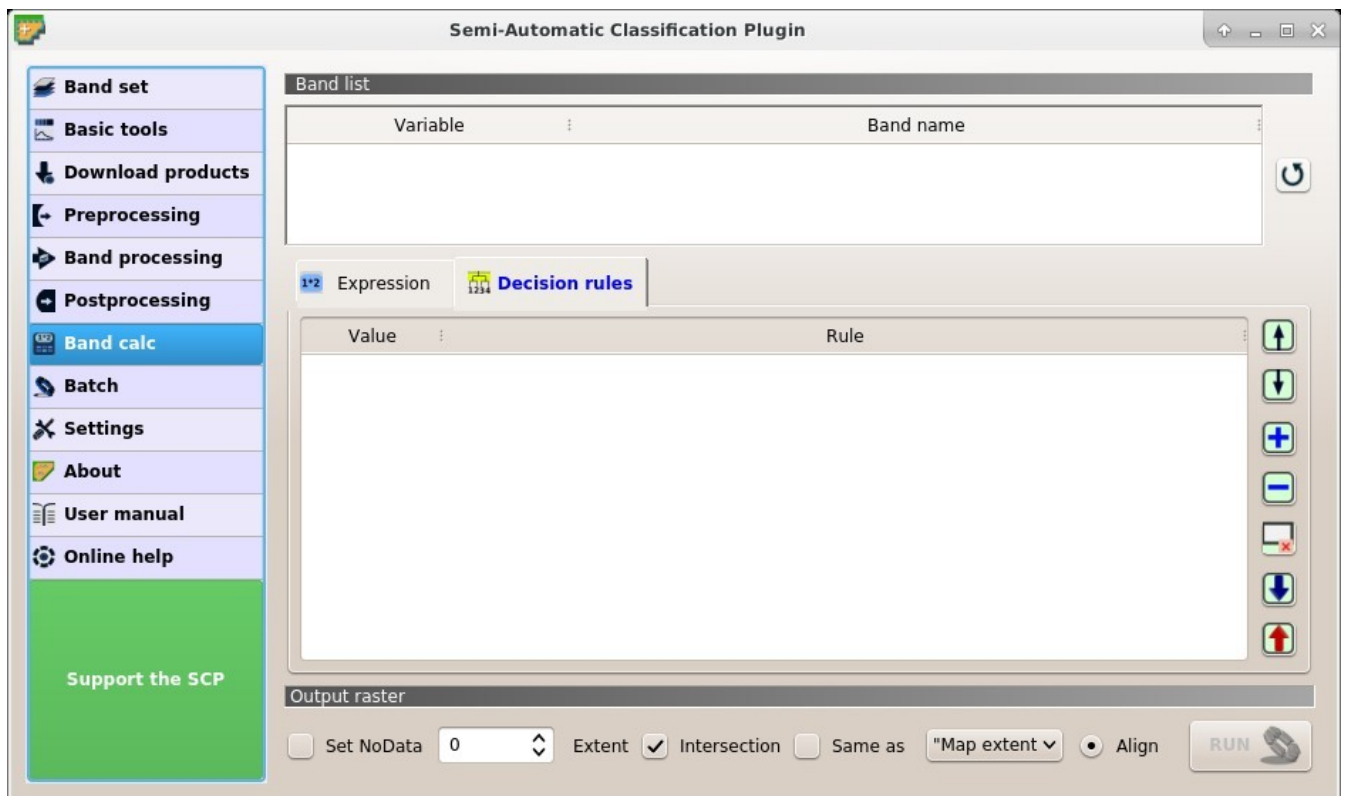
```
NDVI; ( "#NIR#" - "#RED#" ) / ( "#NIR#" + "#RED#" ) @NDVI
EVI; 2.5 * ( "#NIR#" - "#RED#" ) / ( "#NIR#" + 6 * "#RED#" - 7.5 * "#BLUE#" + 1 ) @EVI
SR; ( "#NIR#" / "#RED#" ) @SR
```




Decision rules

Decision rules allows for the calculation of an output raster based on rules. Rules are conditional statements based on other rasters; if the *Rule* is true, the corresponding *Value* is assigned to the output pixel.

Rules are verified from the first to the last row in the table; if the first *Rule* is false, the next *Rule* is verified for that pixel, until the last rule. If multiple rules are true for a certain pixel, the value of the first *Rule* is assigned to that pixel. The NoData value is assigned to those pixels where no *Rule* is true.





-  **Decision rules: table containing the following fields;**
 - *Value*: the value assigned to pixels if the *Rule* is true;
 - *Rule*: the rule to be verified (e.g. `"raster1" > 0`); multiple conditional statements can be entered separated by ; (e.g. `"raster1" > 0; "raster2" < 1` which means to set the *Value* where `raster1 > 0` and `raster2 < 1`);
- : move highlighted rule up;
- : move highlighted rule down;
- : add a new row to the table;
- : delete the highlighted rows from the table;



- : clear the table;
- : export the rules to a text file that can be imported later;
- : import rules from a text file;

Output raster

The output raster is a .tif file, with the same spatial resolution and projection of input rasters; if input rasters have different spatial resolutions, then the highest resolution (i.e. minimum pixel size) is used for output raster.

- ☒ *Use NoData value* : if checked, set the value of NoData pixels in output raster;
- **Extent: if the following options are unchecked, the output raster extent will include the extents of all input rasters;**
 - ☒ *Intersection*: if checked, the extent of output raster equals the intersection of input raster extents (i.e. minimum extent);
 - ☒ *Same as* : if checked, the extent of output raster equals the extent of “Map extent” (the extent of the map currently displayed) or a selected layer;
-  *Align*: if checked, and ☒ *Same as* is checked selecting a raster, the calculation is performed using the same extent and pixel alignment of selected raster;
-  *RUN*: if Expression is active and text is green, choose the output destination and start the calculation based on Expression; if Decision rules is active and text is green, choose the output destination and start the calculation based on Decision rules;

3.4.8 Batch

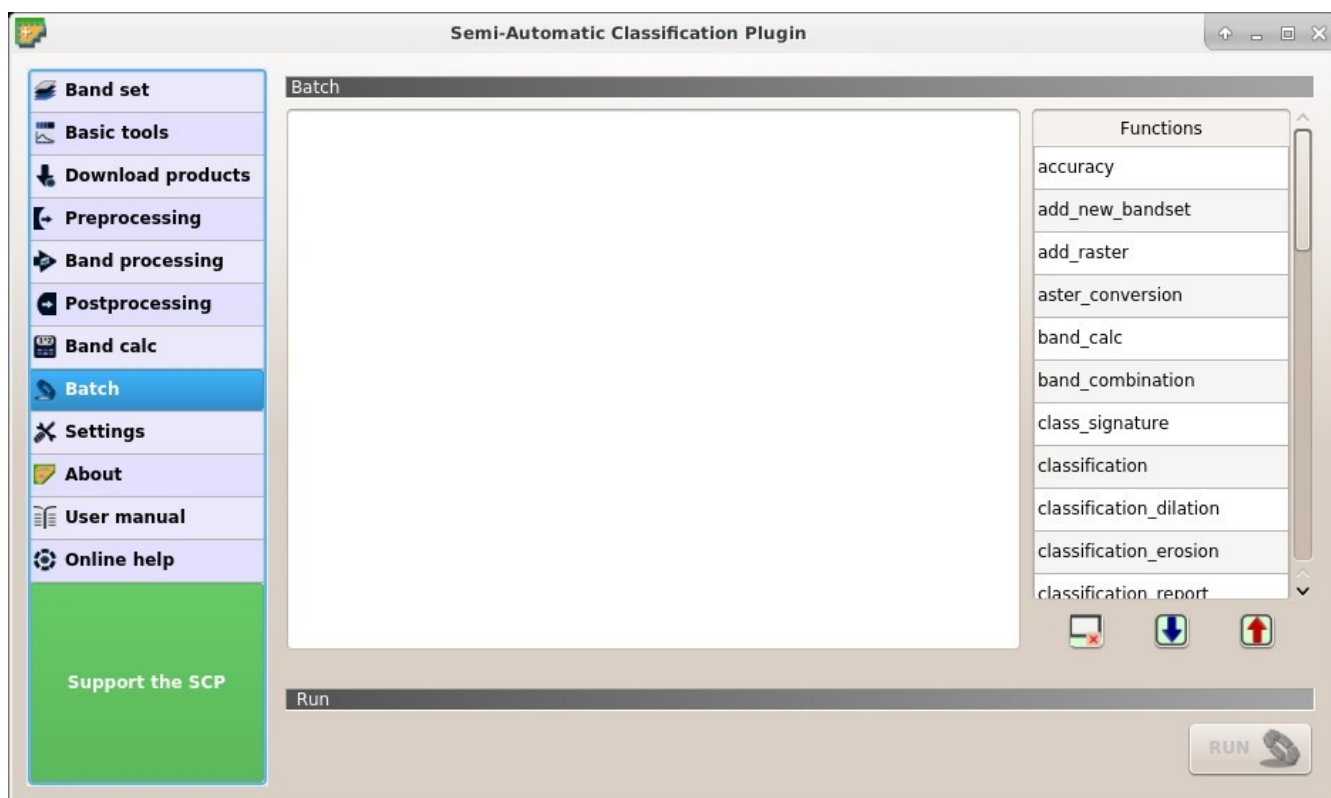


Fig. 48:  Batch

This tab allows for the automatic execution (batch) of several *SCP* functions using a scripting interface.

Batch

Enter a batch expression; each function must be in a new line. Functions have the following structure:

```
function name;function options
```



Each function has options, identified by a name, with the following structure:


```
option name:option argument
```

Options must be separated by the character `;`. Each function option represents an option in the corresponding interface of *SCP*; option arguments of type text must be between the character `'`; in case of checkboxes, the value 1 represents checked, while the value 0 represents unchecked. A new line beginning with `#` can be used for commenting.

According to the function, some of the options are mandatory while other options can be omitted from the expression. Option names that contain `path` require the full path to a file. Some options require multiple arguments such as lists; lists must be separated by `,`.

If the expression contains errors, the text is red. An expression check label is displayed with a brief description of the error.

- : clear the expression;
- : export the batch expression to a file;

- : import a previously saved batch expression from file;

A table *Functions* is displayed at the right side; double click to insert a function in the expression; the following functions are

- *Accuracy* (page 75): calculate accuracy (`accuracy;classification_file_path : '';reference_file_path : '';shapefile_field_name : '';output_raster_path : ''`);
- *ASTER* (page 61): ASTER conversion (`aster_conversion;input_raster_path : '';celsius_temperature : 0;apply_dos1 : 0;use_nodata : 1;nodata_value : 0;create_bandset : 1;output_dir : ''`);
- *Band calc* (page 87): band calculation (`band_calc;expression : '';output_raster_path : '';extent_same_as_raster_name : '';extent_intersection : 1;set_nodata : 0;nodata_value : 0`);
- *Band combination* (page 70): band combination (`band_combination;band_set : 1;output_raster_path : ''`);
- *Class signature* (page 79): class signature (`class_signature;input_raster_path : '';band_set : 1;save_signatures : 1;output_text_path : ''`);
- *Classification output* (page 33): perform classification (`classification;use_macroclass : 0;algorithm_name : 'Minimum Distance';use_lcs : 0;use_lcs_algorithm : 0;use_lcs_only_overlap : 0;apply_mask : 0;mask_file_path : '';vector_output : 0;classification_report : 0;save_algorithm_files : 0;output_classification_path : ''`);
- *Classification dilation* (page 86): dilation of a classification (`classification_dilation;input_raster_path : '';class_values : '';size_in_pixels : 1;pixel_connection : 4;output_raster_path : ''`);
- *Classification erosion* (page 85): erosion of a classification (`classification_erosion;input_raster_path : '';class_values : '';size_in_pixels : 1;pixel_connection : 4;output_raster_path : ''`);
- *Classification report* (page 77): report of a classification (`classification_report;input_raster_path : '';use_nodata : 0;nodata_value : 0;output_report_path : ''`);
- *Classification sieve* (page 84): classification sieve(`classification_sieve;input_raster_path : '';size_threshold : 2;pixel_connection : 4;output_raster_path : ''`);
- *Classification to vector* (page 80): convert classification to vector (`classification_to_vector;input_raster_path : '';use_signature_list_code : 1;code_field : 'C_ID';output_vector_path : ''`);
- *Clip multiple rasters* (page 65): clip multiple rasters (`clip_multiple_rasters;input_raster_path : '';output_dir : '';use_shapefile : 0;shapefile_path : '';ul_x : '';ul_y : '';lr_x : '';lr_y : '';nodata_value : 0;output_name_prefix : 'clip'`);
- *Cloud masking* (page 69): cloud masking (`cloud_masking;band_set : 1;input_raster_path : '';class_values : '';use_buffer : 1;size_in_pixels : 1;nodata_value : 0;output_name_prefix : 'mask';output_dir : ''`);
- *Clustering* (page 72): clustering (`clustering;band_set : 1;clustering_method : 1;use_distance_threshold : 1;threshold_value : 0.0001;number_of_classes : 10;max_iterations : 10;isodata_max_std_dev : 0.0001;isodata_min_class_size : 10;use_nodata : 0;nodata_value`

- ```
: 0;seed_signatures : 1;distance_algorithm : 1;save_signatures :
0;output_raster_path : ''');
```
- *Cross classification* (page 78): cross classification (cross\_classification; classification\_file\_path : '';use\_nodata : 0;nodata\_value : 0;reference\_file\_path : '';shapefile\_field\_name : '';output\_raster\_path : ''');
  - *Edit raster* (page 82): edit raster values using a shapefile); (edit\_raster\_using\_shapefile; input\_raster\_path : '';input\_vector\_path : '';vector\_field\_name : '';constant\_value : 0;expression : 'where(raster == 1, 2, raster)');
  - *Land cover change* (page 76): calculate land cover change (land\_cover\_change; reference\_raster\_path : '';new\_raster\_path : '';output\_raster\_path : ''');
  - *Landsat* (page 56): Landsat conversion (landsat\_conversion;input\_dir : ''; mtl\_file\_path : '';celsius\_temperature : 0;apply\_dos1 : 0; use\_nodata : 1;nodata\_value : 0;pansharpening : 0;create\_bandset : 1;output\_dir : ''');
  - *MODIS* (page 62): MODIS conversion (modis\_conversion;input\_raster\_path : '';reproject\_wgs84 : 1;use\_nodata : 1;nodata\_value : -999; create\_bandset : 1;output\_dir : ''');
  - *PCA* (page 71): Principal Component Analysis (pca;use\_number\_of\_components : 0, number\_of\_components : 2;use\_nodata : 1;nodata\_value : 0; output\_dir : ''');
  - *Reclassification* (page 81): raster reclassification (reclassification; input\_raster\_path : '';value\_list : 'oldVal-newVal; oldVal-newVal';use\_signature\_list\_code : 1;code\_field : 'MC\_ID'; output\_raster\_path : ''');
  - *Sentinel-2* (page 58): Sentinel-2 conversion (sentinel2\_conversion;input\_dir : '';mtd\_safl1c\_file\_path : '';apply\_dos1 : 0;use\_nodata : 1; nodata\_value : 0;create\_bandset : 1;output\_dir : ''');
  - *Sentinel-3* (page 59): Sentinel-3 conversion (sentinel3\_conversion;input\_dir : '';apply\_dos1 : 0;dos1\_only\_blue\_green : 1;use\_nodata : 1; nodata\_value : 0;create\_bandset : 1;output\_dir : '';band\_set : 1);
  - *Spectral distance* (page 73): spectral distance of band sets (spectral\_distance; first\_band\_set : 1;second\_band\_set : 2;distance\_algorithm : 1; use\_distance\_threshold : 1;threshold\_value : 0.1;output\_dir : ''');
  - *Split raster bands* (page 66): split raster to single bands (split\_raster\_bands; input\_raster\_path : '';output\_dir : '';output\_name\_prefix : 'split');
  - *Stack raster bands* (page 67): stack rasters into a single file (stack\_raster\_bands; input\_raster\_path : '';output\_raster\_path : ''');
  - *Vector to raster* (page 64): convert vector to raster (vector\_to\_raster;vector\_file\_path : '';use\_value\_field : 1;vector\_field\_name : '';constant\_value : 1;reference\_raster\_path : '';type\_of\_conversion : 'Center of pixels';output\_raster\_path : ''');

In addition, the following functions are available:

- *Add a new band set*: add a new empty band set (add\_new\_bandset);

- *Add raster to QGIS*: add a raster to QGIS (`add_raster;input_raster_path : '';`  
`input_raster_name : ''`);
- *Create band set*: create a *Band set* assigning bands (`create_bandset;`  
`raster_path_list : ''`; `center_wavelength : ''`; `wavelength_unit :`  
`1`; `multiplicative_factor : ''`; `additive_factor : ''`);
- *Open training input*: open a training input file (`open_training_input;`  
`training_file_path : ''`);
- *Remove band set*: remove a band set by the number thereof (`remove_bandset;band_set :`  
`1`);
- *Select band set*: select a band set (*active band set*) by the number thereof (`select_bandset;`  
`band_set : 1`);
- *Set working directory*: set a working directory (argument is the path to a directory) (!  
`working_dir!;''`);


If a working directory is defined, `!working_dir!` can be entered in other functions where a path is required (e.g. `add_raster;input_raster_path : '!working_dir!/raster1.tif';`  
`input_raster_name : 'raster1.tif'`); An example of batch expression is:

```
!working_dir!; '/home/user/Desktop/temp/'
add_raster;input_raster_path : '!working_dir!/raster1.tif';input_raster_name :
↪ 'raster1.tif'
band_calc;expression : 'where("raster1.tif" > 1, 1,0)';output_raster_path : '!
↪ working_dir!/calc1.tif';set_nodata : 1;nodata_value : 0
band_calc;expression : '"raster1.tif" * "calc1.tif"';output_raster_path : '!
↪ working_dir!/calc2.tif';extent_intersection : 0
```

## Run







-  *RUN* : if text in the batch expression is green, start the batch processes;

## 3.4.9 Settings

The tab  *Settings* allows for the customization of *SCP*.

### Processing

#### Classification process

-  *Play sound when finished*  : if checked, play a sound when the classification process is completed;
-  *Use virtual rasters for temp files*  : if checked, create virtual rasters for certain temporary files, instead of creating real rasters; it is useful for reducing disk space usage during calculations;
-  *Raster compression*  : if checked, a lossless compression (DEFLATE or PACKBITS) is applied to raster outputs in order to save disk space; it is recommended to check this option, however compressed files are sometimes larger than files without compression;

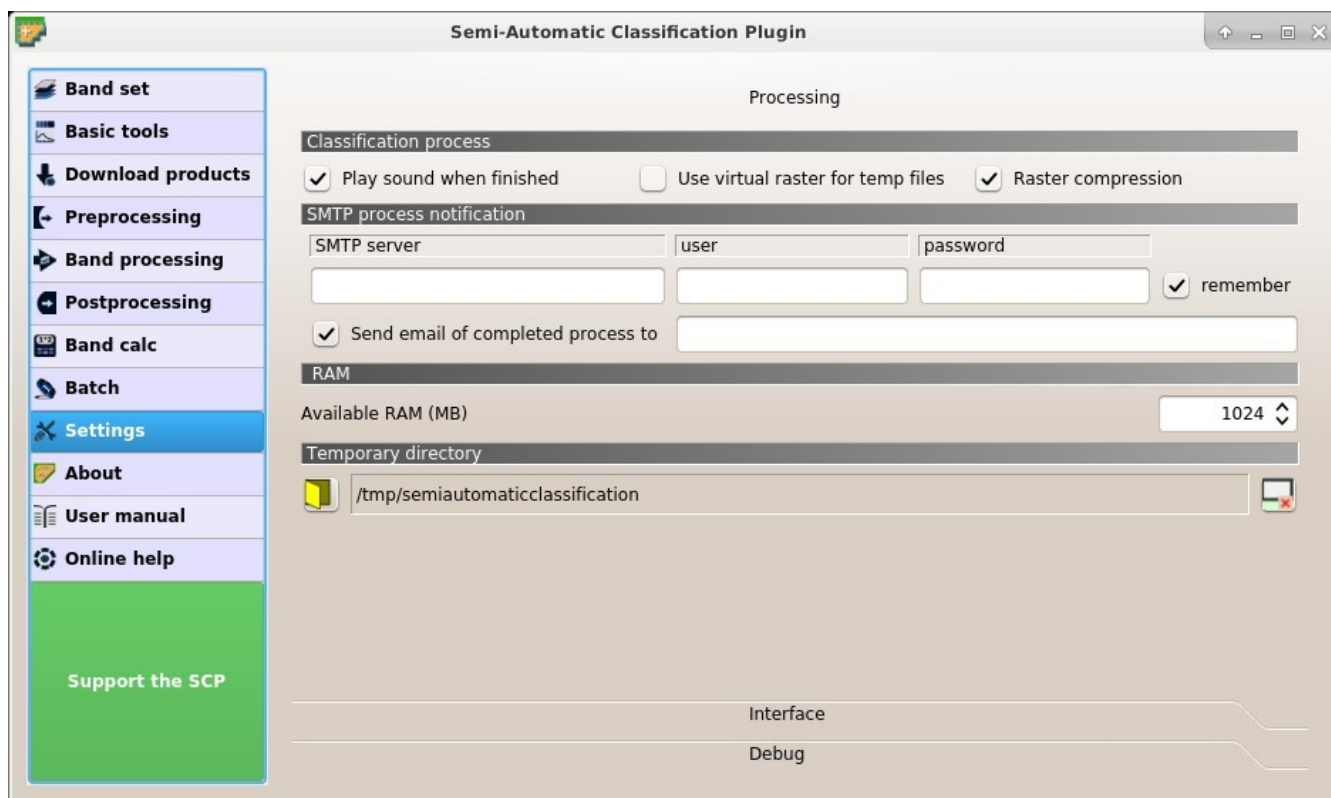


Fig. 49: Processing

### SMTP process notification

- *SMTP server*  : the SMTP server to login for sending a notification email when all the *SCP* processes are finished (a notification is sent also in case of error, but not in case of crash);
- *user*  : the SMTP server user;
- *password*  : the SMTP server password;
- *Send email of completed process to*  : a list of addresses (separated by comma) to send the notification email to;



### RAM

- *Available RAM (MB)*  : set the available RAM (in MB) that is used during the processes in order to improve the *SCP* performance; this value should be half of the system RAM (e.g. 1024MB if system has 2GB of RAM); in case of errors, set a value lower than 512MB;

<http://www.youtube.com/watch?v=KDI3ud9L6UY>



## Temporary directory

-  : select a new temporary directory where temporary files are saved during processing; the path to the current temporary directory is displayed; default is a system temporary directory;
-  : reset to default temporary directory;

## Interface

Customization of the interface.

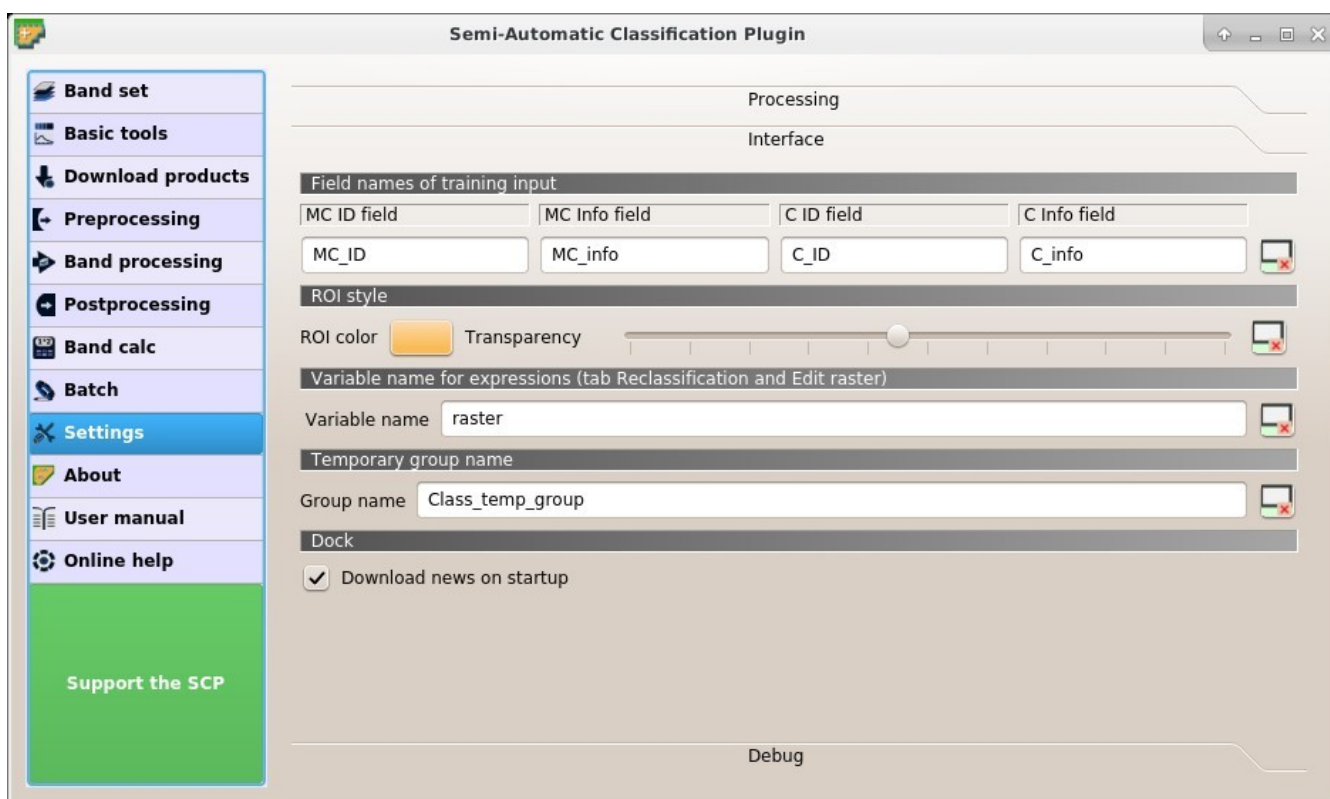







Fig. 50: Interface





## Field names of training input

Set the names of fields in the *Training input* (page 24) . Changing field names should usually be avoided.

- *MC ID field*  : name of the Macroclass ID field (default is MC\_ID);
- *MC Info field*  : name of the Macroclass Information field (default is MC\_info);
- *C ID field*  : name of the Class ID field (default is C\_ID);
- *C Info field*  : name of the Class Information field (default is C\_info);
-  : reset field names to default;




## ROI style

Change ROI color and transparency for a better visualization of temporary ROIs on the map.

- *ROI color*  : button for changing ROI color;
- *Transparency*   : change ROI transparency;
-  : reset ROI color and transparency to default;




## Variable name for expressions

Set the variable name used in expressions of the *Reclassification* (page 81) and *Edit raster* (page 82) .


- *Variable name*   : set variable name (default is `raster`);
-  : reset variable name to default;

## Temporary group name

Set the temporary group name in QGIS Layers used for temporary layers .

- *Group name*   : set group name (default is `Class_temp_group`);
-  : reset group name to default;

## Dock

-  *Download news on startup*: if checked, news about the *SCP* and related services are downloaded on startup and displayed in *Dock*;





## Debug

Debugging utilities for the creation of a Log file (i.e. recording of *SCP* activities for reporting issues) and testing *SCP* dependencies.

<http://www.youtube.com/watch?v=So04gNzDC9Y>

If you found a plugin error, please read *How can I report an error?* (page 228) .

## Log file

-  *Records events in a log file*  : if checked, start recording events in a Log file;
-  : export the Log file (i.e. a .txt file);
-  : clear the content of Log file;

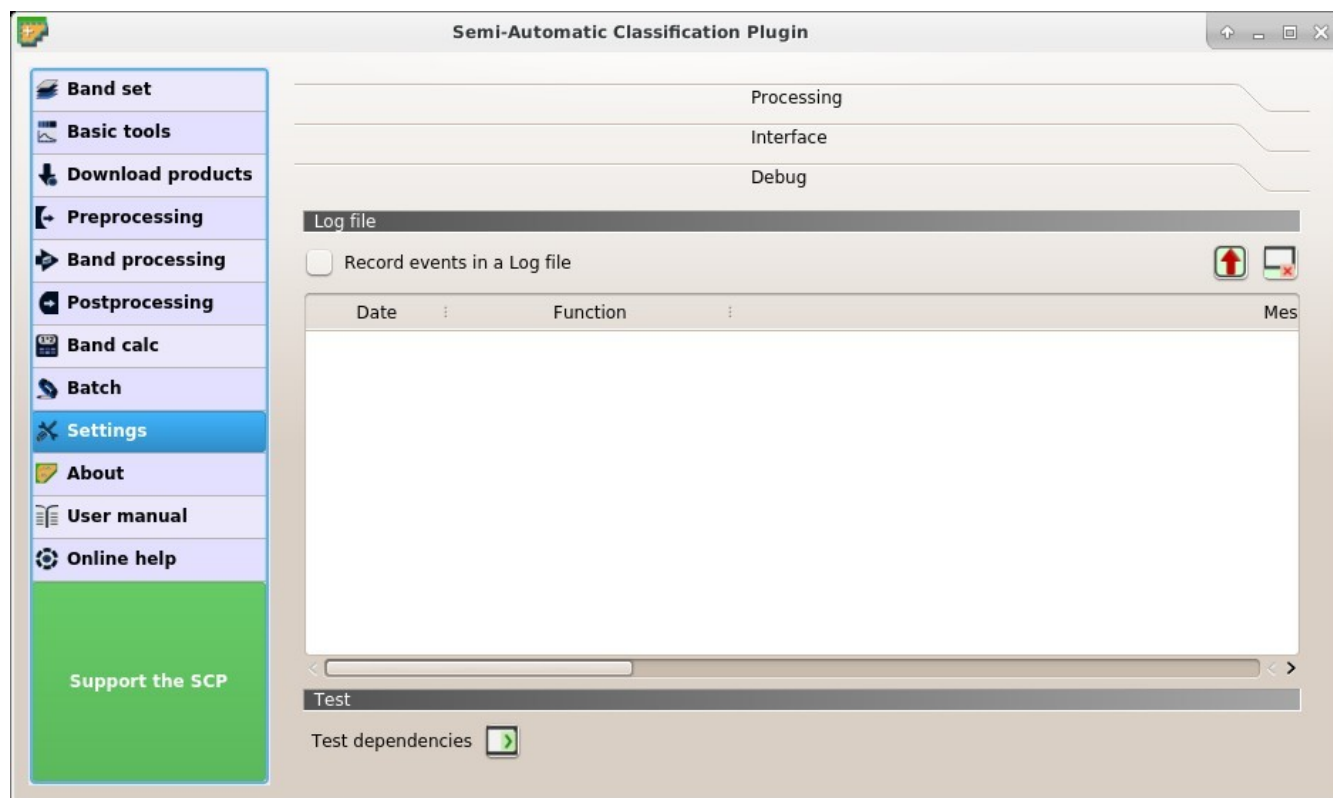



Fig. 51: Debug

## Test

-  **Test dependencies**: test *SCP* dependencies (GDAL, GDAL subprocess, NumPy, SciPy, Matplotlib, Internet connection); results are displayed in a window;


## 3.5 Spectral Signature Plot

The window *Spectral Signature Plot* includes several functions for displaying spectral signature values as a function of wavelength (defined in the *Band set* (page 37)). Signatures can be added to the *Spectral Signature Plot* through the *SCP dock* (page 23).

The window *Spectral Signature Plot* includes also some functions useful for the definition of value ranges used by the *Land Cover Signature Classification* (page 122) (see *LCS threshold* (page 49)).

Overlapping signatures (belonging to different classes or macroclasses) are highlighted in orange in the table *Plot Signature list* (page 98); the overlapping check is performed considering *MC ID* or *C ID* according to the setting Use ☒ *MC ID* ☒ *C ID* in *Algorithm* (page 31). Overlapping signatures sharing the same *ID* are not highlighted.

### 3.5.1 Plot Signature list

-  **Signature list**:
  - *S*: checkbox field; if checked, the spectral signature is displayed in the plot;
  - *MC ID*: signature Macroclass ID;

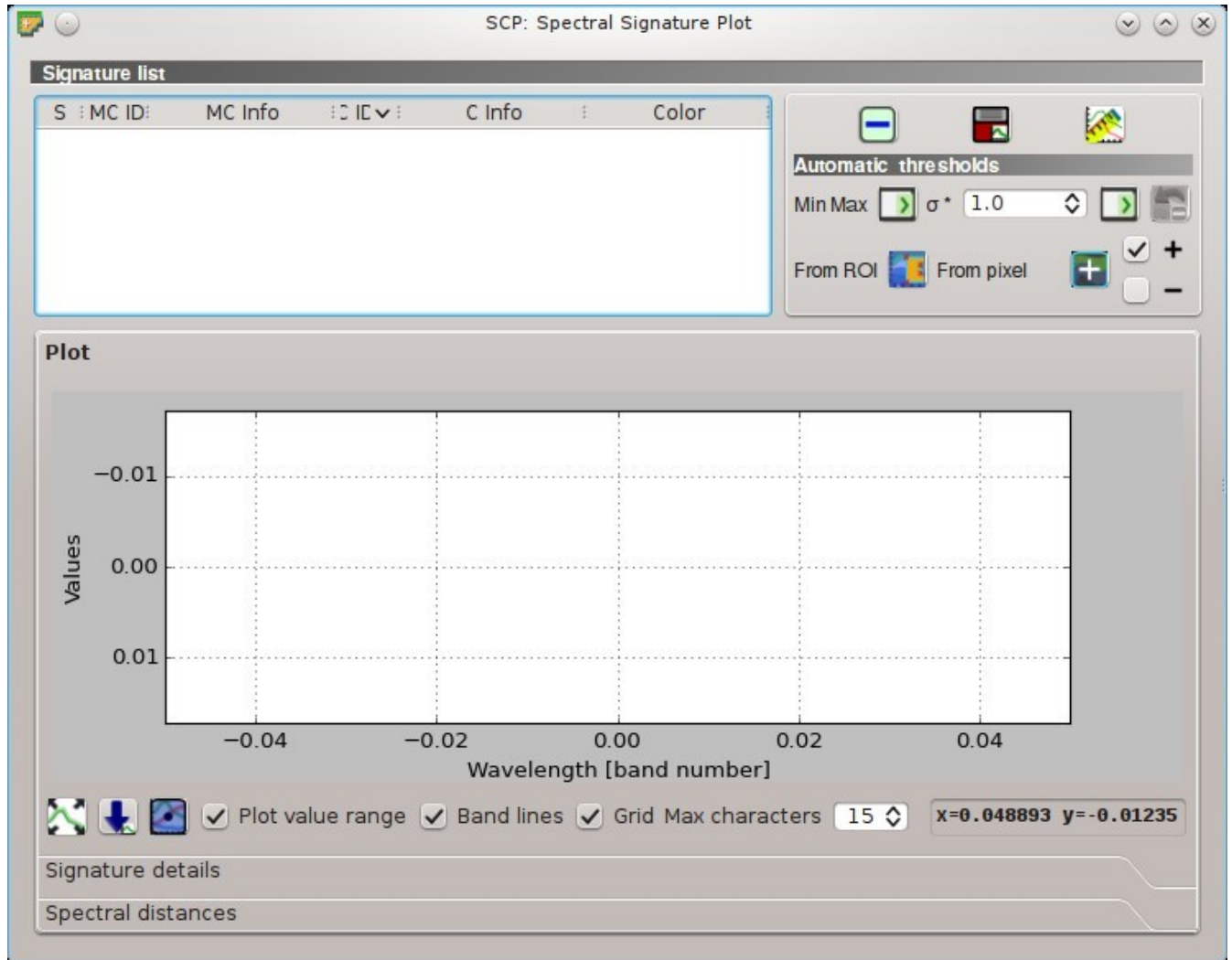










Fig. 52: Spectral Signature Plot

- *MC Info*: signature Macroclass Information;
  - *C ID*: signature Class ID;
  - *C Info*: signature Class Information;
  - *Color [overlap MC\_ID-C\_ID]*: signature color; also, the combination *MC ID-C ID* is displayed in case of overlap with other signatures (see [Land Cover Signature Classification](#) (page 122));
  - *Min B X*: minimum value of band X; this value can be edited;
  - *Max B X*: maximum value of band X; this value can be edited;
- : remove highlighted signatures from this list;
  - : add highlighted spectral signatures to *ROI Signature list* (page 27);
  - : calculate the spectral distances of spectral signatures displayed in the plot; distances are reported in the tab *Spectral distances* (page 101);

### Automatic thresholds


Set thresholds automatically for highlighted signatures in the table *Plot Signature list* (page 98); if no signature is highlighted, then the threshold is applied to all the signatures.



- *Min Max* : set the threshold based on the minimum and maximum of each band;
- $\sigma * \updownarrow$  : set an automatic threshold calculated as  $(\text{band value} + (\sigma * v))$ , where  $\sigma$  is the standard deviation of each band and  $v$  is the defined value;
- : undo the last automatic thresholds;
- *From ROI* : set the threshold using the temporary ROI pixel values, according to the following checkboxes:
  - ☒ +: if checked, signature threshold is extended to include pixel signature;
  - ☒ -: if checked, signature threshold is reduced to exclude pixel signature;
- *From pixel* : set the threshold by clicking on a pixel, according to the following checkboxes:
  - ☒ +: if checked, signature threshold is extended to include pixel signature;
  - ☒ -: if checked, signature threshold is reduced to exclude pixel signature;

### Plot

**Left click** and hold inside the plot to **move** the view of the plot. Use the **mouse wheel** to **zoom in and out** the view of the plot. **Right click** and hold inside the plot to **zoom in a specific area** of the plot. Legend inside the plot can be moved using the mouse.

Plot commands:

- : automatically fit the plot to data;

- : save the plot image to file (available formats are .jpg, .png, and .pdf);
- : activate the cursor for interactively changing the value range of highlighted signatures in the plot; click the plot to set the minimum or maximum value of a band (also for several signatures simultaneously); cursor is deactivated when moving outside the plot area;
- ☒ *Plot value range*: if checked, plot the value range for each signature (semi-transparent area);
- ☒ *Band lines*: if checked, display a vertical line for each band (center wavelength);
- ☒ *Grid*: if checked, display a grid;
- *Max characters* : set the maximum length of text in the legend;
- *x y*: display x y coordinates of mouse cursor inside the plot;

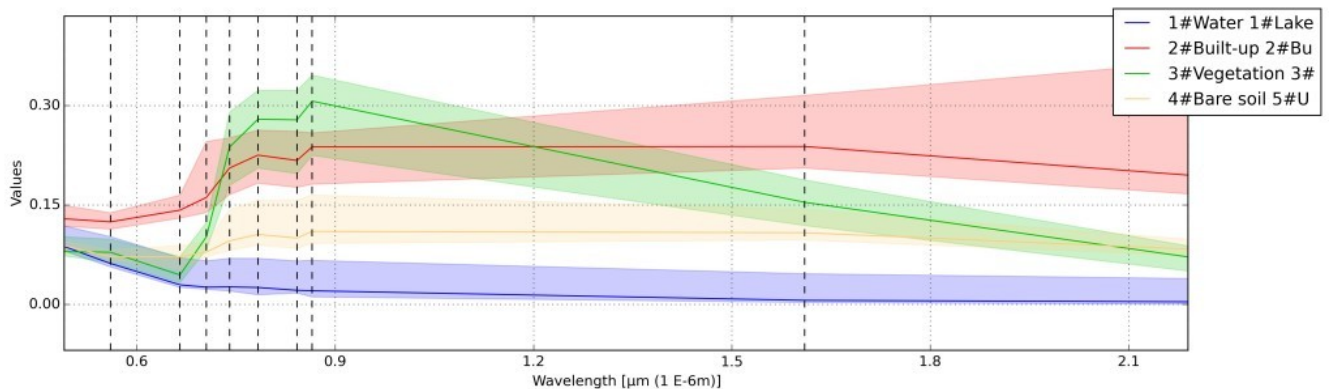


Fig. 53: Spectral Signature: Example of spectral signature plot

## Signature details

Display the details about spectral signatures (i.e. Wavelength, Values, and Standard deviation). In case of signatures calculated from ROIs, the ROI size (number of pixels) is also displayed.

## Spectral distances

Display spectral distances of signatures (see *Plot Signature list* (page 98)), which are useful for assessing ROI separability (see *Spectral Distance* (page 124)).

The following spectral distances are calculated :

- *Jeffries-Matusita Distance* (page 124): range [0 = identical, 2 = different]; useful in particular for *Maximum Likelihood* (page 120) classifications;
- *Spectral Angle* (page 125): range [0 = identical, 90 = different]; useful in particular for *Spectral Angle Mapping* (page 121) classifications;
- *Euclidean Distance* (page 125): useful in particular for *Minimum Distance* (page 120) classifications;
- *Bray-Curtis Similarity* (page 126): range [0 = different, 100 = identical]; useful in general;

Values are displayed in red if signatures are particularly similar.

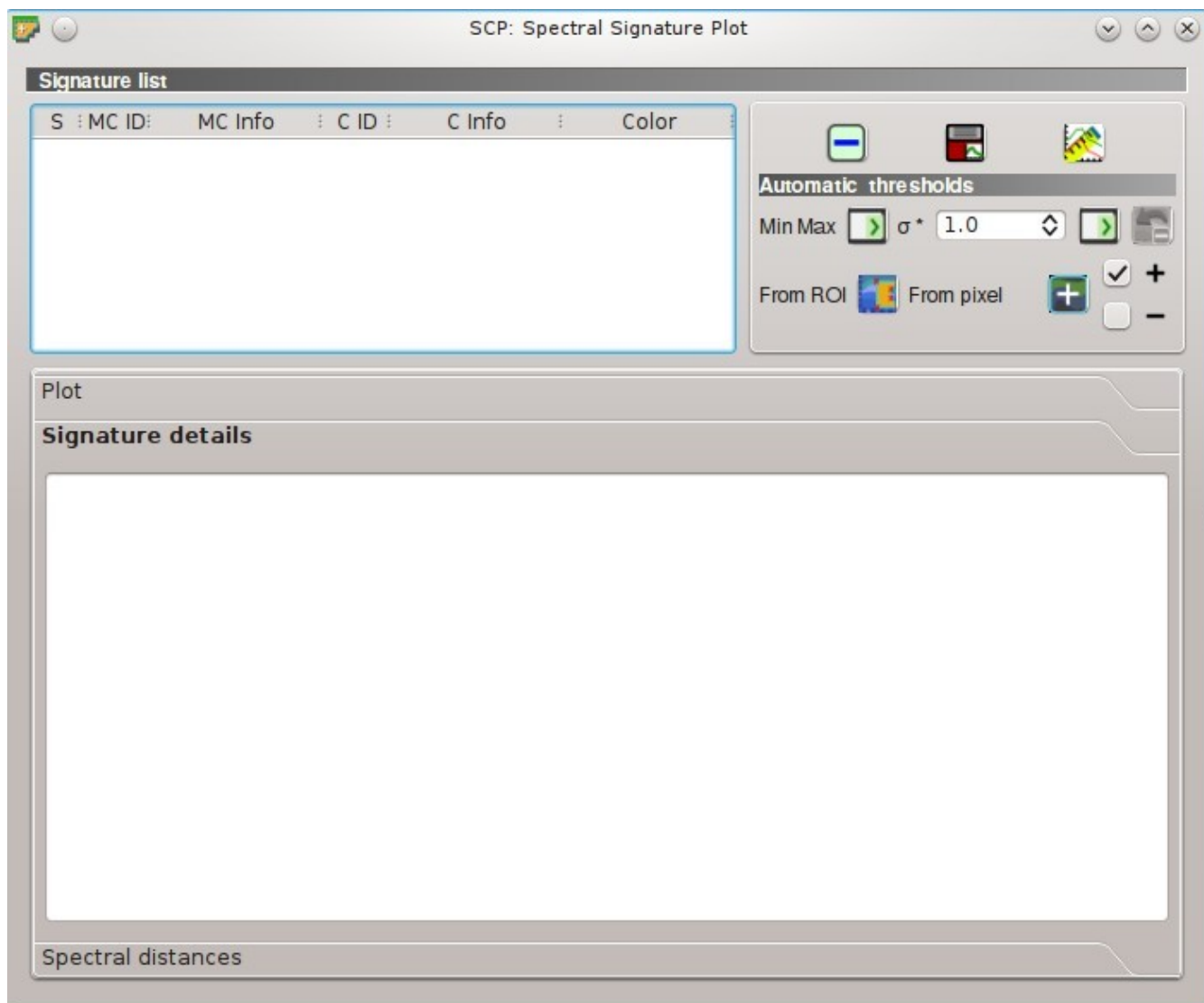


Fig. 54: Spectral Signature: Signature details

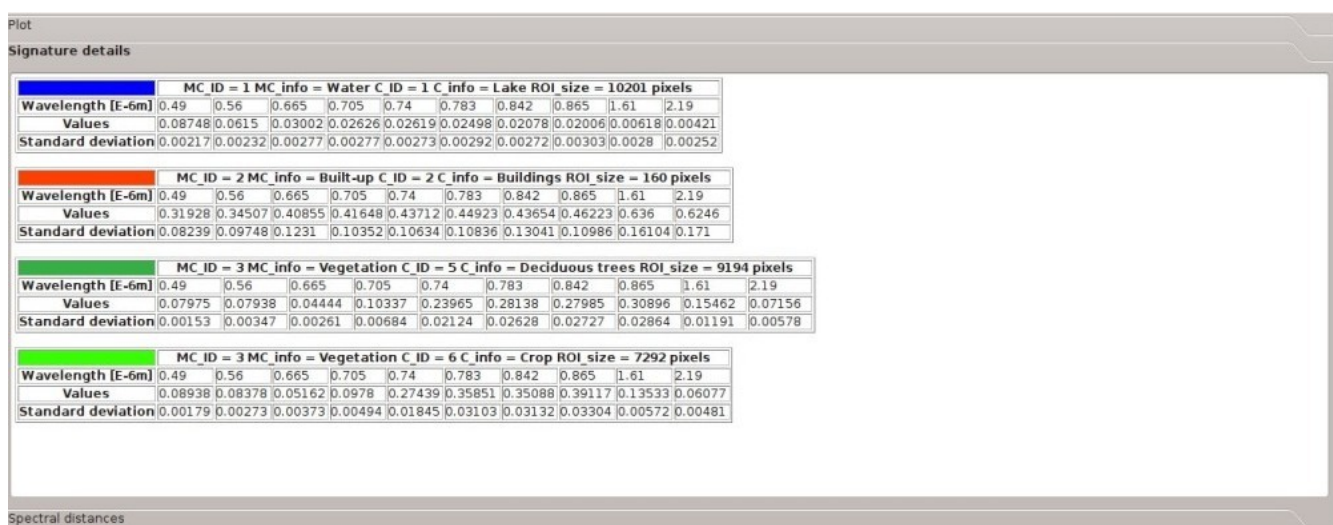


Fig. 55: Spectral Signature: Example of signature details



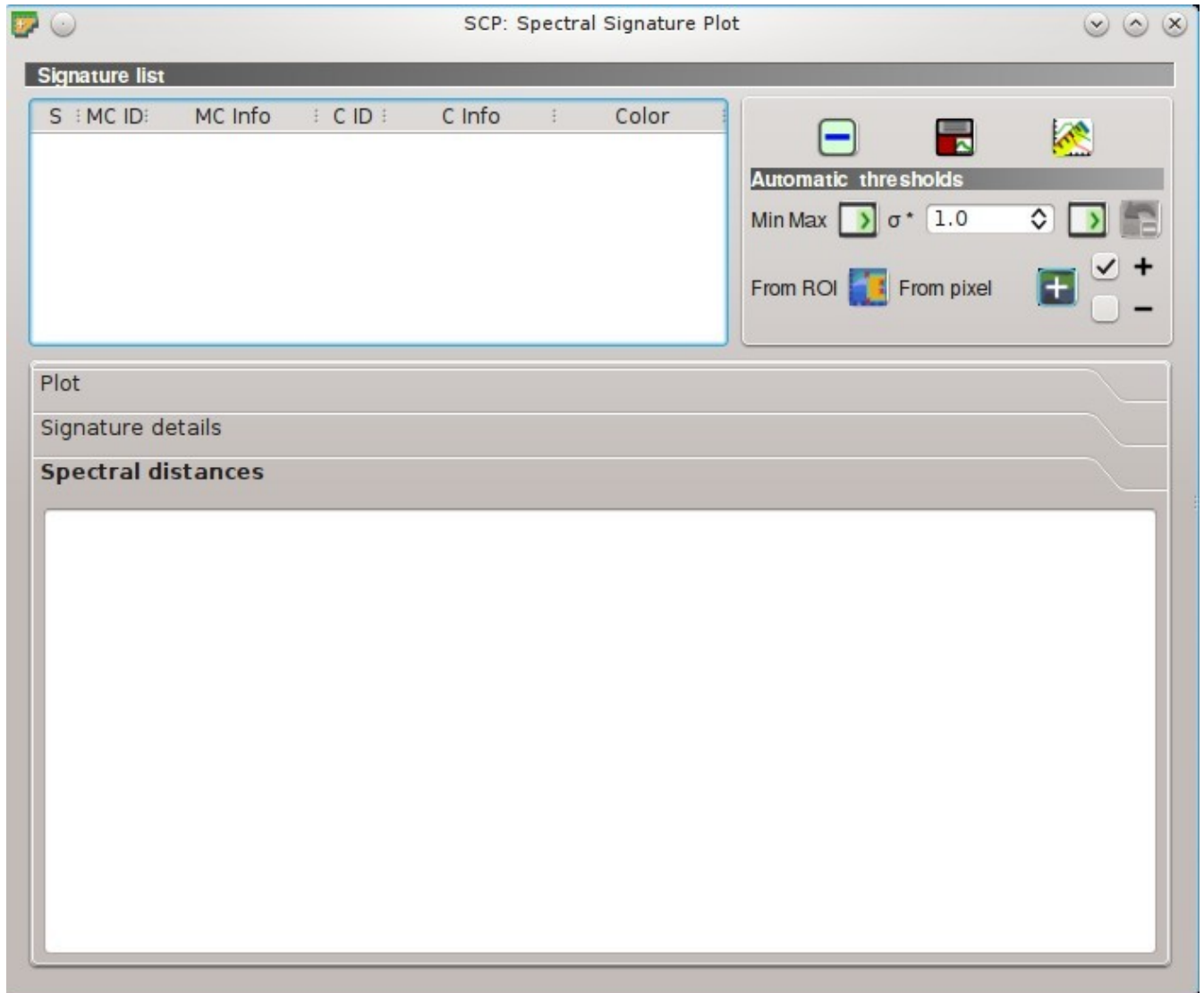


Fig. 56: Spectral Signature: Spectral distances

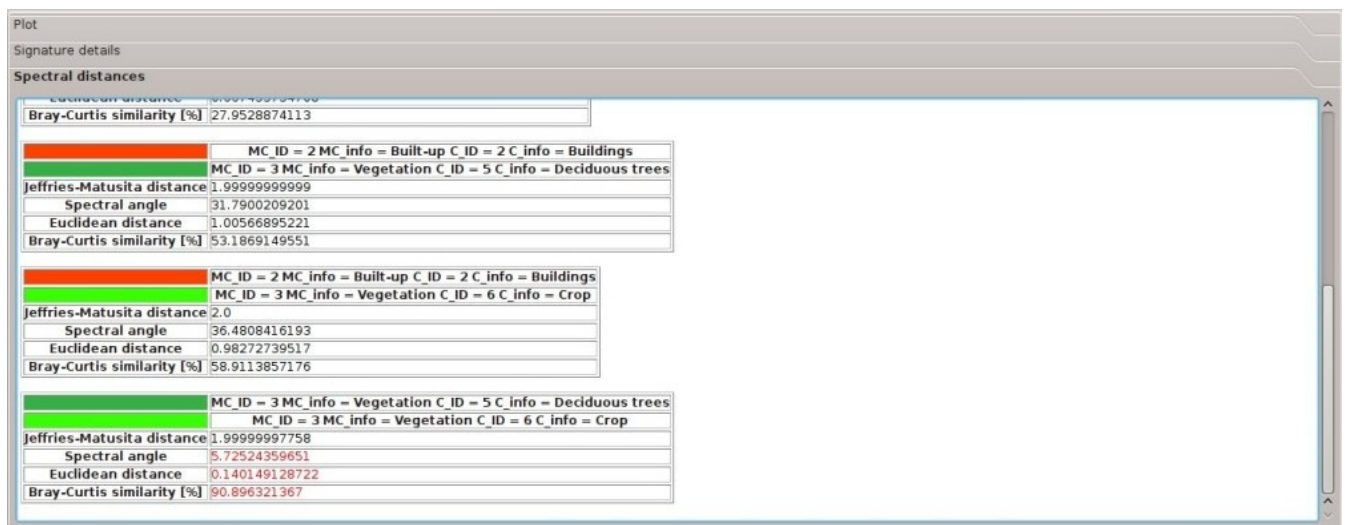


Fig. 57: Spectral Signature: Example of spectral distances

## 3.6 Scatter Plot

The window *Scatter plot* displays pixel values for two raster bands as points in the 2D space. Scatter plots are useful for assessing ROI separability between two bands.

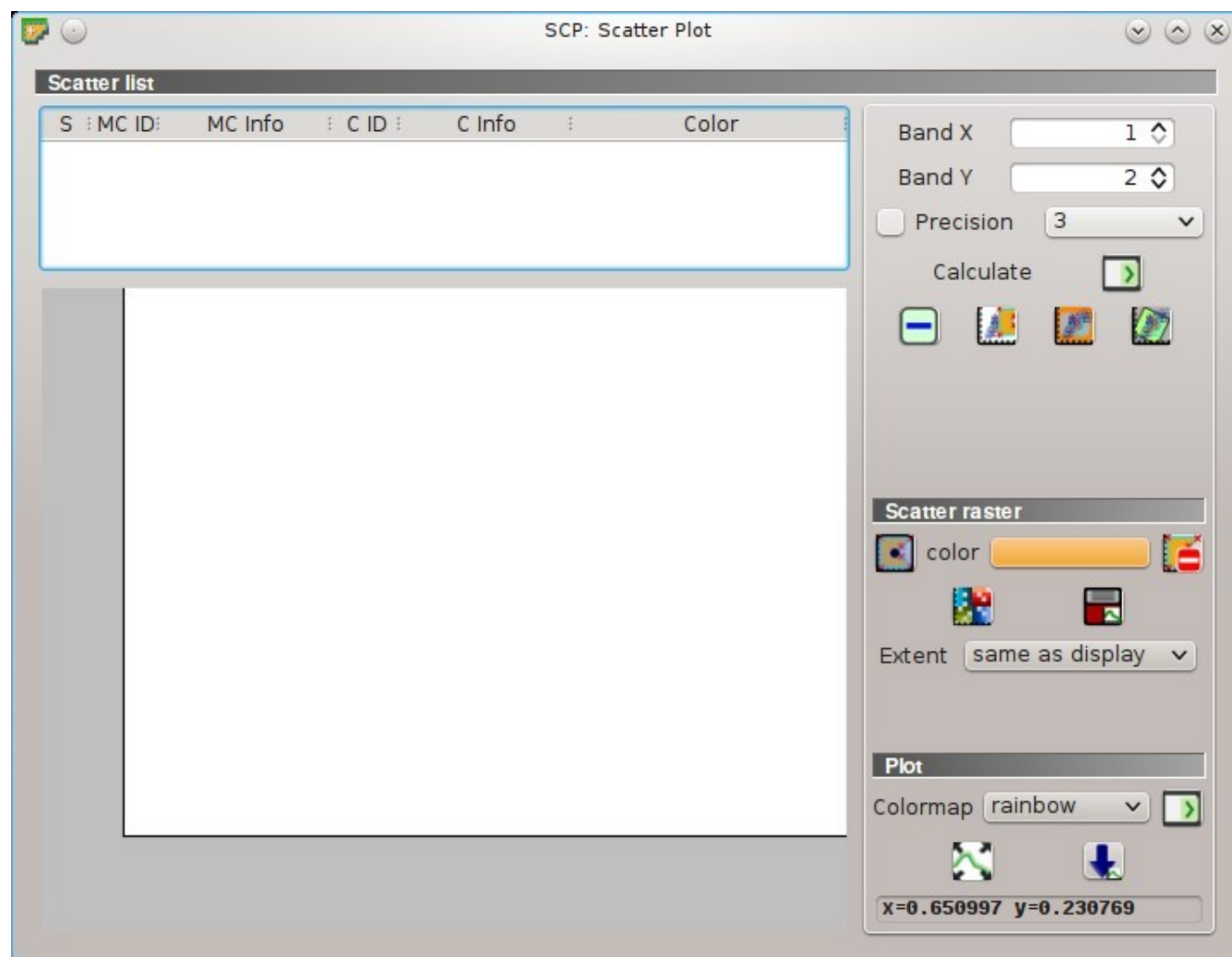












Fig. 58: *Scatter Plot*

The functions are described in detail in the following paragraphs.

### 3.6.1 Scatter list

-  **Scatter list:**
  - *S*: checkbox field; if checked, the spectral signature is displayed in the plot;
  - *MC ID*: signature Macroclass ID;
  - *MC Info*: signature Macroclass Information;
  - *C ID*: signature Class ID;
  - *C Info*: signature Class Information;
  - *Color*: color field; double click to select a color for the plot;
- *Band X* : X band of the plot;

- *Band Y* : Y band of the plot;
-  *Precision* : use custom precision for calculation (precision should be selected according to pixel values):
  - $4 = 10^{-4}$
  - $3 = 10^{-3}$
  - $2 = 10^{-2}$
  - $1 = 10^{-1}$
  - $0 = 1$
  - $-1 = 10$
  - $-2 = 10^2$
  - $-3 = 10^3$
- *Calculate* : calculate the scatter plot for the ROIs checked in the list;
- : remove highlighted signatures from this list;
- : add a temporary scatter plot to the list (as MC Info = tempScatter) and start the plot calculation of the last temporary ROI (see [Working toolbar](#) (page 34));
- : add a temporary scatter plot to the list (as MC Info = tempScatter) and start the plot calculation of pixels in current display extent;
- : add a temporary scatter plot to the list (as MC Info = tempScatter) and start the plot calculation of the entire image;




**WARNING:** Using a precision value that is too high can result in slow calculation or failure.



### Scatter raster

This tool allows for the drawing of selection polygons inside the scatter plot; these selection polygons are used for creating a *Scatter raster* that is a temporary raster classified according to the intersection of scatter plots and drawn polygons.

Pixels of the *active band set* are classified, according to scatter plot bands, if pixel values are in the range of intersection between scatter plots and selection polygons (polygons should not overlap). The value assigned to the *Scatter raster* pixels is the sequential number of selection polygon; also the raster color is derived from the selection polygon.





After the creation of a new *Scatter raster*, old rasters are placed in QGIS Layers inside a layer group named `Class_temp_group` (custom name can be defined in [Temporary group name](#) (page 97)) and are deleted when the QGIS session is closed.

- : activate the cursor for interactively drawing a polygon in the plot; left click on the plot to define the vertices and right click to define the last vertex closing the polygon;
- *color*: select the color of polygon (which is used also in the *Scatter raster*);
- : remove all the selection polygons from the plot;
- : calculate the *Scatter raster* and display it in the map;

- : calculate the spectral signature of the *Scatter raster* (considering all the classified pixels) using the *active band set*, and save the signature to the *ROI Signature list* (page 27);
- **Extent** : **extent of the Scatter raster**; available options are:
  - *Same as display*: extent is the same as map display;
  - *Same as image*: extent is the same as the whole image;

## Plot

**Left click** and hold inside the plot to **move** the view of the plot. Use the **mouse wheel** to **zoom in and out** the view of the plot. **Right click** and hold inside the plot to **zoom in a specific area** of the plot.

- **Colormap** : select a colormap that is applied to highlighted scatter plots in the list when  is clicked; if no scatter plot is highlighted then the colormap is applied to all the scatter plots;
- : automatically fit the plot to data;
- : save the plot image to file (available formats are .jpg, .png, and .pdf);
- *x y*: display *x y* coordinates of mouse cursor inside the plot;

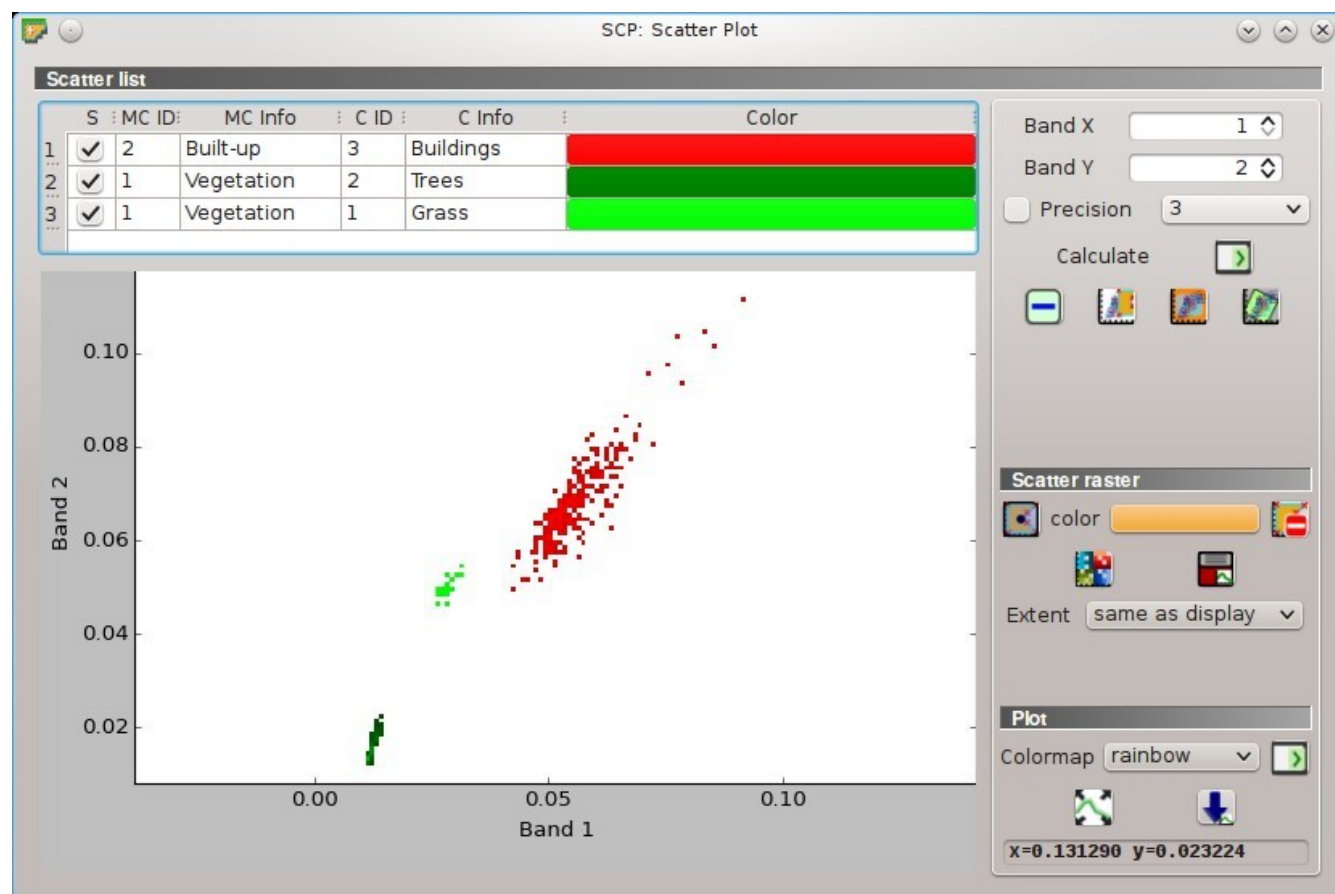


Fig. 59: Example Scatter Plot

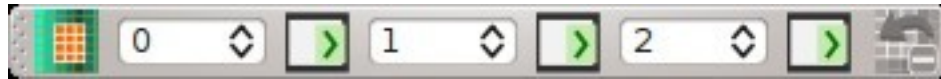
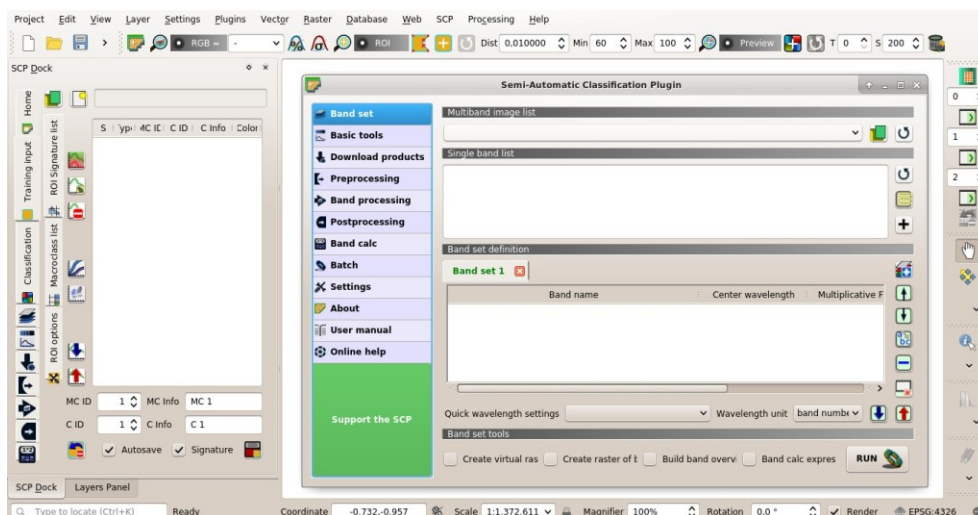


Fig. 60: SCP Tools

### 3.7 SCP Edit Toolbar

The *SCP Edit Toolbar* allows for the direct editing of pixel values in the input raster defined in *Edit raster* (page 82) using ROI polygons. Only pixels beneath ROI polygons are edited.

- : open the tool *SCP Edit Toolbar* for selecting the input raster;
- : edit the raster using the selected constant value;
- : edit the raster using the selected constant value;
- : edit the raster using the selected constant value;
- : undo the last raster edit (available only when using ROI polygons);



The functions described in the following paragraphs use these conventions:

= Input date

= Input text

= List

= Input number

= Optional

= Configuration stored in the active project of QGIS

= Configuration stored in QGIS registry

= Slider



= Table

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## Brief Introduction to Remote Sensing

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- *Basic Definitions* (page 110)
  - *GIS definition* (page 110)
  - *Remote Sensing definition* (page 110)
  - *Sensors* (page 112)
  - *Radiance and Reflectance* (page 112)
  - *Spectral Signature* (page 112)
  - *Land Cover* (page 112)
- *Multispectral satellites* (page 112)
  - *Landsat Satellites* (page 113)
  - *Sentinel-2 Satellite* (page 114)
  - *Sentinel-3 Satellite* (page 114)
  - *ASTER Satellite* (page 115)
  - *MODIS Products* (page 115)
- *Land Cover Classification* (page 116)
  - *Supervised Classification* (page 116)
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  - *Classification Algorithms* (page 118)
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  - *Classification Result* (page 126)
  - *Accuracy Assessment* (page 126)
- *Image processing* (page 127)



- *Principal Component Analysis* (page 127)
- *Pan-sharpening* (page 128)
- *Spectral Indices* (page 128)
- *Clustering* (page 129)
- *Image conversion to reflectance* (page 131)
  - *Radiance at the Sensor's Aperture* (page 131)
  - *Top Of Atmosphere (TOA) Reflectance* (page 131)
  - *Surface Reflectance* (page 132)
  - *DOS1 Correction* (page 132)
- *Conversion to Temperature* (page 134)
  - *Conversion to At-Satellite Brightness Temperature* (page 135)
  - *Estimation of Land Surface Temperature* (page 135)
- *References* (page 136)

## 4.1 Basic Definitions

This chapter provides basic definitions about GIS and remote sensing. For other useful resources see *Free and valuable resources about remote sensing and GIS* (page 231).

### 4.1.1 GIS definition

There are several definitions of **GIS** (Geographic Information Systems), which is not simply a program. In general, GIS are systems that allow for the use of geographic information (data have spatial coordinates). In particular, GIS allow for the view, query, calculation and analysis of spatial data, which are mainly distinguished in raster or vector data structures. Vector is made of objects that can be points, lines or polygons, and each object can have one or more attribute values; a raster is a grid (or image) where each cell has an attribute value (Fisher and Unwin, 2005). Several GIS applications use raster images that are derived from remote sensing.

### 4.1.2 Remote Sensing definition

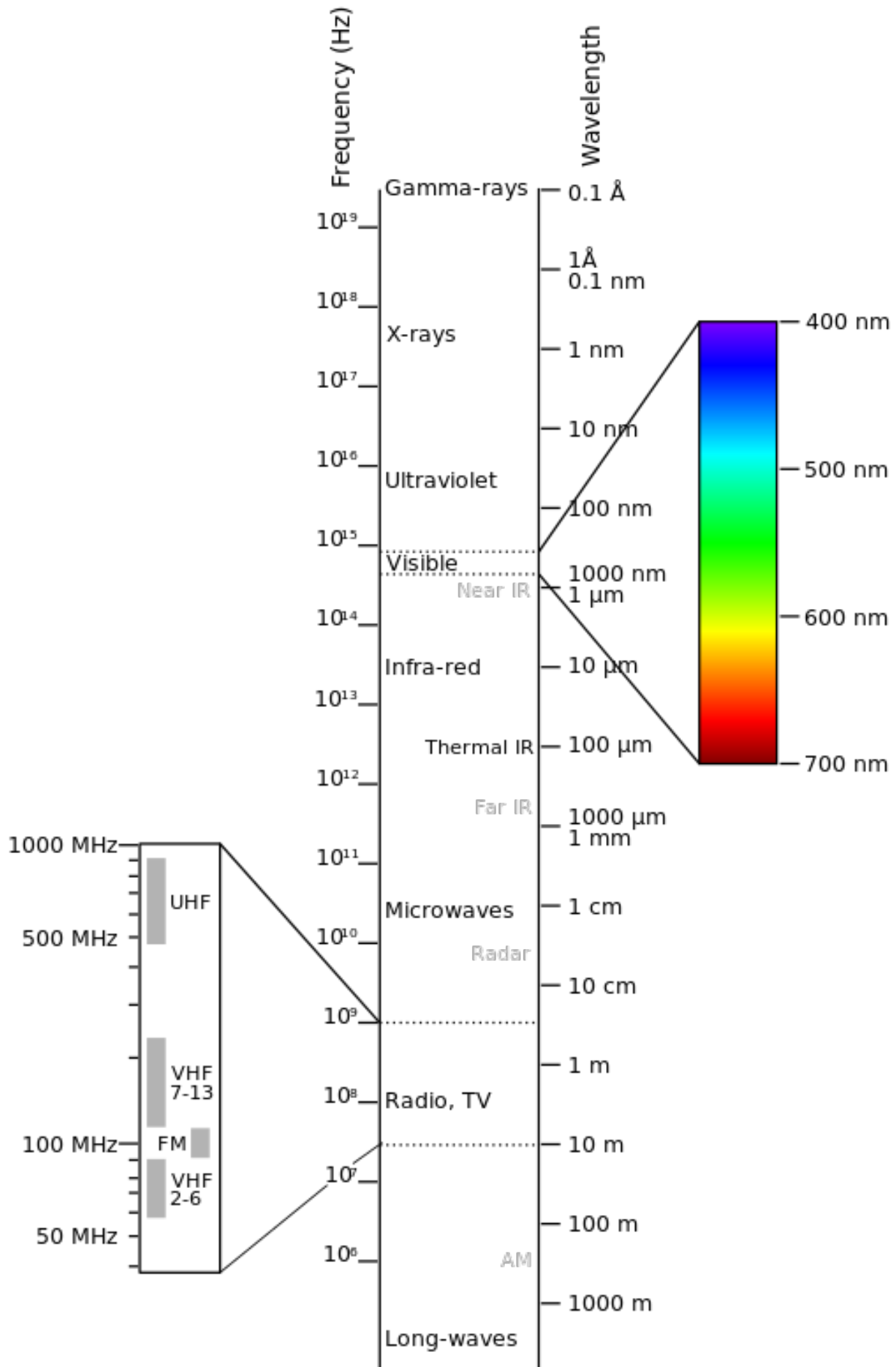
A general definition of **Remote Sensing** is “the science and technology by which the characteristics of objects of interest can be identified, measured or analyzed the characteristics without direct contact” (JARS, 1993).

Usually, remote sensing is the measurement of the energy that is emanated from the Earth's surface. If the source of the measured energy is the sun, then it is called **passive remote sensing**, and the result of this measurement can be a digital image (Richards and Jia, 2006). If the measured energy is not emitted by the Sun but from the sensor platform then it is defined as **active remote sensing**, such as radar sensors which work in the microwave range (Richards and Jia, 2006).

The **electromagnetic spectrum** is “the system that classifies, according to wavelength, all energy (from short cosmic to long radio) that moves, harmonically, at the constant velocity of light” (NASA, 2013). Passive sensors measure energy from the optical regions of the electromagnetic spectrum: visible, near infrared (i.e. IR), short-wave IR, and thermal IR (see Figure *Electromagnetic-Spectrum* (page 111)).

The interaction between solar energy and materials depends on the wavelength; solar energy goes from the Sun to the Earth and then to the sensor. Along this path, **solar energy** is (NASA, 2013):

- **Transmitted** - The energy passes through with a change in velocity as determined by the index of refraction for the two media in question.

Fig. 1: *Electromagnetic-Spectrum*

- **Absorbed** - The energy is given up to the object through electron or molecular reactions.
- **Reflected** - The energy is returned unchanged with the angle of incidence equal to the angle of reflection. Reflectance is the ratio of reflected energy to that incident on a body. The wavelength reflected (not absorbed) determines the color of an object.
- **Scattered** - The direction of energy propagation is randomly changed. Rayleigh and Mie scatter are the two most important types of scatter in the atmosphere.
- **Emitted** - Actually, the energy is first absorbed, then re-emitted, usually at longer wavelengths. The object heats up.

### 4.1.3 Sensors

**Sensors** can be on board of airplanes or on board of satellites, measuring the electromagnetic radiation at specific ranges (usually called bands). As a result, the measures are quantized and converted into a digital image, where each picture elements (i.e. pixel) has a discrete value in units of Digital Number (DN) (NASA, 2013). The resulting images have different characteristics (resolutions) depending on the sensor. There are several kinds of **resolutions**:

- **Spatial resolution**, usually measured in pixel size, “is the resolving power of an instrument needed for the discrimination of features and is based on detector size, focal length, and sensor altitude” (NASA, 2013); spatial resolution is also referred to as geometric resolution or IFOV;
- **Spectral resolution**, is the number and location in the electromagnetic spectrum (defined by two wavelengths) of the spectral bands (NASA, 2013) in multispectral sensors, for each band corresponds an image;
- **Radiometric resolution**, usually measured in bits (binary digits), is the range of available brightness values, which in the image correspond to the maximum range of DNs; for example an image with 8 bit resolution has 256 levels of brightness (Richards and Jia, 2006);
- For satellites sensors, there is also the **temporal resolution**, which is the time required for revisiting the same area of the Earth (NASA, 2013).

### 4.1.4 Radiance and Reflectance

Sensors measure the **radiance**, which corresponds to the brightness in a given direction toward the sensor; it useful to define also the **reflectance** as the ratio of reflected versus total power energy.

### 4.1.5 Spectral Signature

The **spectral signature** is the reflectance as a function of wavelength (see Figure *Spectral Reflectance Curves of Four Different Targets* (page 113)); each material has a unique signature, therefore it can be used for material classification (NASA, 2013).

### 4.1.6 Land Cover

**Land cover** is the material at the ground, such as soil, vegetation, water, asphalt, etc. (Fisher and Unwin, 2005). Depending on the sensor resolutions, the number and kind of land cover classes that can be identified in the image can vary significantly.

## 4.2 Multispectral satellites

There are several satellites with different characteristics that acquire multispectral images of earth surface. The following satellites are particularly useful for land cover monitoring because images are provided for free and can be downloaded directly from SCP; data have been acquired for the past few decades and the archive is continuously growing with recent images.

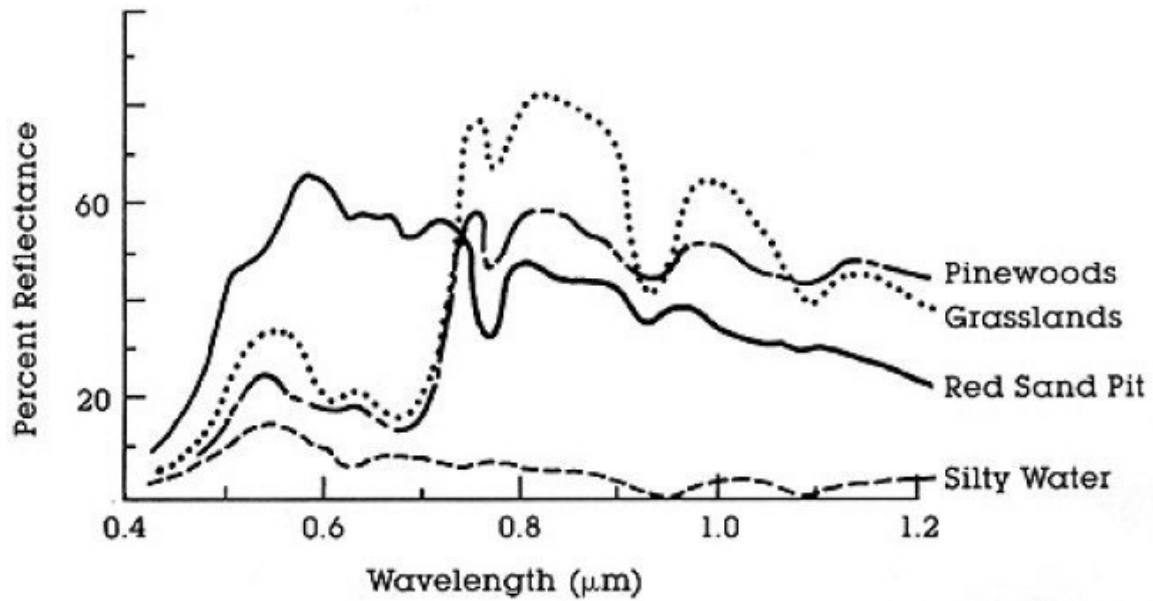


Fig. 2: *Spectral Reflectance Curves of Four Different Targets*  
(from NASA, 2013)

#### 4.2.1 Landsat Satellites

**Landsat** is a set of multispectral satellites developed by the NASA (National Aeronautics and Space Administration of USA), since the early 1970's.

Landsat images are very used for environmental research. The resolutions of Landsat 4 and Landsat 5 sensors are reported in the following table (from [http://landsat.usgs.gov/band\\_designations\\_landsat\\_satellites.php](http://landsat.usgs.gov/band_designations_landsat_satellites.php)); also, Landsat temporal resolution is 16 days (NASA, 2013).

*Landsat 4 and Landsat 5 Bands*

| Landsat 4, Landsat 5 Bands   | Wavelength [micrometers] | Resolution [meters]   |
|------------------------------|--------------------------|-----------------------|
| Band 1 - Blue                | 0.45 - 0.52              | 30                    |
| Band 2 - Green               | 0.52 - 0.60              | 30                    |
| Band 3 - Red                 | 0.63 - 0.69              | 30                    |
| Band 4 - Near Infrared (NIR) | 0.76 - 0.90              | 30                    |
| Band 5 - SWIR                | 1.55 - 1.75              | 30                    |
| Band 6 - Thermal Infrared    | 10.40 - 12.50            | 120 (resampled to 30) |
| Band 7 - SWIR                | 2.08 - 2.35              | 30                    |

The resolutions of Landsat 7 sensor are reported in the following table (from [http://landsat.usgs.gov/band\\_designations\\_landsat\\_satellites.php](http://landsat.usgs.gov/band_designations_landsat_satellites.php)); also, Landsat temporal resolution is 16 days (NASA, 2013).

*Landsat 7 Bands*

| Landsat 7 Bands              | Wavelength [micrometers] | Resolution [meters]  |
|------------------------------|--------------------------|----------------------|
| Band 1 - Blue                | 0.45 - 0.52              | 30                   |
| Band 2 - Green               | 0.52 - 0.60              | 30                   |
| Band 3 - Red                 | 0.63 - 0.69              | 30                   |
| Band 4 - Near Infrared (NIR) | 0.77 - 0.90              | 30                   |
| Band 5 - SWIR                | 1.57 - 1.75              | 30                   |
| Band 6 - Thermal Infrared    | 10.40 - 12.50            | 60 (resampled to 30) |
| Band 7 - SWIR                | 2.09 - 2.35              | 30                   |
| Band 8 - Panchromatic        | 0.52 - 0.90              | 15                   |

The resolutions of Landsat 8 sensor are reported in the following table (from [http://landsat.usgs.gov/band\\_designations\\_landsat\\_satellites.php](http://landsat.usgs.gov/band_designations_landsat_satellites.php)); also, Landsat temporal resolution is 16 days (NASA, 2013).

#### *Landsat 8 Bands*

| Landsat 8 Bands                     | Wavelength [micrometers] | Resolution [meters]   |
|-------------------------------------|--------------------------|-----------------------|
| Band 1 - Coastal aerosol            | 0.43 - 0.45              | 30                    |
| Band 2 - Blue                       | 0.45 - 0.51              | 30                    |
| Band 3 - Green                      | 0.53 - 0.59              | 30                    |
| Band 4 - Red                        | 0.64 - 0.67              | 30                    |
| Band 5 - Near Infrared (NIR)        | 0.85 - 0.88              | 30                    |
| Band 6 - SWIR 1                     | 1.57 - 1.65              | 30                    |
| Band 7 - SWIR 2                     | 2.11 - 2.29              | 30                    |
| Band 8 - Panchromatic               | 0.50 - 0.68              | 15                    |
| Band 9 - Cirrus                     | 1.36 - 1.38              | 30                    |
| Band 10 - Thermal Infrared (TIRS) 1 | 10.60 - 11.19            | 100 (resampled to 30) |
| Band 11 - Thermal Infrared (TIRS) 2 | 11.50 - 12.51            | 100 (resampled to 30) |

A vast archive of images is freely available from the [U.S. Geological Survey](#) . For more information about how to freely download Landsat images read [this](#) .

Images are identified with the paths and rows of the WRS ([Worldwide Reference System for Landsat](#) ).

## 4.2.2 Sentinel-2 Satellite

**Sentinel-2** is a multispectral satellite developed by the European Space Agency (ESA) in the frame of [Copernicus](#) land monitoring services. Sentinel-2 acquires 13 spectral bands with the spatial resolution of 10m, 20m and 60m depending on the band, as illustrated in the following table (ESA, 2015).

#### *Sentinel-2 Bands*

| Sentinel-2 Bands              | Central Wavelength [micrometers] | Resolution [meters] |
|-------------------------------|----------------------------------|---------------------|
| Band 1 - Coastal aerosol      | 0.443                            | 60                  |
| Band 2 - Blue                 | 0.490                            | 10                  |
| Band 3 - Green                | 0.560                            | 10                  |
| Band 4 - Red                  | 0.665                            | 10                  |
| Band 5 - Vegetation Red Edge  | 0.705                            | 20                  |
| Band 6 - Vegetation Red Edge  | 0.740                            | 20                  |
| Band 7 - Vegetation Red Edge  | 0.783                            | 20                  |
| Band 8 - NIR                  | 0.842                            | 10                  |
| Band 8A - Vegetation Red Edge | 0.865                            | 20                  |
| Band 9 - Water vapour         | 0.945                            | 60                  |
| Band 10 - SWIR - Cirrus       | 1.375                            | 60                  |
| Band 11 - SWIR                | 1.610                            | 20                  |
| Band 12 - SWIR                | 2.190                            | 20                  |

Sentinel-2 images are freely available from the ESA website <https://scihub.copernicus.eu>.

## 4.2.3 Sentinel-3 Satellite

**Sentinel-3** is a satellite developed by the European Space Agency (ESA) in the frame of [Copernicus](#) land monitoring services. It carries several instruments, in particular the Ocean and Land Colour Instrument (OLCI) is a push-broom imaging spectrometer acquiring 21 bands in the range 0.4-1.02  $\mu\text{m}$  with a swath width of 1,270km and 300m spatial resolution (ESA, 2013). The revisit time is about 2 days.

#### *Sentinel-3 Bands*

| Sentinel-3 Bands | Central Wavelength [micrometers] |
|------------------|----------------------------------|
| Oa1              | 0.400                            |
| Oa2              | 0.4125                           |
| Oa3              | 0.4425                           |
| Oa4              | 0.490                            |
| Oa5              | 0.510                            |
| Oa6              | 0.560                            |
| Oa7              | 0.620                            |
| Oa8              | 0.665                            |
| Oa9              | 0.67375                          |
| Oa10             | 0.68125                          |
| Oa11             | 0.70875                          |
| Oa12             | 0.75375                          |
| Oa13             | 0.76125                          |
| Oa14             | 0.764375                         |
| Oa15             | 0.7675                           |
| Oa16             | 0.77875                          |
| Oa17             | 0.865                            |
| Oa18             | 0.885                            |
| Oa19             | 0.900                            |
| Oa20             | 0.940                            |
| Oa21             | 1.020                            |

#### 4.2.4 ASTER Satellite

The **ASTER** (Advanced Spaceborne Thermal Emission and Reflection Radiometer) satellite was launched in 1999 by a collaboration between the Japanese Ministry of International Trade and Industry (MITI) and the NASA. ASTER has 14 bands whose spatial resolution varies with wavelength: 15m in the visible and near-infrared, 30m in the short wave infrared, and 90m in the thermal infrared (USGS, 2015). ASTER bands are illustrated in the following table (due to a sensor failure **SWIR data acquired since April 1, 2008 is not available** ). An additional band 3B (backwardlooking near-infrared) provides stereo coverage.

##### *ASTER Bands*

| ASTER Bands                   | Wavelength [micrometers] | Resolution [meters] |
|-------------------------------|--------------------------|---------------------|
| Band 1 - Green                | 0.52 - 0.60              | 15                  |
| Band 2 - Red                  | 0.63 - 0.69              | 15                  |
| Band 3N - Near Infrared (NIR) | 0.78 - 0.86              | 15                  |
| Band 4 - SWIR 1               | 1.60 - 1.70              | 30                  |
| Band 5 - SWIR 2               | 2.145 - 2.185            | 30                  |
| Band 6 - SWIR 3               | 2.185 - 2.225            | 30                  |
| Band 7 - SWIR 4               | 2.235 - 2.285            | 30                  |
| Band 8 - SWIR 5               | 2.295 - 2.365            | 30                  |
| Band 9 - SWIR 6               | 2.360 - 2.430            | 30                  |
| Band 10 - TIR 1               | 8.125 - 8.475            | 90                  |
| Band 11 - TIR 2               | 8.475 - 8.825            | 90                  |
| Band 12 - TIR 3               | 8.925 - 9.275            | 90                  |
| Band 13 - TIR 4               | 10.25 - 10.95            | 90                  |
| Band 14 - TIR 5               | 10.95 - 11.65            | 90                  |

#### 4.2.5 MODIS Products

The **MODIS** (Moderate Resolution Imaging Spectroradiometer) is an instrument operating on the Terra and Aqua satellites launched by NASA in 1999 and 2002 respectively. Its temporal resolutions allows for viewing the entire

Earth surface every one to two days, with a swath width of 2,330km. Its sensors measure 36 spectral bands at three spatial resolutions: 250m, 500m, and 1,000m (see [https://lpdaac.usgs.gov/dataset\\_discovery/modis](https://lpdaac.usgs.gov/dataset_discovery/modis)).

Several products are available, such as surface reflectance and vegetation indices. In this manual we are considering the surface reflectance bands available at 250m and 500m spatial resolution (Vermote, Roger, & Ray, 2015).

#### *MODIS Bands*

| MODIS Bands                  | Wavelength [micrometers] | Resolution [meters] |
|------------------------------|--------------------------|---------------------|
| Band 1 - Red                 | 0.62 - 0.67              | 250 - 500           |
| Band 2 - Near Infrared (NIR) | 0.841 - 0.876            | 250 - 500           |
| Band 3 - Blue                | 0.459 - 0.479            | 500                 |
| Band 4 - Green               | 0.545 - 0.565            | 500                 |
| Band 5 - SWIR 1              | 1.230 - 1.250            | 500                 |
| Band 6 - SWIR 2              | 1.628 - 1.652            | 500                 |
| Band 7 - SWIR 3              | 2.105 - 2.155            | 500                 |

The following products (Version 6, see [https://lpdaac.usgs.gov/dataset\\_discovery/modis/modis\\_products\\_table](https://lpdaac.usgs.gov/dataset_discovery/modis/modis_products_table)) are available for download (Vermote, Roger, & Ray, 2015):

- MOD09GQ: daily reflectance at 250m spatial resolution from Terra MODIS;
- MYD09GQ: daily reflectance at 250m spatial resolution from Aqua MODIS;
- MOD09GA: daily reflectance at 500m spatial resolution from Terra MODIS;
- MYD09GA: daily reflectance at 500m spatial resolution from Aqua MODIS;
- MOD09Q1: reflectance at 250m spatial resolution, which is a composite of MOD09GQ (each pixel contains the best possible observation during an 8-day period);
- MYD09Q1: reflectance at 250m spatial resolution, which is a composite of MYD09GQ (each pixel contains the best possible observation during an 8-day period);
- MOD09A1: reflectance at 250m spatial resolution, which is a composite of MOD09GA (each pixel contains the best possible observation during an 8-day period);
- MYD09A1: reflectance at 250m spatial resolution, which is a composite of MYD09GA (each pixel contains the best possible observation during an 8-day period);

## 4.3 Land Cover Classification

This chapter provides basic definitions about land cover classifications.

### 4.3.1 Supervised Classification

A **semi-automatic classification** (also supervised classification) is an image processing technique that allows for the identification of materials in an image, according to their spectral signatures. There are several kinds of classification algorithms, but the general purpose is to produce a thematic map of the land cover.

Image processing and GIS spatial analyses require specific software such as the Semi-Automatic Classification Plugin for QGIS.

### 4.3.2 Color Composite

Often, a combination is created of three individual monochrome images, in which each is assigned a given color; this is defined **color composite** and is useful for photo interpretation (NASA, 2013). Color composites are usually expressed as:



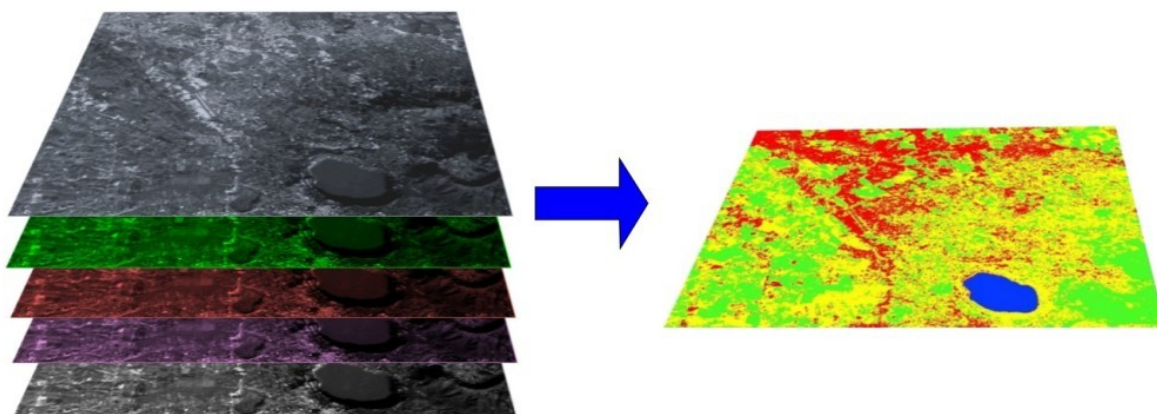


Fig. 3: A multispectral image processed to produce a land cover classification  
(Landsat image provided by USGS)

“R G B = Br Bg Bb”

where:

- R stands for Red;
- G stands for Green;
- B stands for Blue;
- Br is the band number associated to the Red color;
- Bg is the band number associated to the Green color;
- Bb is the band number associated to the Blue color.

The following Figure *Color composite of a Landsat 8 image* (page 118) shows a color composite “R G B = 4 3 2” of a Landsat 8 image (for Landsat 7 the same color composite is R G B = 3 2 1; for Sentinel-2 is R G B = 4 3 2) and a color composite “R G B = 5 4 3” (for Landsat 7 the same color composite is R G B = 4 3 2; for Sentinel-2 is R G B = 8 4 3). The composite “R G B = 5 4 3” is useful for the interpretation of the image because vegetation pixels appear red (healthy vegetation reflects a large part of the incident light in the near-infrared wavelength, resulting in higher reflectance values for band 5, thus higher values for the associated color red).

### 4.3.3 Training Areas

Usually, supervised classifications require the user to select one or more Regions of Interest (ROIs, also Training Areas) for each land cover class identified in the image. **ROIs** are polygons drawn over homogeneous areas of the image that overlay pixels belonging to the same land cover class.

#### Region Growing Algorithm

The Region Growing Algorithm allows to select pixels similar to a seed one, considering the **spectral similarity** (i.e. spectral distance) of adjacent pixels. In *SCP* the Region Growing Algorithm is available for the training area creation. The parameter **distance** is related to the similarity of pixel values (the lower the value, the more similar are selected pixels) to the seed one (i.e. selected clicking on a pixel). An additional parameter is the **maximum width**, which is the side length of a square, centred at the seed pixel, which inscribes the training area (if all the pixels had the same value, the training area would be this square). The **minimum size** is used a constraint (for every single band), selecting at least the pixels that are more similar to the seed one until the number of selected pixels equals the minimum size.

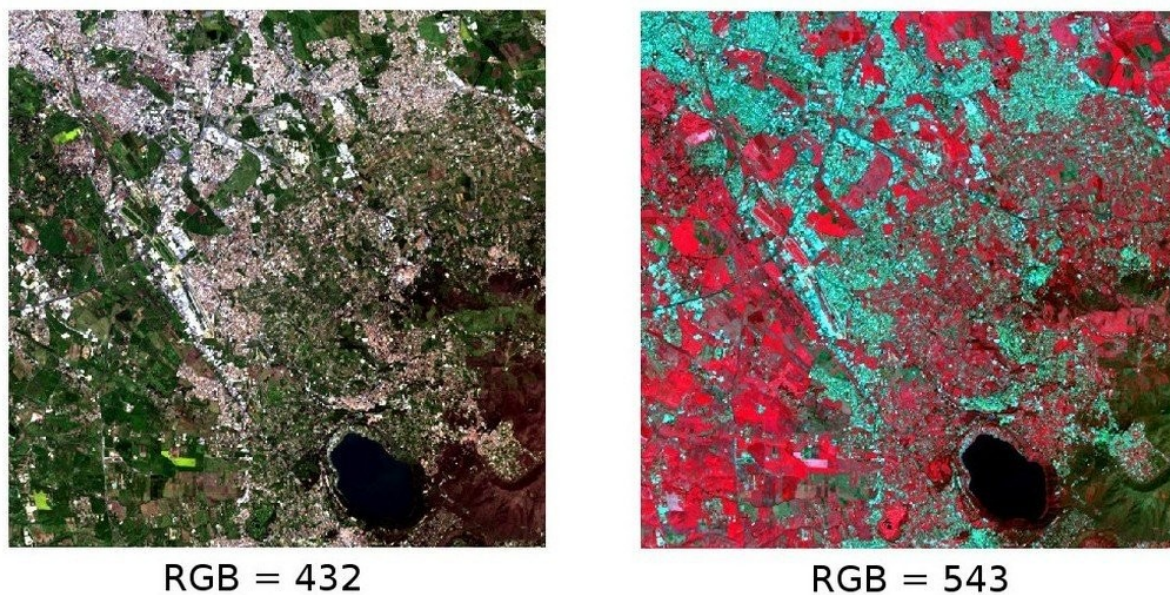


Fig. 4: *Color composite of a Landsat 8 image*  
Data available from the U.S. Geological Survey

In figure [Region growing example](#) (page 119) the central pixel is used as seed (image a) for the region growing of one band (image b) with the parameter spectral distance = 0.1; similar pixels are selected to create the training area (image c and image d).

#### 4.3.4 Classes and Macroclasses

Land cover classes are identified with an arbitrary ID code (i.e. Identifier). *SCP* allows for the definition of **Macroclass ID** (i.e. MC ID) and **Class ID** (i.e. C ID), which are the identification codes of land cover classes. A **Macroclass** is a group of ROIs having different Class ID, which is useful when one needs to classify materials that have different spectral signatures in the same land cover class. For instance, one can identify grass (e.g. ID class = 1 and Macroclass ID = 1) and trees (e.g. ID class = 2 and Macroclass ID = 1) as vegetation class (e.g. Macroclass ID = 1). Multiple Class IDs can be assigned to the same Macroclass ID, but the same Class ID cannot be assigned to multiple Macroclass IDs, as shown in the following table.

*Example of Macroclasses*

| Macroclass name | Macroclass ID | Class name | Class ID |
|-----------------|---------------|------------|----------|
| Vegetation      | 1             | Grass      | 1        |
| Vegetation      | 1             | Trees      | 2        |
| Built-up        | 2             | Buildings  | 3        |
| Built-up        | 2             | Roads      | 4        |

Therefore, Classes are subsets of a Macroclass as illustrated in Figure [Macroclass example](#) (page 119).

If the use of Macroclass is not required for the study purpose, then the same Macroclass ID can be defined for all the ROIs (e.g. Macroclass ID = 1) and Macroclass values are ignored in the classification process.

#### 4.3.5 Classification Algorithms

The **spectral signatures** (spectral characteristics) of reference land cover classes are calculated considering the values of pixels under each ROI having the same Class ID (or Macroclass ID). Therefore, the classification algorithm classifies the whole image by comparing the spectral characteristics of each pixel to the spectral characteristics of reference land cover classes. *SCP* implements the following classification algorithms.

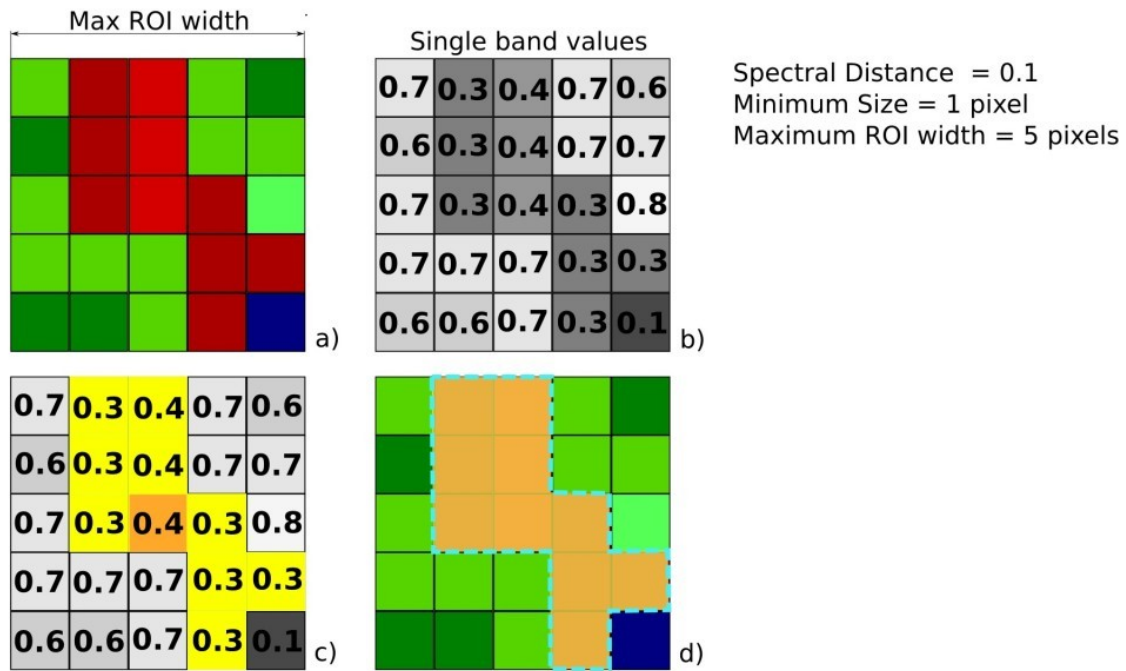


Fig. 5: Region growing example

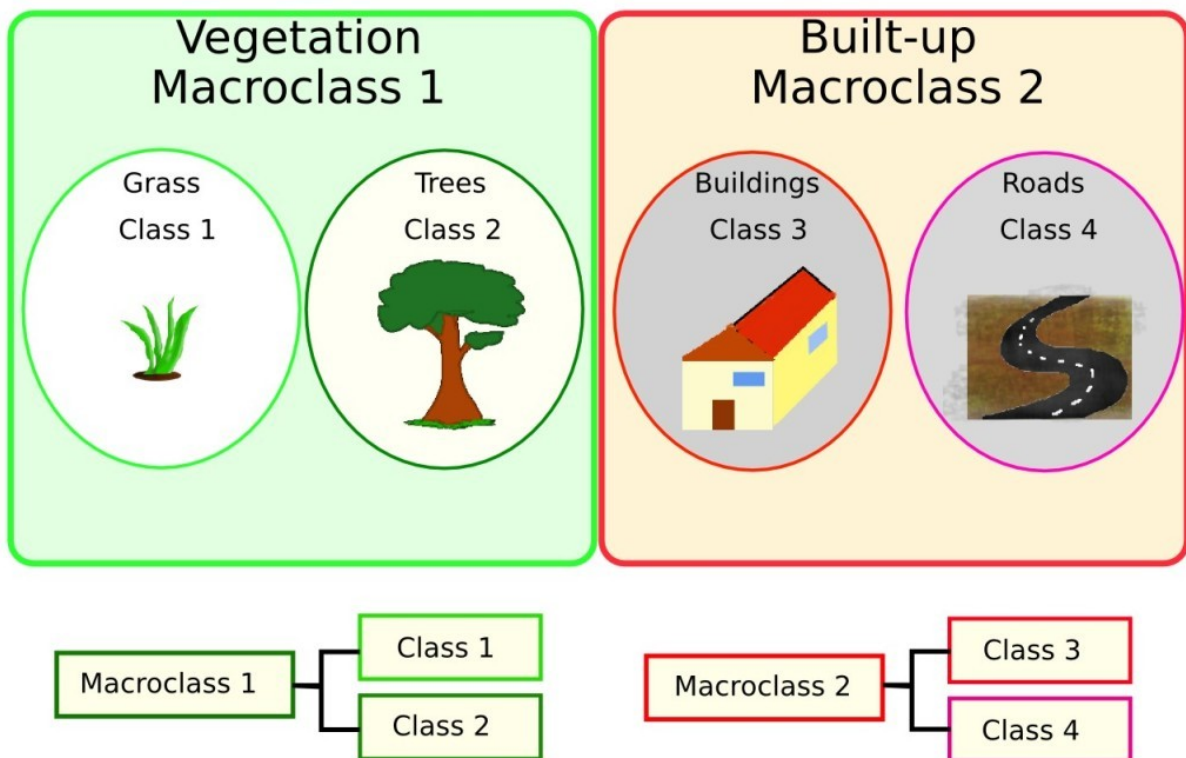


Fig. 6: Macroclass example

## Minimum Distance

Minimum Distance algorithm calculates the Euclidean distance  $d(x, y)$  between spectral signatures of image pixels and training spectral signatures, according to the following equation:

$$d(x, y) = \sqrt{\sum_{i=1}^n (x_i - y_i)^2}$$

where:

- $x$  = spectral signature vector of an image pixel;
- $y$  = spectral signature vector of a training area;
- $n$  = number of image bands.

Therefore, the distance is calculated for every pixel in the image, assigning the class of the spectral signature that is closer, according to the following discriminant function (adapted from Richards and Jia, 2006):

$$x \in C_k \iff d(x, y_k) < d(x, y_j) \forall k \neq j$$

where:

- $C_k$  = land cover class  $k$ ;
- $y_k$  = spectral signature of class  $k$ ;
- $y_j$  = spectral signature of class  $j$ .

It is possible to define a threshold  $T_i$  in order to exclude pixels below this value from the classification:

$$\begin{aligned} x \in C_k \iff d(x, y_k) < d(x, y_j) \forall k \neq j \\ \text{and} \\ d(x, y_k) < T_i \end{aligned}$$

## Maximum Likelihood

Maximum Likelihood algorithm calculates the probability distributions for the classes, related to Bayes' theorem, estimating if a pixel belongs to a land cover class. In particular, the probability distributions for the classes are assumed the of form of multivariate normal models (Richards & Jia, 2006). In order to use this algorithm, a sufficient number of pixels is required for each training area allowing for the calculation of the covariance matrix. The discriminant function, described by Richards and Jia (2006), is calculated for every pixel as:

$$g_k(x) = \ln p(C_k) - \frac{1}{2} \ln |\Sigma_k| - \frac{1}{2} (x - y_k)^t \Sigma_k^{-1} (x - y_k)$$

where:

- $C_k$  = land cover class  $k$ ;
- $x$  = spectral signature vector of a image pixel;
- $p(C_k)$  = probability that the correct class is  $C_k$ ;
- $|\Sigma_k|$  = determinant of the covariance matrix of the data in class  $C_k$ ;
- $\Sigma_k^{-1}$  = inverse of the covariance matrix;
- $y_k$  = spectral signature vector of class  $k$ .

Therefore:

$$x \in C_k \iff g_k(x) > g_j(x) \forall k \neq j$$



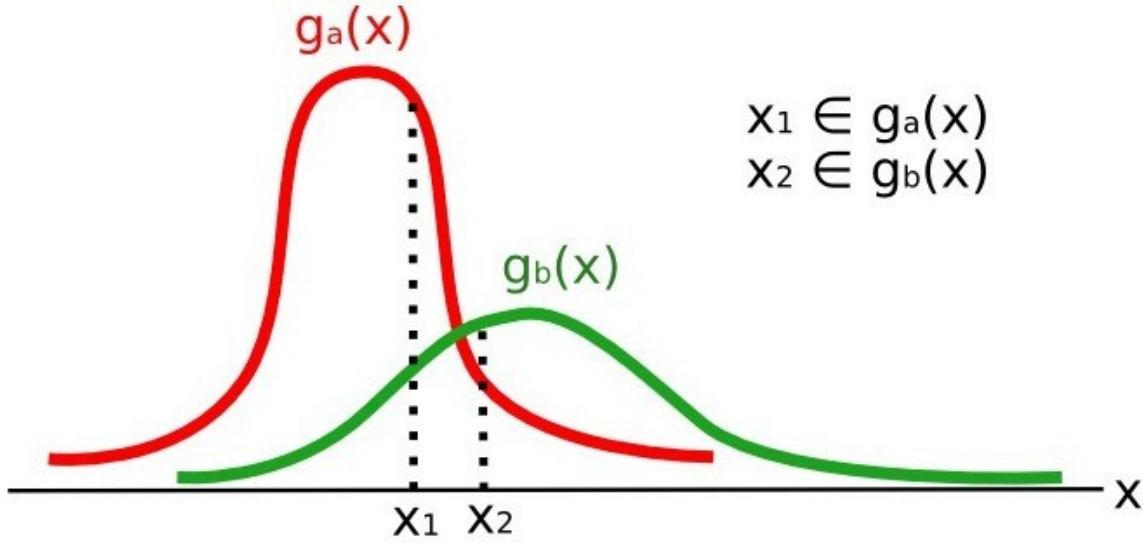


Fig. 7: Maximum Likelihood example

In addition, it is possible to define a threshold to the discriminant function in order to exclude pixels below this value from the classification. Considering a threshold  $T_i$  the classification condition becomes:

$$x \in C_k \iff g_k(x) > g_j(x) \forall k \neq j$$

and

$$g_k(x) > T_i$$

Maximum likelihood is one of the most common supervised classifications, however the classification process can be slower than *Minimum Distance* (page 120).

### Spectral Angle Mapping

The Spectral Angle Mapping calculates the spectral angle between spectral signatures of image pixels and training spectral signatures. The spectral angle  $\theta$  is defined as (Kruse et al., 1993):

$$\theta(x, y) = \cos^{-1} \left( \frac{\sum_{i=1}^n x_i y_i}{(\sum_{i=1}^n x_i^2)^{\frac{1}{2}} * (\sum_{i=1}^n y_i^2)^{\frac{1}{2}}} \right)$$

Where:

- $x$  = spectral signature vector of an image pixel;
- $y$  = spectral signature vector of a training area;
- $n$  = number of image bands.

Therefore a pixel belongs to the class having the lowest angle, that is:

$$x \in C_k \iff \theta(x, y_k) < \theta(x, y_j) \forall k \neq j$$

where:

- $C_k$  = land cover class  $k$ ;
- $y_k$  = spectral signature of class  $k$ ;
- $y_j$  = spectral signature of class  $j$ .

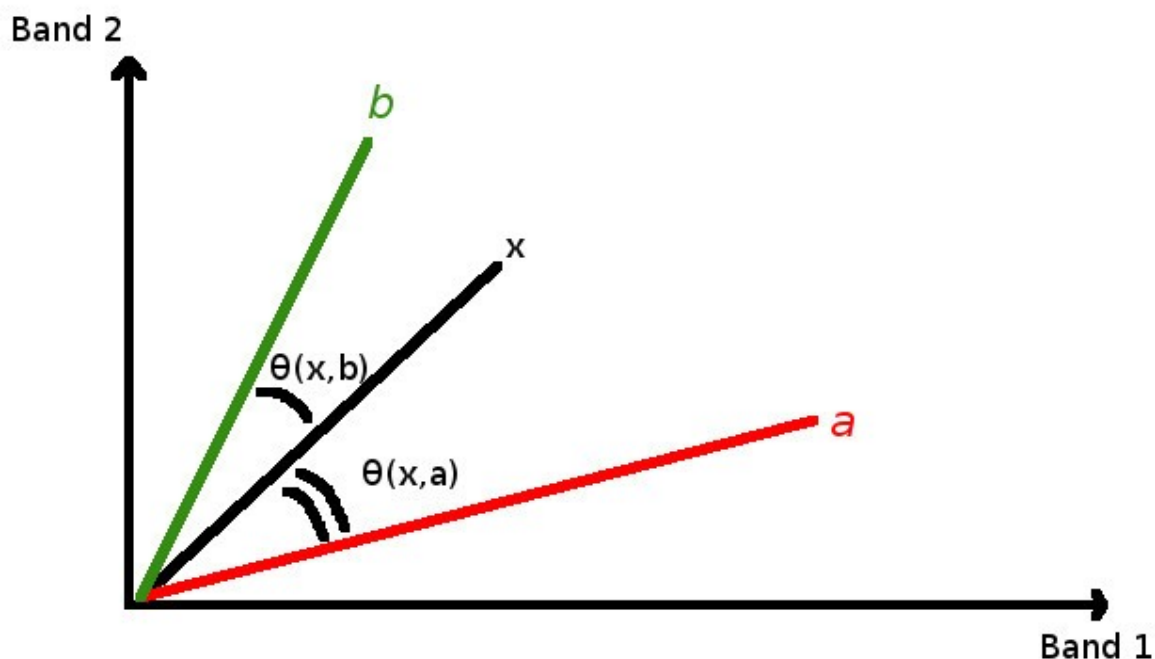


Fig. 8: Spectral Angle Mapping example

In order to exclude pixels below this value from the classification it is possible to define a threshold  $T_i$ :

$$x \in C_k \iff \theta(x, y_k) < \theta(x, y_j) \forall k \neq j$$

and

$$\theta(x, y_k) < T_i$$

Spectral Angle Mapping is largely used, especially with hyperspectral data.

### Parallelepiped Classification

Parallelepiped classification is an algorithm that considers a range of values for each band, forming a multidimensional parallelepiped that defines a land cover class. A pixel is classified if the values thereof are inside a parallelepiped. One of the major drawbacks is that pixels whose signatures lie in the overlapping area of two or more parallelepipeds cannot be classified (Richards and Jia, 2006).

### Land Cover Signature Classification

*Land Cover Signature Classification* is available in SCP (see [Land Cover Signature Classification](#) (page 33)). This classification allows for the definition of spectral thresholds for each training input signature (a minimum value and a maximum value for each band). The thresholds of each training input signature define a spectral region belonging to a certain land cover class.

Spectral signatures of image pixels are compared to the training spectral signatures; a pixel belongs to `class X` if pixel spectral signature is completely contained in the spectral region defined by `class X`. In case of pixels falling inside overlapping regions or outside any spectral region, it is possible to use additional classification algorithms (i.e. [Minimum Distance](#) (page 120), [Maximum Likelihood](#) (page 120), [Spectral Angle Mapping](#) (page 121)) considering the spectral characteristics of the original input signature.

In the following image, a scheme illustrates the *Land Cover Signature Classification* for a simple case of two spectral bands  $x$  and  $y$ . User defined spectral regions define three classes ( $g_a$ ,  $g_b$ , and  $g_c$ ). Point  $p_1$  belongs to class  $g_a$  and point  $p_2$  belongs to class  $g_b$ . However, point  $p_3$  is inside the spectral regions of both classes  $g_b$

and  $g_c$  (overlapping regions); in this case, point  $p_3$  will be unclassified or classified according to an additional classification algorithm. Point  $p_4$  is outside any spectral region, therefore it will be unclassified or classified according to an additional classification algorithm. Given that point  $p_4$  belongs to class  $g_c$ , the spectral region thereof could be extended to include point  $p_4$ .

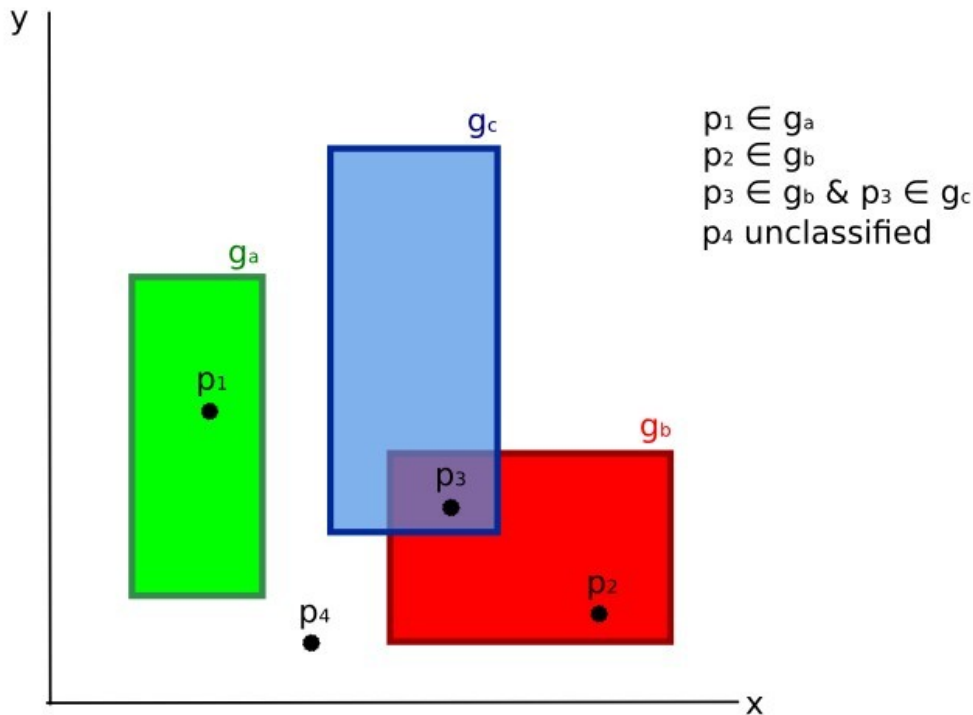


Fig. 9: Land cover signature classification

This is similar to *Parallelepiped Classification* (page 122), with the exception that spectral regions are defined by user, and can be assigned independently for the upper and lower bounds. One can imagine spectral regions as the set of all the spectral signatures of pixels belonging to one class.

In figure *Plot of spectral ranges* (page 124) the spectral ranges of three classes ( $g_a$ ,  $g_b$ , and  $g_c$ ) are displayed; the colored lines inside the ranges (i.e. semi-transparent area) represent the spectral signatures of pixels that defined the upper and lower bounds of the respective ranges. Pixel  $p_1$  (dotted line) belongs to class  $g_b$  because the spectral signature thereof is completely inside the range of class  $g_b$  (in the upper limit); pixel  $p_2$  (dashed line) is unclassified because the spectral signature does not fall completely inside any range; pixel  $p_3$  (dotted line) belongs to class  $g_a$ .

It is worth noticing that these spectral thresholds can be applied to any spectral signature, regardless of spectral characteristics thereof; this function can be very useful for separating similar spectral signatures that differ only in one band, defining thresholds that include or exclude specific signatures. In fact, classes are correctly separated if the spectral ranges thereof are not overlapping at least in one band. Of course, even if spectral regions are overlapping, chances are that no pixel will fall inside the overlapping region and be misclassified; which is the upper (or lower) bound of a range do not imply the existence, in the image, of any spectral signature having the maximum (or minimum) range values for all the bands (for instance pixel  $p_1$  of figure *Plot of spectral ranges* (page 124) could not exist).

One of the main benefit of the *Land Cover Signature Classification* is that it is possible to select pixels and include the signature thereof in a spectral range; therefore, the classification should be the direct representation of the class expected for every spectral signature. This is very suitable for the classification of a single land cover class (defined by specific spectral thresholds), and leave unclassified the rest of the image that is of no interest for the purpose of the classification.



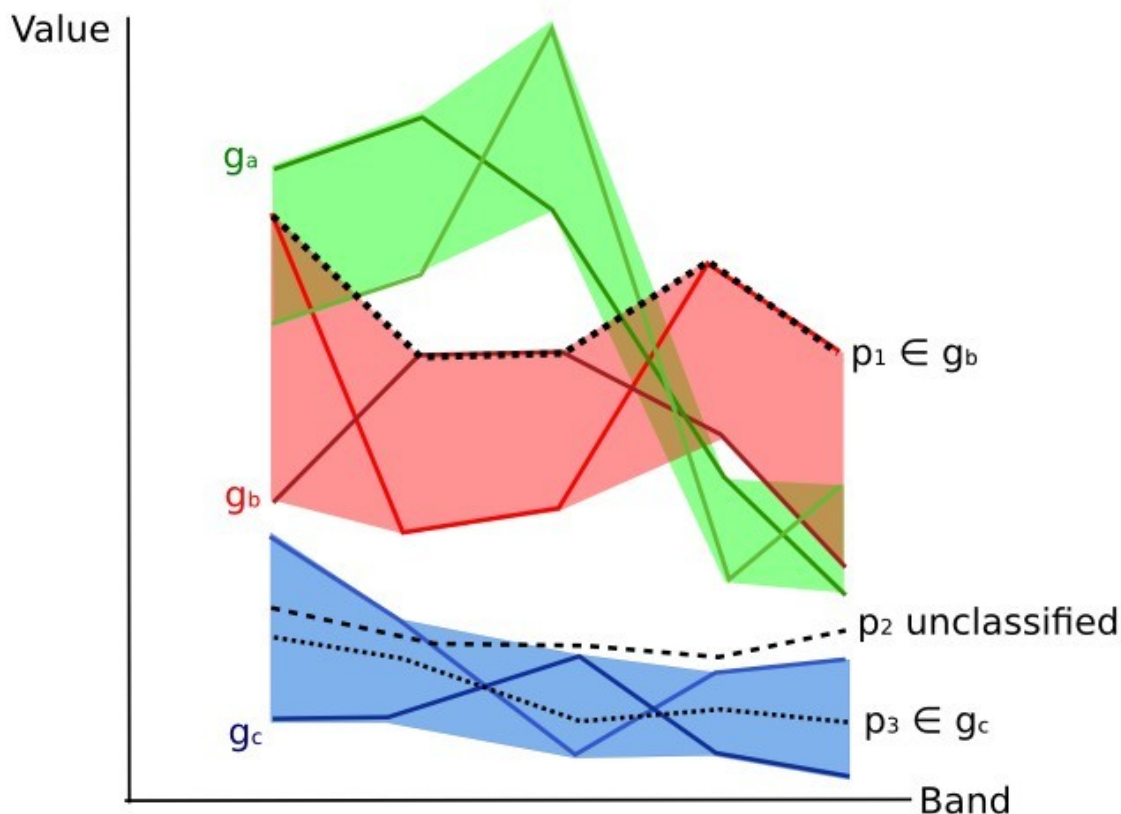


Fig. 10: Plot of spectral ranges

### Algorithm raster

An algorithm raster represents the “distance” (according to the definition of the classification algorithm) of an image pixel to a specific spectral signature.

In general, an algorithm raster is produced for every spectral signature used as training input. The value of every pixel is the result of the algorithm calculation for a specific spectral signature. Therefore, a pixel belongs to `class X` if the value of the algorithm raster corresponding to `class X` is the lowest in case of *Minimum Distance* (page 120) or *Spectral Angle Mapping* (page 121) (or highest in case of *Maximum Likelihood* (page 120)).

Given a classification, a combination of algorithm rasters can be produced, in order to create a raster with the lowest “distances” (i.e. pixels have the value of the algorithm raster corresponding to the class they belong in the classification). Therefore, this raster can be useful to identify pixels that require the collection of more similar spectral signatures (see *Classification preview* (page 35)).

### 4.3.6 Spectral Distance

It is useful to evaluate the spectral distance (or separability) between training signatures or pixels, in order to assess if different classes that are too similar could cause classification errors. The *SCP* implements the following algorithms for assessing similarity of spectral signatures.

#### Jeffries-Matusita Distance

Jeffries-Matusita Distance calculates the separability of a pair of probability distributions. This can be particularly meaningful for evaluating the results of *Maximum Likelihood* (page 120) classifications.

The Jeffries-Matusita Distance  $J_{xy}$  is calculated as (Richards and Jia, 2006):

$$J_{xy} = 2(1 - e^{-B})$$

where:

$$B = \frac{1}{8}(x - y)^t \left( \frac{\Sigma_x + \Sigma_y}{2} \right)^{-1} (x - y) + \frac{1}{2} \ln \left( \frac{|\frac{\Sigma_x + \Sigma_y}{2}|}{|\Sigma_x|^{\frac{1}{2}} |\Sigma_y|^{\frac{1}{2}}} \right)$$

where:

- $x$  = first spectral signature vector;
- $y$  = second spectral signature vector;
- $\Sigma_x$  = covariance matrix of sample  $x$ ;
- $\Sigma_y$  = covariance matrix of sample  $y$ ;

The Jeffries-Matusita Distance is asymptotic to 2 when signatures are completely different, and tends to 0 when signatures are identical.

## Spectral Angle

The Spectral Angle is the most appropriate for assessing the *Spectral Angle Mapping* (page 121) algorithm. The spectral angle  $\theta$  is defined as (Kruse et al., 1993):

$$\theta(x, y) = \cos^{-1} \left( \frac{\sum_{i=1}^n x_i y_i}{(\sum_{i=1}^n x_i^2)^{\frac{1}{2}} * (\sum_{i=1}^n y_i^2)^{\frac{1}{2}}} \right)$$

Where:

- $x$  = spectral signature vector of an image pixel;
- $y$  = spectral signature vector of a training area;
- $n$  = number of image bands.

Spectral angle goes from 0 when signatures are identical to 90 when signatures are completely different.

## Euclidean Distance

The Euclidean Distance is particularly useful for the evaluating the result of *Minimum Distance* (page 120) classifications. In fact, the distance is defined as:

$$d(x, y) = \sqrt{\sum_{i=1}^n (x_i - y_i)^2}$$

where:

- $x$  = first spectral signature vector;
- $y$  = second spectral signature vector;
- $n$  = number of image bands.

The Euclidean Distance is 0 when signatures are identical and tends to increase according to the spectral distance of signatures.

## Bray-Curtis Similarity

The Bray-Curtis Similarity is a statistic used for assessing the relationship between two samples ([read this](#)). It is useful in general for assessing the similarity of spectral signatures, and Bray-Curtis Similarity  $S(x, y)$  is calculated as:

$$S(x, y) = 100 - \left( \frac{\sum_{i=1}^n |(x_i - y_i)|}{\sum_{i=1}^n x_i + \sum_{i=1}^n y_i} \right) * 100$$

where:

- $x$  = first spectral signature vector;
- $y$  = second spectral signature vector;
- $n$  = number of image bands.

The Bray-Curtis similarity is calculated as percentage and ranges from 0 when signatures are completely different to 100 when spectral signatures are identical.

## 4.3.7 Classification Result

The result of the classification process is a raster (see an example of Landsat classification in Figure [Landsat classification](#) (page 126)), where pixel values correspond to class IDs and each color represent a land cover class.

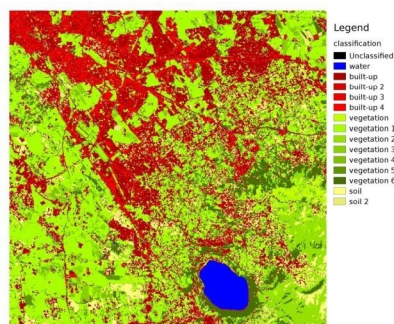


Fig. 11: *Landsat classification*  
Data available from the U.S. Geological Survey

A certain amount of errors can occur in the land cover classification (i.e. pixels assigned to a wrong land cover class), due to spectral similarity of classes, or wrong class definition during the ROI collection.

## 4.3.8 Accuracy Assessment

After the classification process, it is useful to assess the accuracy of land cover classification, in order to identify and measure map errors. Usually, **accuracy assessment** is performed with the calculation of an error matrix, which is a table that compares map information with reference data (i.e. ground truth data) for a number of sample areas (Congalton and Green, 2009).

The following table is a scheme of error matrix, where  $k$  is the number of classes identified in the land cover classification, and  $n$  is the total number of collected sample units. The items in the major diagonal ( $a_{ii}$ ) are the number of samples correctly identified, while the other items are classification error.

*Scheme of Error Matrix*

|                | Ground truth 1 | Ground truth 2 | ... | Ground truth k | Total    |
|----------------|----------------|----------------|-----|----------------|----------|
| <b>Class 1</b> | $a_{11}$       | $a_{12}$       | ... | $a_{1k}$       | $a_{1+}$ |
| <b>Class 2</b> | $a_{21}$       | $a_{22}$       | ... | $a_{2k}$       | $a_{2+}$ |
| ...            | ...            | ...            | ... | ...            | ...      |
| <b>Class k</b> | $a_{k1}$       | $a_{k2}$       | ... | $a_{kk}$       | $a_{k+}$ |
| <b>Total</b>   | $a_{+1}$       | $a_{+2}$       | ... | $a_{+k}$       | $n$      |

Therefore, it is possible to calculate the overall accuracy as the ratio between the number of samples that are correctly classified (the sum of the major diagonal), and the total number of sample units  $n$  (Congalton and Green, 2009).

The overall accuracy (also expressed in percentage) is defined as:

$$O = \sum_{i=1}^k a_{ii}/n$$

The user's accuracy for each class is defined as the ratio (also expressed in percentage) between correct samples and the row total:

$$U_i = a_{ii}/a_{i+}$$

The commission error  $CE_i = 1 - U_i$  corresponds to pixels classified as class  $i$  that actually belong to a different class.

The producer's accuracy for each class is calculated as the ratio (also expressed in percentage) between correct samples and the column total:

$$P_i = a_{ii}/a_{+i}$$

The omission error  $OE_i = 1 - P_i$  corresponds to pixels actually belonging to class  $i$  that were classified erroneously as a different class.

User's accuracy is It is recommended to calculate the area based error matrix (Olofsson, et al., 2014) where each element represents the estimated area proportion of each class. This allows for estimating the unbiased user's accuracy and producer's accuracy, the unbiased area of classes according to reference data, and the standard error of area estimates.

For further information, the following documentation is freely available: [Landsat 7 Science Data User's Handbook](#), [Remote Sensing Note](#), or [Wikipedia](#).

## 4.4 Image processing

Remote sensing images can be processed in various ways in order to obtain classification, indices, or other derived information that can be useful for land cover characterization.

### 4.4.1 Principal Component Analysis

Principal Component Analysis (PCA) is a method for reducing the dimensions of measured variables (bands) to the principal components (JARS, 1993).

The principal component transformation provides a new set of bands (principal components) having the following characteristic: principal components are uncorrelated; each component has variance less than the previous component. Therefore, this is an efficient method for extracting information and data compression (Ready and Wintz, 1973).

Given an image with  $N$  spectral bands, the principal components are obtained by matrix calculation (Ready and Wintz, 1973; Richards and Jia, 2006):

$$Y = D^t X$$

where:

- $Y$  = vector of principal components
- $D$  = matrix of eigenvectors of the covariance matrix  $C_x$  in X space
- $t$  denotes vector transpose

And  $X$  is calculated as:

$$X = P - M$$

- $P$  = vector of spectral values associated with each pixel
- $M$  = vector of the mean associated with each band

Thus, the mean of  $X$  associated with each band is 0.  $D$  is formed by the eigenvectors (of the covariance matrix  $C_x$ ) ordered as the eigenvalues from maximum to minimum, in order to have the maximum variance in the first component. This way, the principal components are uncorrelated and each component has variance less than the previous component (Ready and Wintz, 1973).

Usually the first two components contain more than the 90% of the variance. For example, the first principal components can be displayed in a *Color Composite* (page 116) for highlighting *Land Cover* (page 112) classes, or used as input for *Supervised Classification* (page 116).

#### 4.4.2 Pan-sharpening

Pan-sharpening is the combination of the spectral information of multispectral bands (MS), which have lower spatial resolution (for Landsat bands, spatial resolution is 30m), with the spatial resolution of a panchromatic band (PAN), which for Landsat 7 and 8 it is 15m. The result is a multispectral image with the spatial resolution of the panchromatic band (e.g. 15m). In *SCP*, a Brovey Transform is applied, where the pan-sharpened values of each multispectral band are calculated as (Johnson, Tateishi and Hoan, 2012):

$$MSpan = MS * PAN / I$$

where  $I$  is Intensity, which is a function of multispectral bands.

The following weights for  $I$  are defined, basing on several tests performed using the *SCP*. For Landsat 8, Intensity is calculated as:

$$I = (0.42 * Blue + 0.98 * Green + 0.6 * Red) / 2$$

For Landsat 7, Intensity is calculated as:

$$I = (0.42 * Blue + 0.98 * Green + 0.6 * Red + NIR) / 3$$

#### 4.4.3 Spectral Indices

Spectral indices are operations between spectral bands that are useful for extracting information such as vegetation cover (JARS, 1993). One of the most popular spectral indices is the **Normalized Difference Vegetation Index** (NDVI), defined as (JARS, 1993):

$$NDVI = (NIR - Red) / (NIR + Red)$$

NDVI values range from -1 to 1. Dense and healthy vegetation show higher values, while non-vegetated areas show low NDVI values.

Another index is the **Enhanced Vegetation Index** (EVI) which attempts to account for atmospheric effects such as path radiance calculating the difference between the blue and the red bands (Didan, et al., 2015). EVI is defined as:

$$EVI = G(NIR - Red) / (NIR + C_1 Red - C_2 Blue + L)$$



Fig. 12: Example of pan-sharpening of a Landsat 8 image. Left, original multispectral bands (30m); right, pan-sharpened bands (15m)

Data available from the U.S. Geological Survey

where:  $G$  is a scaling factor,  $C_1$  and  $C_2$  are coefficients for the atmospheric effects, and  $L$  is a factor for accounting the differential NIR and Red radiant transfer through the canopy. Typical coefficient values are:  $G = 2.5$ ,  $L = 1$ ,  $C_1 = 6$ ,  $C_2 = 7.5$  (Didan, et al., 2015).

#### 4.4.4 Clustering

Clustering is the grouping of pixels based on spectral similarity (e.g. *Euclidean Distance* (page 125) or *Spectral Angle* (page 125)) calculated for a multispectral image (Richards and Jia, 2006).

Clustering can be used for unsupervised classification or for the automatic selection of spectral signatures. It is worth noticing that, while *Supervised Classification* (page 116) produces a classification with the classes identified during the training process, the classes produced by clustering (i.e. clusters) have no definition and consequently the user must assign a land cover label to each class.

The main advantage of clustering resides in automation. Of course, clusters do not necessarily represent a particular land cover type and additional processing could be required for producing an accurate classification.

There are several types of clustering, mainly based on iterative methods; the following are the algorithms provided in *SCP*.

##### K-means

The K-means method is based on the calculation of the average spectral signature of clusters (Wikipedia, 2017; JARS, 1993).

At first, the user defines the number of clusters expected in the image, which correspond to as many spectral signatures (i.e. seeds). Starting spectral signatures can be selected in various ways (e.g. randomly, provided by the user, calculated automatically from image values).

During the first iteration clusters are produced calculating the pixel spectral distance with initial spectral signatures. The algorithms *Euclidean Distance* (page 125) or *Spectral Angle* (page 125) can be used for distance calculation. Pixels are assigned according to the most similar spectral signature, therefore producing clusters.

Then, the average spectral signature is calculated for each cluster of pixels, resulting in the spectral signatures that will be used in the following iteration.



This process continues iteratively producing clusters and mean spectral signatures, until one of the following condition is verified:

- the spectral distance between the spectral signatures produced in this iteration with the corresponding ones produced in the previous iteration is lower than a certain threshold;
- the maximum number of iterations is reached.

After the last iteration, a raster of clusters is produced using the spectral signatures derived from the last iteration.

## ISODATA

The ISODATA (Iterative Self-Organizing Data Analysis Technique) method is similar to K-means but with the additional steps of merging clusters having similar spectral signatures and splitting clusters having too high variability (i.e. standard deviation) of spectral signatures (Ball & Hall, 1965). Following, the SCP implementation of ISODATA is described.

At first, the user defines the number of clusters expected in the image, which correspond to as many spectral signatures (i.e. seeds). Starting spectral signatures can be selected in various ways (e.g. randomly, provided by the user, calculated automatically from image values). Initial parameters provided by user are:

- $C$  = number of desired clusters
- $N_{min}$  = minimum number of pixels for a cluster
- $\sigma_t$  = maximum standard deviation threshold for splitting
- $D_t$  = distance threshold for merging

During the first iteration clusters are produced calculating the *Euclidean Distance* (page 125) of pixels with initial spectral signatures. Pixels are assigned according to the most similar spectral signature, therefore producing clusters.

Therefore, the following parameters are calculated:

- $N_i$  = number of pixels of cluster  $i$
- $S_i$  = average spectral signature of cluster  $i$
- $AVERAGEDIST_i$  = average distance of cluster  $i$  with the seed spectral signature
- $AVERAGEDISTANCE$  = overall average distance of all clusters
- $\sigma_{ij}$  = standard deviation of cluster  $i$  in band  $j$
- $\sigma max_i$  = maximum standard deviation of cluster  $i$  (i.e.  $\max(\sigma_{ij})$ )
- $k_i$  = band where  $\sigma max_i$  occurred
- $Sk_i$  = value of  $S_i$  at band  $k_i$
- $P$  = number of clusters

Then, for each cluster  $i$ , if  $N_i < N_{min}$ , then the cluster  $i$  is discarded.

If  $P \leq C$  then try to split clusters. For each cluster  $i$ :

- If  $\sigma max_i > \sigma_t$  :
  - If  $((AVERAGEDIST_i > AVERAGEDISTANCE) \text{ AND } (N_i > (2 * N_{min} + 2))) \text{ OR } (C > 2 * P)$ :
    - \* create a new spectral signature  $S_{p+1} = S_i$
    - \* in  $S_i$  set the value  $Sk_i = Sk_i + \sigma max_i$
    - \* in  $S_{p+1}$  set the value  $Sk_{p+1} = Sk_i - \sigma max_i$
    - \*  $P = P + 1$
    - \* start a new iteration



If  $P > (2 * C)$  then try to merge clusters.

- For each combination  $xy$  of spectral signatures calculate  $D_{xy} = \text{Euclidean Distance}$  (page 125) of spectral signatures  $S_x$  and  $S_y$ .
- If the minimum  $D_{xy}$  is greater than  $D_t$ :
  - $S_{\{i\}} = (N_i * S_{\{i\}} + N_j * S_{\{j\}}) / (N_i + N_j)$
  - discard  $S_{\{j\}}$
  - $P = P - 1$
  - start a new iteration

After the last iteration, a raster of clusters is produced using the spectral signatures derived from the last iteration. The number of clusters can vary according to the processes of splitting and merging.

## 4.5 Image conversion to reflectance

This chapter provides information about the conversion to reflectance implemented in *SCP*.

### 4.5.1 Radiance at the Sensor's Aperture

**Radiance** is the “flux of energy (primarily irradiant or incident energy) per solid angle leaving a unit surface area in a given direction”, “Radiance is what is measured at the sensor and is somewhat dependent on reflectance” (NASA, 2011, p. 47).

Images such as Landsat or Sentinel-2 are composed of several bands and a metadata file which contains information required for the conversion to reflectance.

Landsat images are provided in radiance, scaled prior to output. for Landsat images **Spectral Radiance at the sensor's aperture** ( $L_\lambda$ , measured in [watts/(meter squared \* ster \*  $\mu m$ ))] is given by ([https://landsat.usgs.gov/Landsat8\\_Using\\_Product.php](https://landsat.usgs.gov/Landsat8_Using_Product.php)):

$$L_\lambda = M_L * Q_{cal} + A_L$$

where:

- $M_L$  = Band-specific multiplicative rescaling factor from Landsat metadata (RADIANCE\_MULT\_BAND\_x, where x is the band number)
- $A_L$  = Band-specific additive rescaling factor from Landsat metadata (RADIANCE\_ADD\_BAND\_x, where x is the band number)
- $Q_{cal}$  = Quantized and calibrated standard product pixel values (DN)

Sentinel-2 images (Level-1C) are already provided in *Top Of Atmosphere (TOA) Reflectance* (page 131), scaled prior to output (ESA, 2015).

### 4.5.2 Top Of Atmosphere (TOA) Reflectance

Images in radiance can be converted to Top Of Atmosphere (TOA) Reflectance (combined surface and atmospheric reflectance) in order to reduce the in between-scene variability through a normalization for solar irradiance. This TOA reflectance ( $\rho_p$ ), which is the unitless ratio of reflected versus total power energy (NASA, 2011), is calculated by:

$$\rho_p = (\pi * L_\lambda * d^2) / (ESUN_\lambda * \cos\theta_s)$$

where:

- $L_\lambda$  = Spectral radiance at the sensor's aperture (at-satellite radiance)

- $d$  = Earth-Sun distance in astronomical units (provided with Landsat 8 metadata file, and an excel file is available from [http://landsathandbook.gsfc.nasa.gov/excel\\_docs/d.xls](http://landsathandbook.gsfc.nasa.gov/excel_docs/d.xls))
- $ESUN_{\lambda}$  = Mean solar exo-atmospheric irradiances
- $\theta_s$  = Solar zenith angle in degrees, which is equal to  $\theta_s = 90^\circ - \theta_e$  where  $\theta_e$  is the Sun elevation

It is worth pointing out that Landsat 8 images are provided with band-specific rescaling factors that allow for the direct conversion from DN to TOA reflectance.

Sentinel-2 images are already provided in scaled TOA reflectance, which can be converted to TOA reflectance with a simple calculation using the Quantification Value provided in the metadata (see [https://sentinel.esa.int/documents/247904/349490/S2\\_MSI\\_Product\\_Specification.pdf](https://sentinel.esa.int/documents/247904/349490/S2_MSI_Product_Specification.pdf)).

Sentinel-3 images are already provided in scaled TOA radiance. Conversion to reflectance is performed applying the coefficients `scale_factor` and `add_offset` provided in the metadata of each band. The ancillary raster `tie_geometries.nc` provides the value of sun zenith angle and the ancillary raster `instrument_data` provides information about the solar flux for each band, which are used for the conversion to reflectance with the correction for sun angle. In addition, the georeferencing of the bands is performed using the ancillary raster `geo_coordinates.nc` which provides coordinates of every pixel.

### 4.5.3 Surface Reflectance

The effects of the atmosphere (i.e. a disturbance on the reflectance that varies with the wavelength) should be considered in order to measure the reflectance at the ground.

As described by Moran et al. (1992), the **land surface reflectance** ( $\rho$ ) is:

$$\rho = [\pi * (L_{\lambda} - L_p) * d^2] / [T_v * ((ESUN_{\lambda} * \cos\theta_s * T_z) + E_{down})]$$

where:

- $L_p$  is the path radiance
- $T_v$  is the atmospheric transmittance in the viewing direction
- $T_z$  is the atmospheric transmittance in the illumination direction
- $E_{down}$  is the downwelling diffuse irradiance

Therefore, we need several atmospheric measurements in order to calculate  $\rho$  (physically-based corrections). Alternatively, it is possible to use **image-based techniques** for the calculation of these parameters, without in-situ measurements during image acquisition. It is worth mentioning that **Landsat Surface Reflectance High Level Data Products** for Landsat 8 are available (for more information read [http://landsat.usgs.gov/CDR\\_LSR.php](http://landsat.usgs.gov/CDR_LSR.php)).

### 4.5.4 DOS1 Correction

The **Dark Object Subtraction** (DOS) is a family of image-based atmospheric corrections. Chavez (1996) explains that “the basic assumption is that within the image some pixels are in complete shadow and their radiances received at the satellite are due to atmospheric scattering (path radiance). This assumption is combined with the fact that very few targets on the Earth’s surface are absolute black, so an assumed one-percent minimum reflectance is better than zero percent”. It is worth pointing out that the accuracy of image-based techniques is generally lower than physically-based corrections, but they are very useful when no atmospheric measurements are available as they can improve the estimation of land surface reflectance. The **path radiance** is given by (Sobrino, et al., 2004):

$$L_p = L_{min} - L_{DO1\%}$$

where:

- $L_{min}$  = “radiance that corresponds to a digital count value for which the sum of all the pixels with digital counts lower or equal to this value is equal to the 0.01% of all the pixels from the image considered” (Sobrino, et al., 2004, p. 437), therefore the radiance obtained with that digital count value ( $DN_{min}$ )

- $L_{DO1\%}$  = radiance of Dark Object, assumed to have a reflectance value of 0.01

In particular for Landsat images:

$$L_{min} = M_L * DN_{min} + A_L$$

Sentinel-2 images are converted to radiance prior to DOS1 calculation.

The **radiance of Dark Object** is given by (Sobrino, et al., 2004):

$$L_{DO1\%} = 0.01 * [(ESUN_{\lambda} * \cos\theta_s * T_z) + E_{down}] * T_v / (\pi * d^2)$$

Therefore the **path radiance** is:

$$L_p = M_L * DN_{min} + A_L - 0.01 * [(ESUN_{\lambda} * \cos\theta_s * T_z) + E_{down}] * T_v / (\pi * d^2)$$

There are several DOS techniques (e.g. DOS1, DOS2, DOS3, DOS4), based on different assumption about  $T_v$ ,  $T_z$ , and  $E_{down}$ . The simplest technique is the **DOS1**, where the following assumptions are made (Moran et al., 1992):

- $T_v = 1$
- $T_z = 1$
- $E_{down} = 0$

Therefore the **path radiance** is:

$$L_p = M_L * DN_{min} + A_L - 0.01 * ESUN_{\lambda} * \cos\theta_s / (\pi * d^2)$$

And the resulting **land surface reflectance** is given by:

$$\rho = [\pi * (L_{\lambda} - L_p) * d^2] / (ESUN_{\lambda} * \cos\theta_s)$$

ESUN [W/(m<sup>2</sup> \* μm)] values for Landsat sensors are provided in the following table.

*ESUN values for Landsat bands*

| Band | Landsat 1<br>MSS* | Landsat 2<br>MSS* | Landsat 3<br>MSS* | Landsat 4<br>TM* | Landsat 5<br>TM* | Landsat 7<br>ETM+** |
|------|-------------------|-------------------|-------------------|------------------|------------------|---------------------|
| 1    |                   |                   |                   | 1983             | 1983             | 1970                |
| 2    |                   |                   |                   | 1795             | 1796             | 1842                |
| 3    |                   |                   |                   | 1539             | 1536             | 1547                |
| 4    | 1823              | 1829              | 1839              | 1028             | 1031             | 1044                |
| 5    | 1559              | 1539              | 1555              | 219.8            | 220              | 225.7               |
| 6    | 1276              | 1268              | 1291              |                  |                  |                     |
| 7    | 880.1             | 886.6             | 887.9             | 83.49            | 83.44            | 82.06               |
| 8    |                   |                   |                   |                  |                  | 1369                |

\* from Chander, Markham, & Helder (2009)

\*\* from [http://landsathandbook.gsfc.nasa.gov/data\\_prod/prog\\_sect11\\_3.html](http://landsathandbook.gsfc.nasa.gov/data_prod/prog_sect11_3.html)

For **Landsat 8**, *ESUN* can be calculated as (from <http://grass.osgeo.org/grass65/manuals/i.landsat.toar.html>):

$$ESUN = (\pi * d^2) * RADIANCE\_MAXIMUM / REFLECTANCE\_MAXIMUM$$

where RADIANCE\_MAXIMUM and REFLECTANCE\_MAXIMUM are provided by image metadata.

ESUN [W/(m<sup>2</sup> \* μm)] values for **Sentinel-2** sensor (provided in image metadata) are illustrated in the following table.

*ESUN values for Sentinel-2 bands*

| Band | Sentinel-2 |
|------|------------|
| 1    | 1913.57    |
| 2    | 1941.63    |
| 3    | 1822.61    |
| 4    | 1512.79    |
| 5    | 1425.56    |
| 6    | 1288.32    |
| 7    | 1163.19    |
| 8    | 1036.39    |
| 8A   | 955.19     |
| 9    | 813.04     |
| 10   | 367.15     |
| 11   | 245.59     |
| 12   | 85.25      |

ESUN [ $\text{W}/(\text{m}^2 * \mu\text{m})$ ] values for **ASTER** sensor are illustrated in the following table (from Finn, et al., 2012).

*ESUN values for ASTER bands*

| Band | ASTER |
|------|-------|
| 1    | 1848  |
| 2    | 1549  |
| 3    | 1114  |
| 4    | 225.4 |
| 5    | 86.63 |
| 6    | 81.85 |
| 7    | 74.85 |
| 8    | 66.49 |
| 9    | 59.85 |

An example of comparison of TOA reflectance, DOS1 corrected reflectance and the Landsat Surface Reflectance High Level Data Products (ground truth) is provided in Figure *Spectral signatures of a built-up pixel* (page 134).

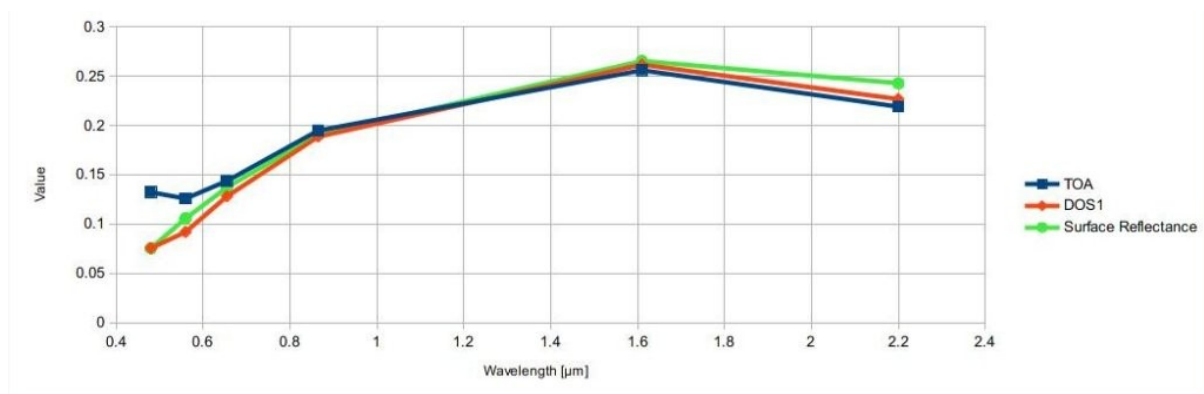


Fig. 13: *Spectral signatures of a built-up pixel*

Comparison of TOA reflectance, DOS1 corrected reflectance and Landsat Surface Reflectance High Level Data Products

## 4.6 Conversion to Temperature

This chapter provides the basic information about the conversion to **At-Satellite Brightness Temperature** implemented in *SCP* and the estimation of **Land Surface Temperature**.

### 4.6.1 Conversion to At-Satellite Brightness Temperature

For thermal bands, the conversion of DN to At-Satellite Brightness Temperature is given by (from [https://landsat.usgs.gov/Landsat8\\_Using\\_Product.php](https://landsat.usgs.gov/Landsat8_Using_Product.php)):

$$T_B = K_2 / \ln[(K_1 / L_\lambda) + 1]$$

where:

- $K_1$  = Band-specific thermal conversion constant (in watts/meter squared \* ster \*  $\mu m$ )
- $K_2$  = Band-specific thermal conversion constant (in kelvin)

and  $L_\lambda$  is the Spectral Radiance at the sensor's aperture, measured in watts/(meter squared \* ster \*  $\mu m$ ).

The  $K_1$  and  $K_2$  constants for Landsat sensors are provided in the following table.

*Thermal Conversion Constants for Landsat*

| Constant | Landsat 4* | Landsat 5* | Landsat 7** |
|----------|------------|------------|-------------|
| $K_1$    | 671.62     | 607.76     | 666.09      |
| $K_2$    | 1284.30    | 1260.56    | 1282.71     |

\* from Chander & Markham (2003)

\*\* from NASA (2011)

For **Landsat 8**, the  $K_1$  and  $K_2$  values are provided in the image metadata file.

$K_1$  and  $K_2$  are calculated as (Jimenez-Munoz & Sobrino, 2010):

$$K_1 = c_1 / \lambda^5$$

$$K_2 = c_2 / \lambda$$

where (Mohr, Newell, & Taylor, 2015):

- $c_1$  = first radiation constant =  $1.191 * 10^{-16} W m^2 s r^{-1}$
- $c_2$  = second radiation constant =  $1.4388 * 10^{-2} m K$

Therefore, for ASTER bands  $K_1$  and  $K_2$  are provided in the following table.

*Thermal Conversion Constants for ASTER*

| Constant | Band 10        | Band 11        | Band 12        | Band 13        | Band 14        |
|----------|----------------|----------------|----------------|----------------|----------------|
| $K_1$    | $3.024 * 10^3$ | $2.460 * 10^3$ | $1.909 * 10^3$ | $8.900 * 10^2$ | $6.464 * 10^2$ |
| $K_2$    | $1.733 * 10^3$ | $1.663 * 10^3$ | $1.581 * 10^3$ | $1.357 * 10^3$ | $1.273 * 10^3$ |

### 4.6.2 Estimation of Land Surface Temperature

Several studies have described the estimation of Land Surface Temperature. Land Surface Temperature can be calculated from At-Satellite Brightness Temperature  $T_B$  as (Weng, et al. 2004):

$$T = T_B / [1 + (\lambda * T_B / c_2) * \ln(e)]$$

where:

- $\lambda$  = wavelength of emitted radiance
- $c_2 = h * c / s = 1.4388 * 10^{-2} m K$
- $h$  = Planck's constant =  $6.626 * 10^{-34} J s$
- $s$  = Boltzmann constant =  $1.38 * 10^{-23} J/K$

- $c$  = velocity of light =  $2.998 \times 10^8$  m/s

The values of  $\lambda$  for the thermal bands of Landsat and ASTER satellites can be calculated from the tables in *Landsat Satellites* (page 113) and *ASTER Satellite* (page 115).

Several studies used NDVI for the estimation of land surface emissivity (Sobrino, et al., 2004); other studies used a land cover classification for the definition of the land surface emissivity of each class (Weng, et al. 2004). For instance, the emissivity ( $e$ ) values of various land cover types are provided in the following table (from Mallick, et al. 2012).

*Emissivity values*

| Land surface | Emissivity $e$ |
|--------------|----------------|
| Soil         | 0.928          |
| Grass        | 0.982          |
| Asphalt      | 0.942          |
| Concrete     | 0.937          |

## 4.7 References

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The following are very basic tutorials for land cover classification using the Semi-Automatic Classification Plugin (SCP). It is assumed that you have a basic knowledge of QGIS (you can find a guide to QGIS interface [at this page](#)).

### 5.1 Tutorial 1

The following is a basic tutorial about the land cover classification using the Semi-Automatic Classification Plugin (SCP). It is assumed that you have a basic knowledge of QGIS.

- *Tutorial 1: Your First Land Cover Classification* (page 139)
  - *Download the Data* (page 140)
  - *Clip the Data* (page 143)
  - *Convert Data to Surface Reflectance* (page 146)
  - *Define the Band set and create the Training Input File* (page 147)
  - *Create the ROIs* (page 151)
  - *Assess the Spectral Signatures* (page 161)
  - *Create a Classification Preview* (page 167)
  - *Create the Classification Output* (page 167)

#### 5.1.1 Tutorial 1: Your First Land Cover Classification

This is a basic tutorial about the use of SCP for the classification of a multispectral image. It is recommended to read the *Brief Introduction to Remote Sensing* (page 109) before this tutorial.

The purpose of the classification is to identify the following land cover classes:

1. Water;
2. Built-up;

3. Vegetation;
4. Bare soil.

The study area of this tutorial is Greenbelt (Maryland, USA) which is the site of NASA's Goddard Space Flight Center (the institution that will lead the development of the future Landsat 9 flight segment).

Following the video of this tutorial.

<http://www.youtube.com/watch?v=fUZgYxgDjsk>

### Download the Data

We are going to download a *Landsat Satellites* (page 113) image (data available from the U.S. Geological Survey) and use the following bands:


1. Blue;
2. Green;
3. Red;
4. Near-Infrared;
5. Short Wavelength Infrared 1;
6. Short Wavelength Infrared 2.


**TIP :** In case you have a slow connection you can download an image subset from [this archive](#) (about 5 MB, data available from the U.S. Geological Survey), unzip the downloaded file, and skip to *Convert Data to Surface Reflectance* (page 146).

Start QGIS and the *SCP*. Open the tab *Download products* (page 51) clicking the button  in the *Home* (page 24), or in the *SCP menu* (page 21),


We are searching a specific image acquired on 16 April 2017 because it is cloud free. In *Search parameters* (page 53) enter the point coordinates:

- *UL*: -77 / 39
- *LR*: -76.9 / 38.9

**TIP :** In general it is possible to define the area coordinates clicking the button , then left click in the map for the *UL* point and right click in the map for the *LR* point.

Select *L8 OLI/TIRS* from the *Products*  and set:

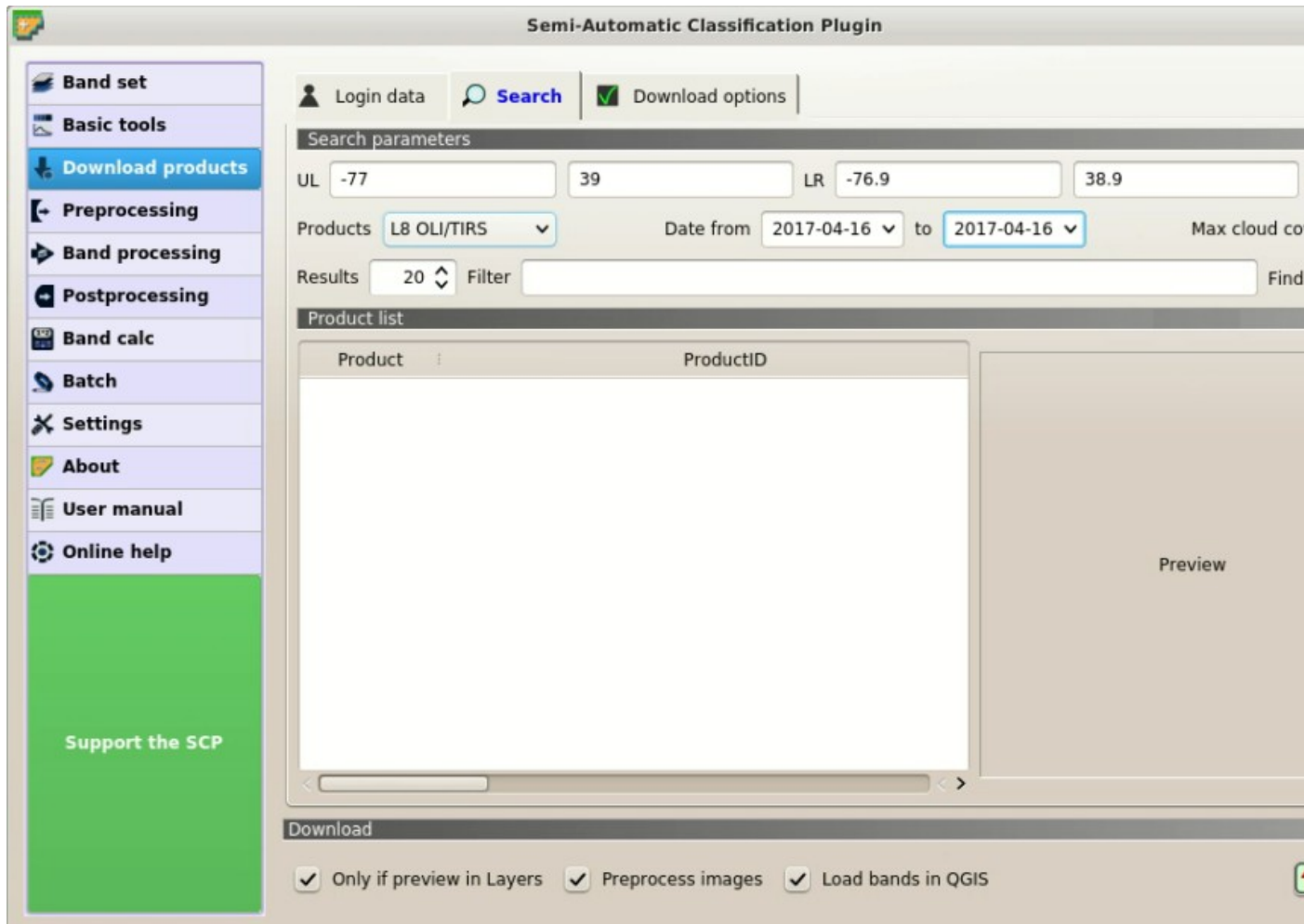
- *Date from*: 2017-04-16
- *to*: 2017-04-16

Now click the button *Find*  and after a few seconds the image will be listed in the *Product list* (page 54). Click the item in the table to display a preview that is useful for assessing the quality of the image and the cloud cover.

Now click the button  to load the preview in the map.

We can also select the bands to be downloaded according to our purpose. In particular, select the tab *Download options* (page 55) and check only the Landsat bands (that will be used in this tutorial): 2, 3, 4, 5, 6, 7, and the ancillary data.

For the purpose of this tutorial, uncheck the option  *Preprocess images* (you should usually leave this checked) because we are going to preprocess the image in *Convert Data to Surface Reflectance* (page 146). To start the

Fig. 1: *Search products*

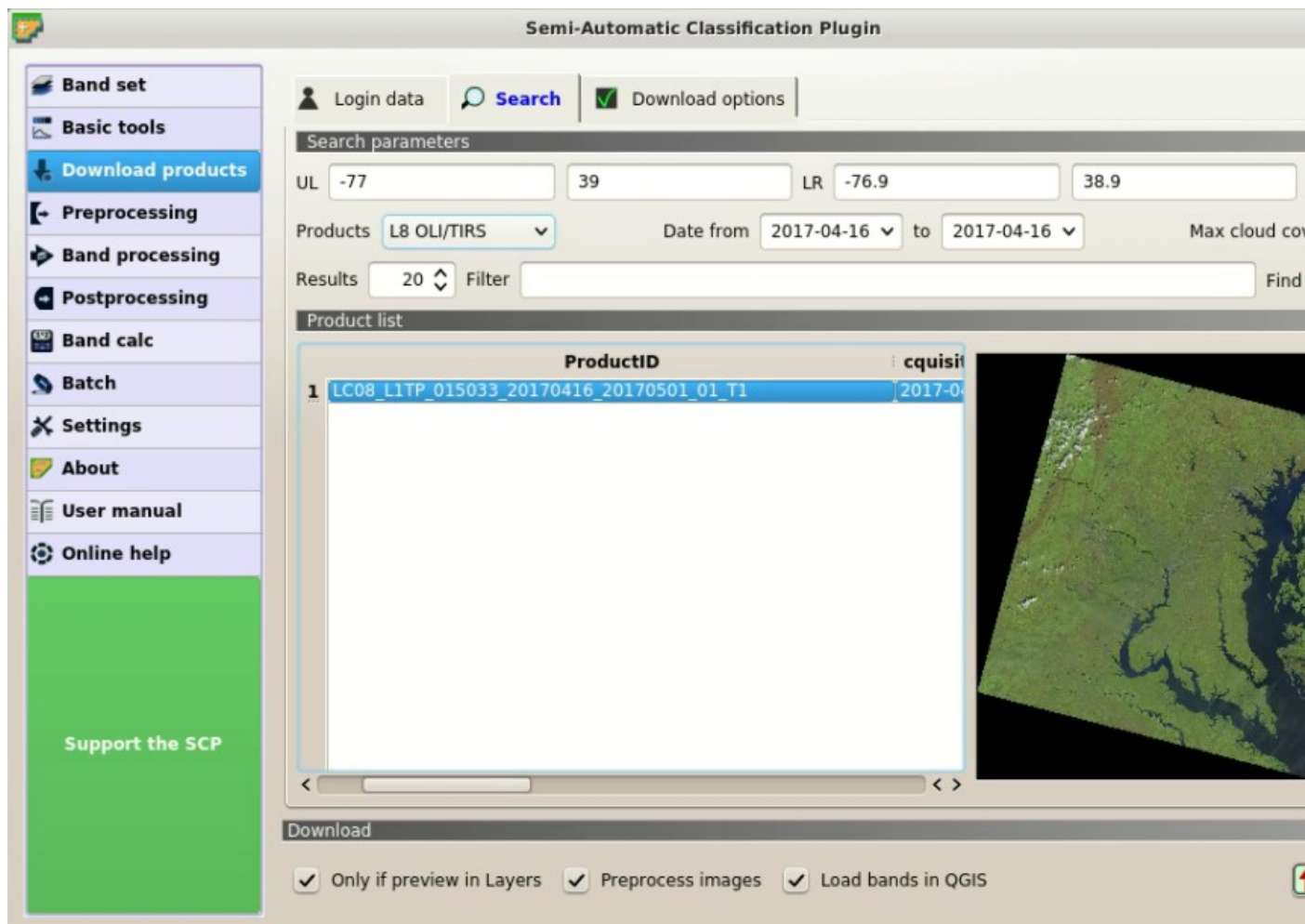


Fig. 2: Search result

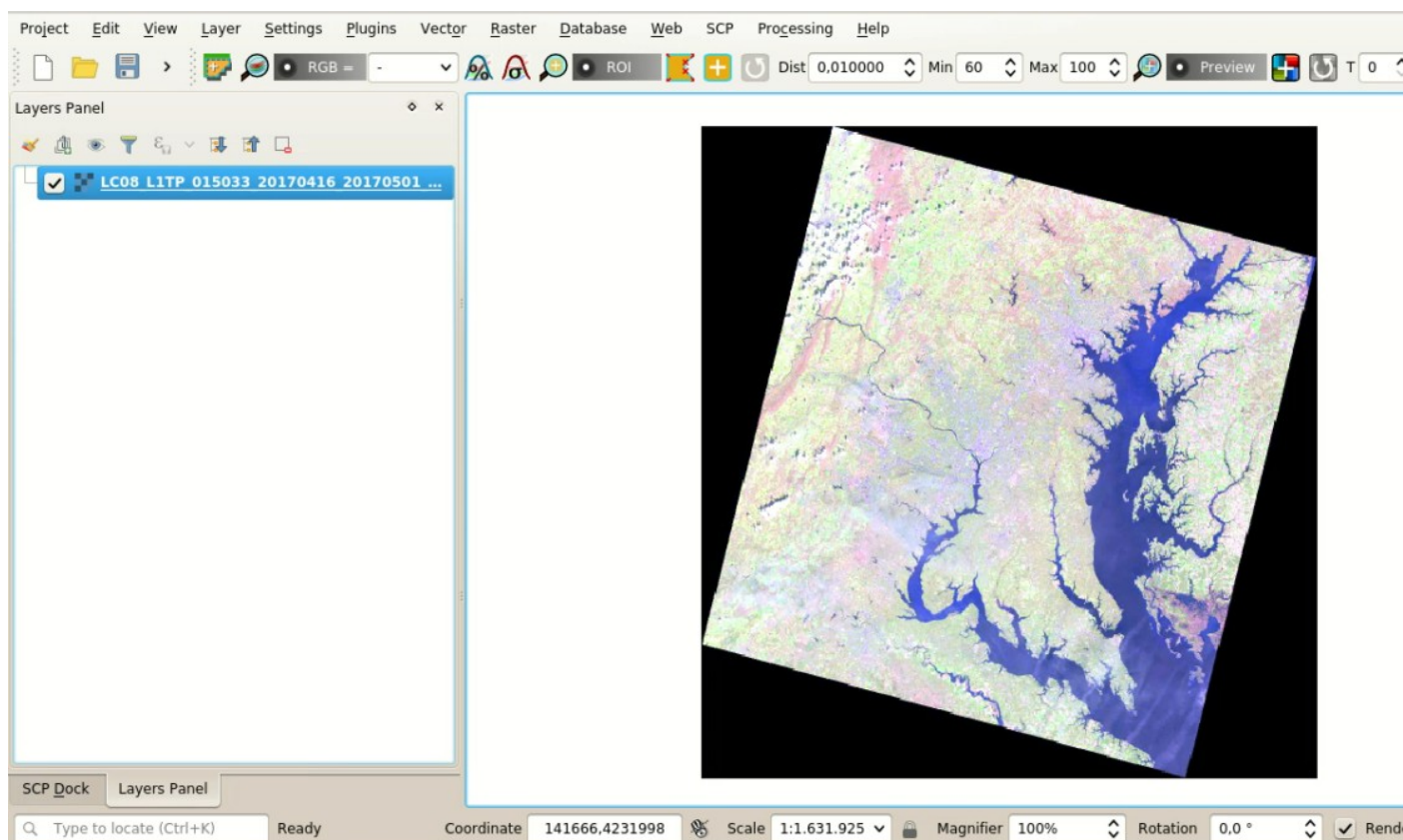




Fig. 3: Image preview


image download, click the button  and select a directory where bands are saved. The download could last a few minutes according to your internet connection speed. The download progress is displayed in a bar.



**TIP :** The option  *Only if preview in Layers* allows for downloading only images in the result table which are loaded as previews in the map. If this option is unchecked, all the products in the list are downloaded.

After the download, all the bands are automatically loaded in the map.


## Clip the Data

For limiting the study area (and reducing the processing time) we can clip the image.

First, we need to define a *Band set* containing the bands to be clipped. Open the tab *Band set* (page 37) clicking the button  in the *SCP menu* (page 21) or the *SCP dock* (page 23).

Click the button  to refresh the layer list, and select the bands: 2, 3, 4, 5, 6, and 7; then click  to add selected rasters to the *Band set 1*.

In *Preprocessing* (page 56) open the tab *Clip multiple rasters* (page 65). We are going to clip the *Band set 1* which contains Landsat bands.

Click the button  and select an area such as the following image (left click in the map for the UL point and right click in the map for the LR point), or enter the following values:

- UL: 330015 / 4324995

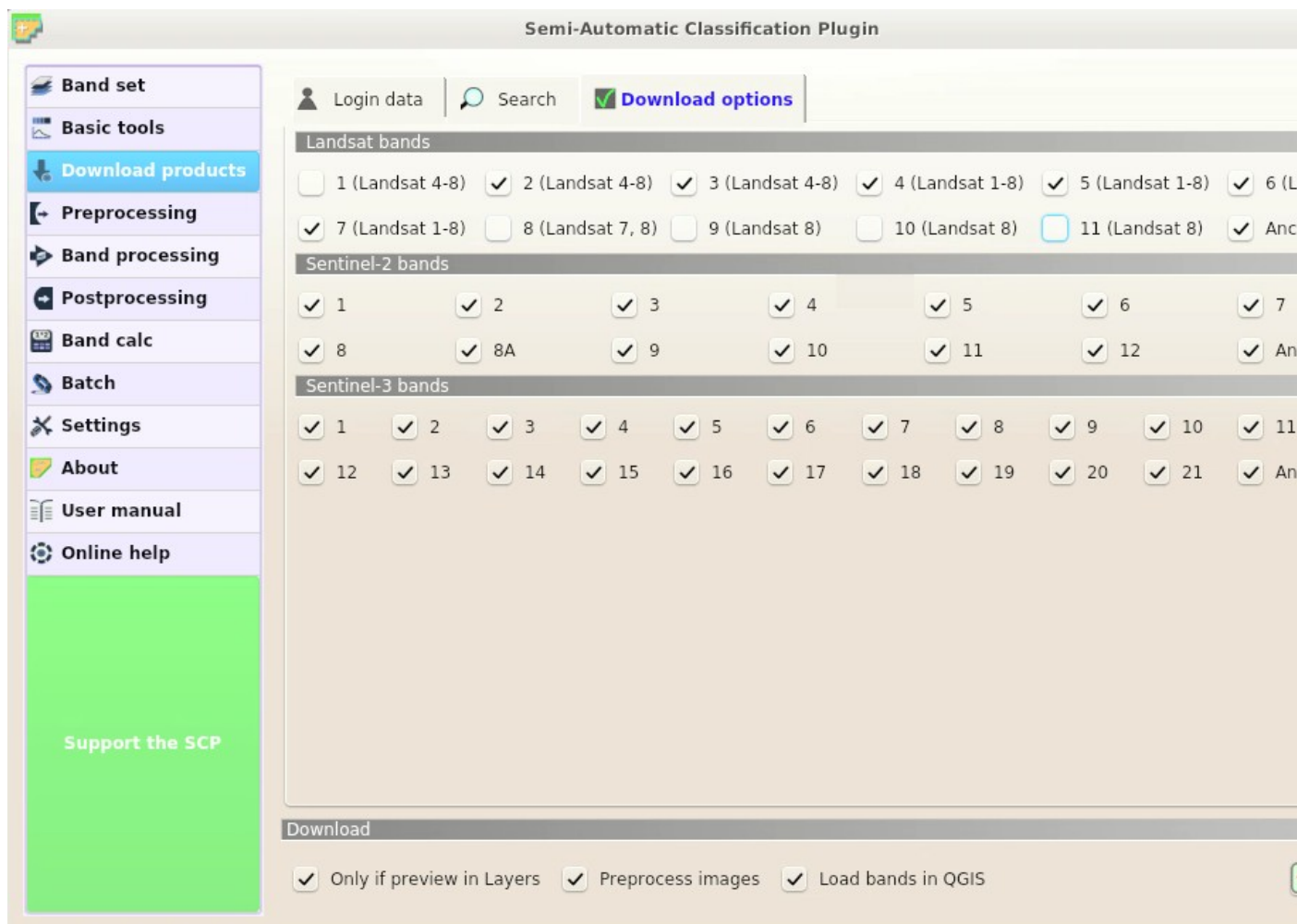


Fig. 4: Download options



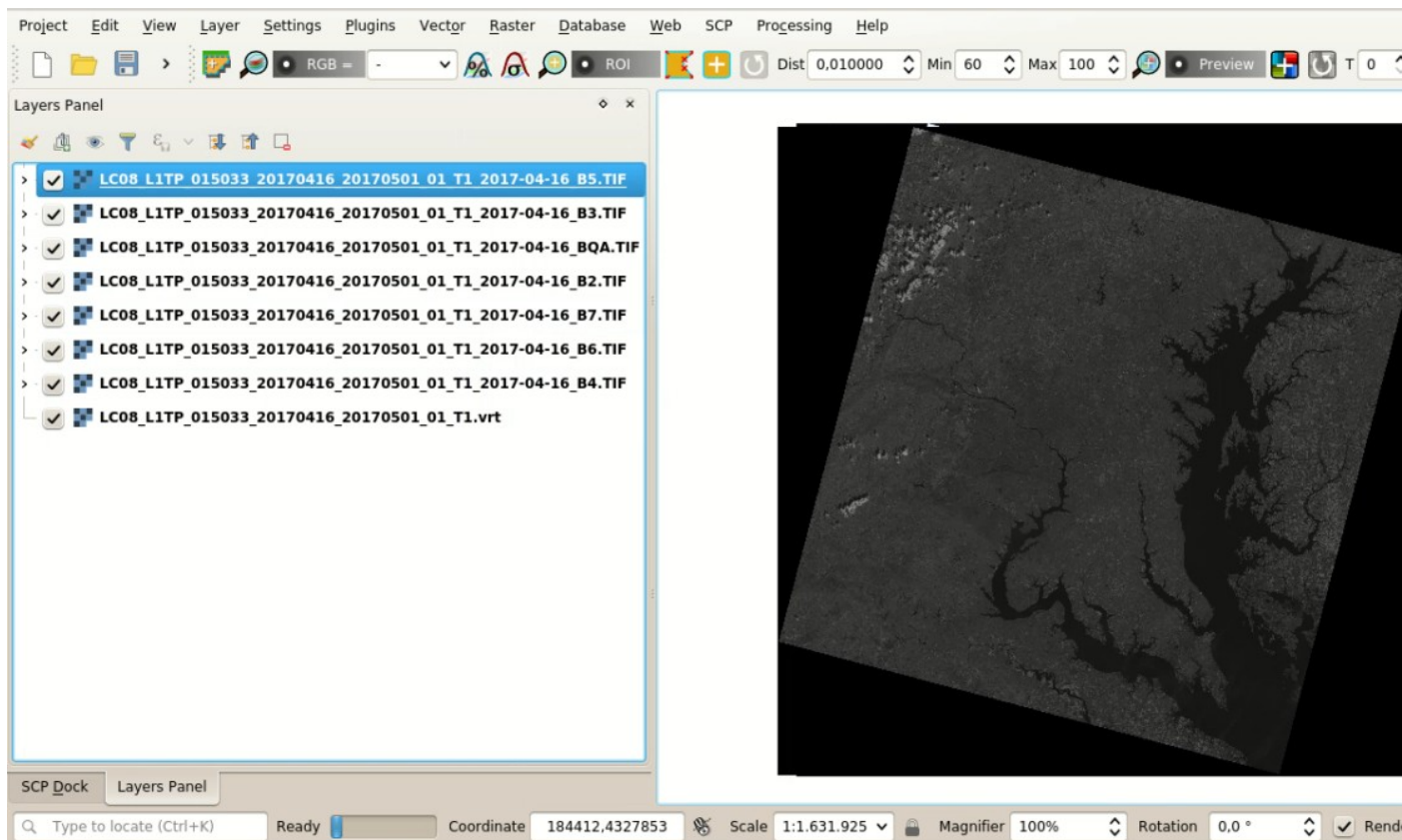


Fig. 5: Download of Landsat bands

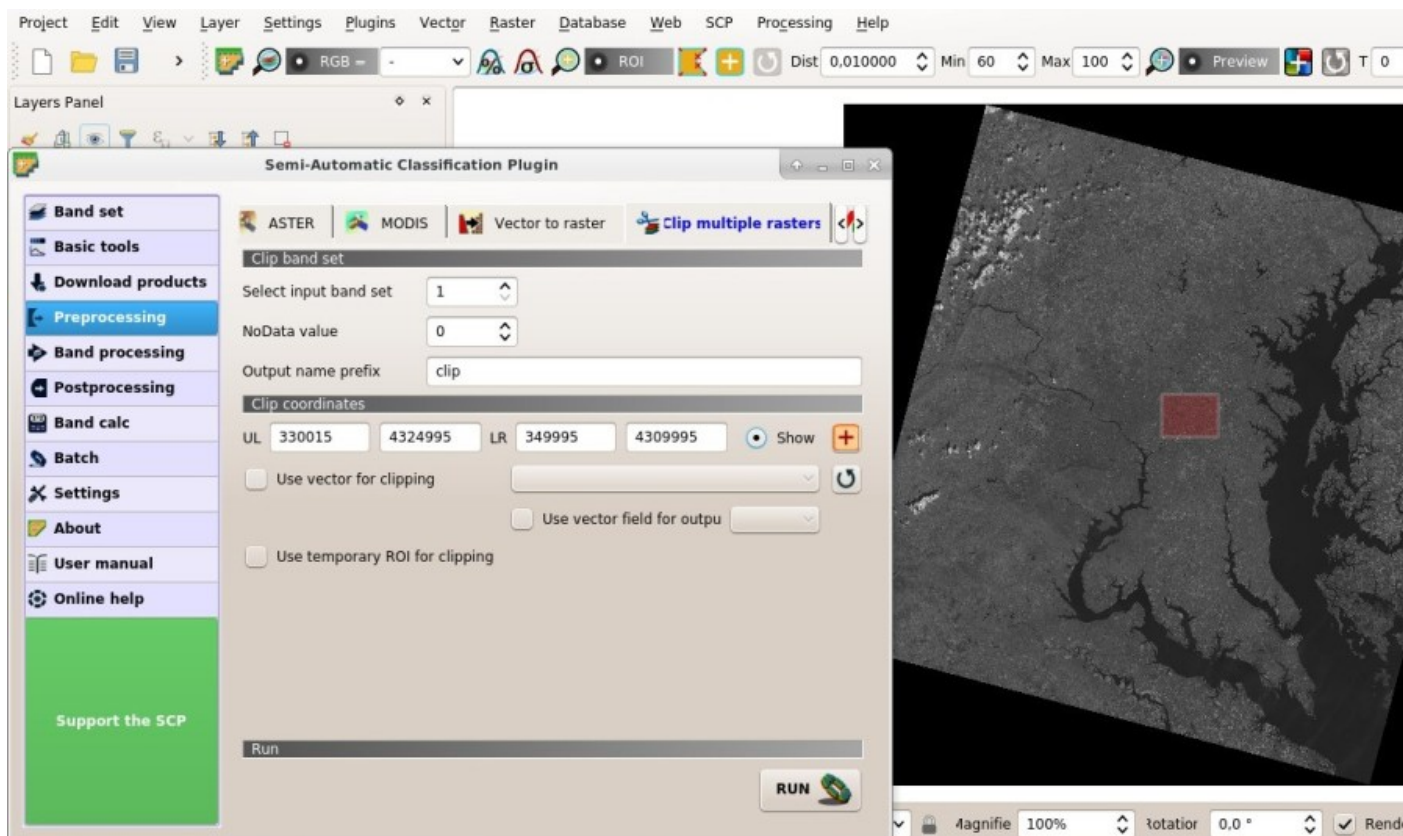


Fig. 6: Band set for clipping

- LR: 349995 / 4309995

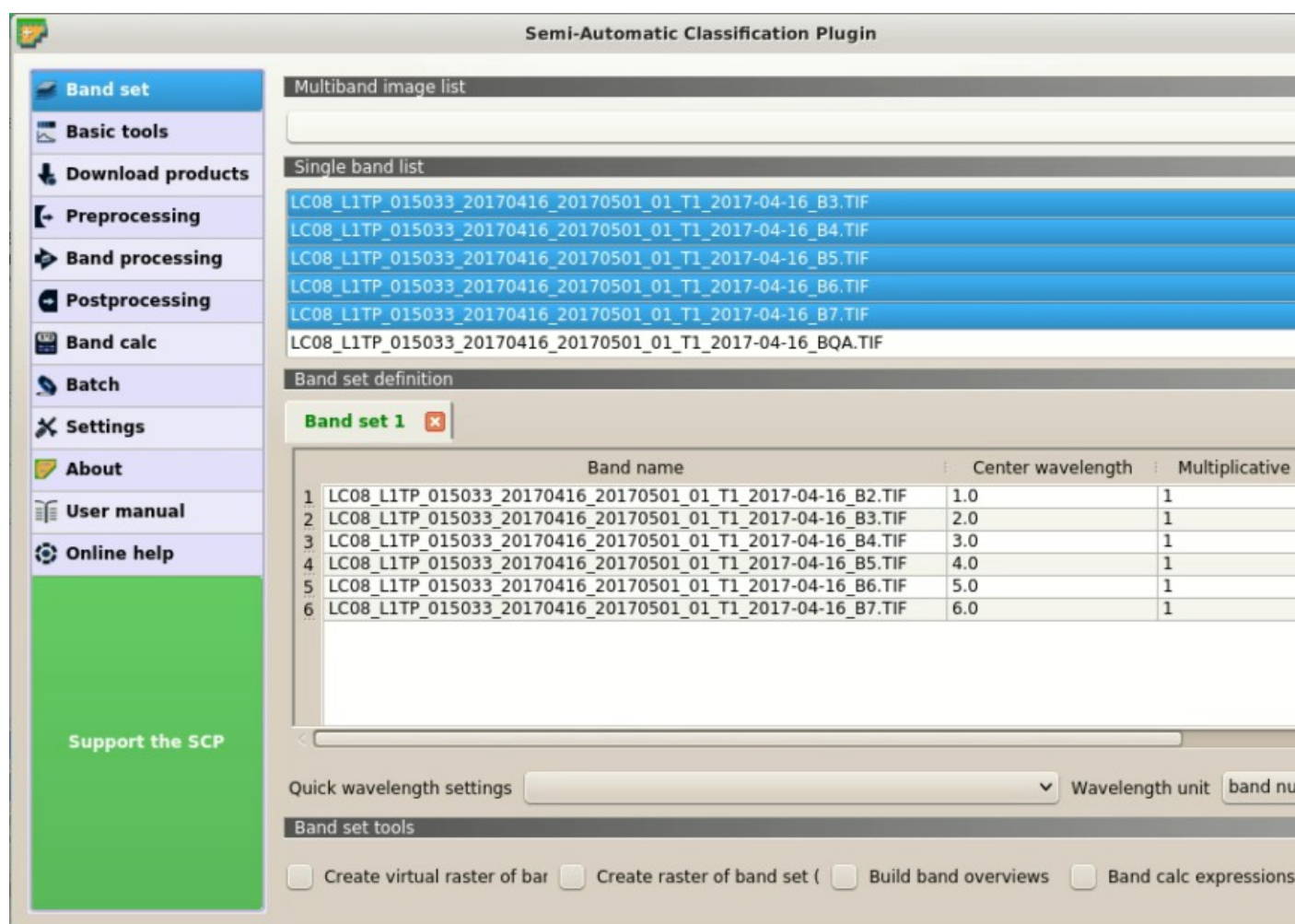





Fig. 7: Clip area

Click the button  and select a directory where clipped bands are saved. New files will be created with the file name prefix defined in *Output name prefix*. When the process is completed, clipped rasters are loaded and displayed.

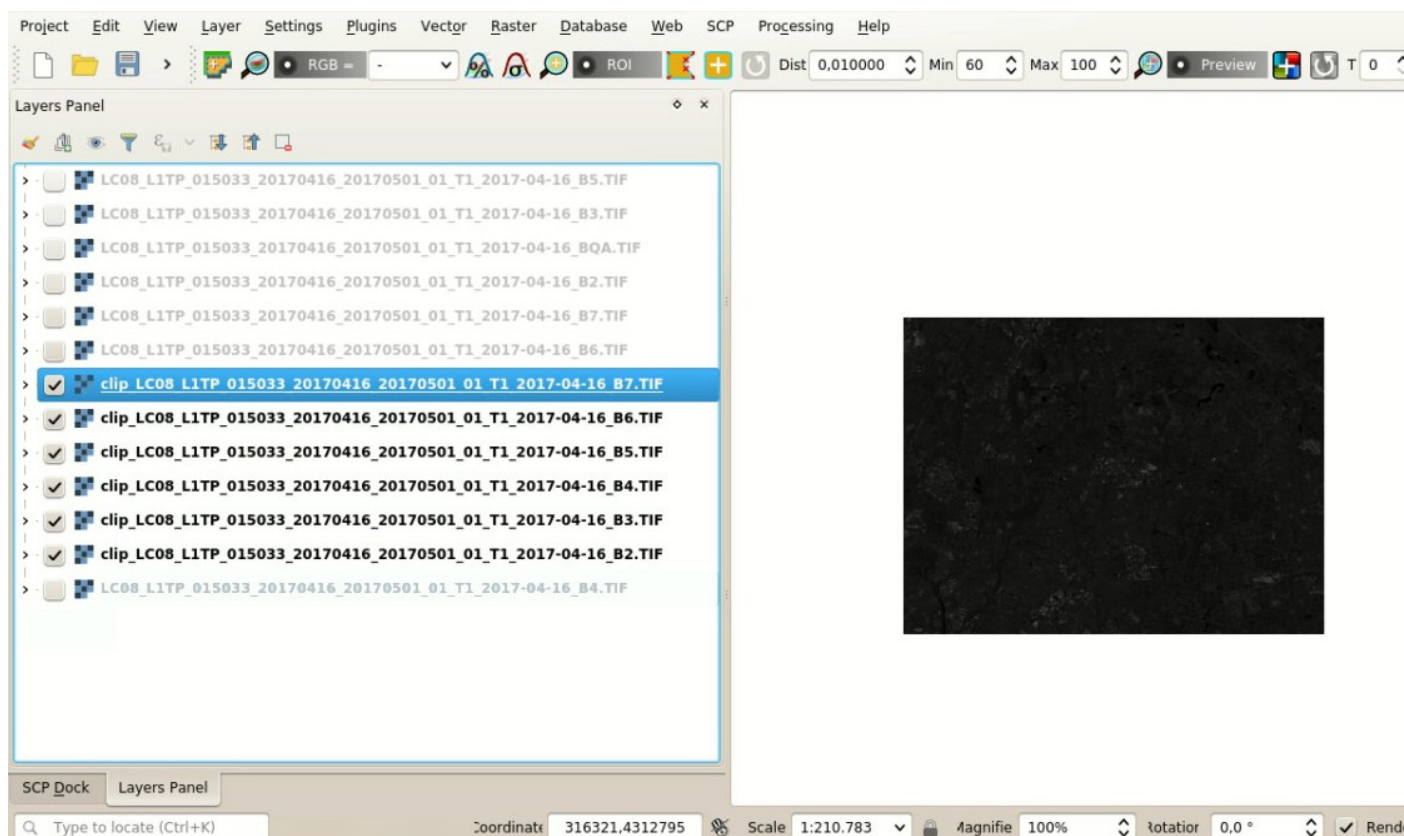
## Convert Data to Surface Reflectance

Conversion to reflectance (see *Radiance and Reflectance* (page 112)) can be performed automatically. The metadata file (a .txt file whose name contains MTL) downloaded with the images contains the required information for the conversion. Read *Image conversion to reflectance* (page 131) for information about the *Top Of Atmosphere (TOA) Reflectance* (page 131) and *Surface Reflectance* (page 132).

In order to convert bands to reflectance, open the *Preprocessing* (page 56) clicking the button  in the *SCP menu* (page 21) or the *SCP dock* (page 23), and select the tab *Landsat* (page 56).

Click the button *Directory containing Landsat bands*  and select the directory of clipped Landsat bands. The list of bands is automatically loaded in the table *Metadata* (page 57).

Click the button *Select MTL file*  and select the metadata file LC08\_L1TP\_015033\_20170416\_20170501\_01\_T1\_MTL.txt from the directory of downloaded

Fig. 8: *Clipped bands*


Landsat images. Metadata information is added to the table *Metadata* (page 57).

In order to calculate *Surface Reflectance* (page 132) we are going to apply the *DOS1 Correction* (page 132);

therefore, enable the option ☒ *Apply DOS1 atmospheric correction*.

**TIP** : In general, it is recommended to perform the DOS1 atmospheric correction for the entire image (before clipping the image) in order to improve the calculation of parameters based on the image.


For the purpose of this tutorial, uncheck the option ☒ *Create Band set and use Band set tools* because we are going to define this in the following step *Define the Band set and create the Training Input File* (page 147).


In order to start the conversion process, click the button *RUN*  and select the directory where converted bands are saved.

After a few minutes, converted bands are loaded and displayed (file name beginning with RT\_). If ☒ *Play sound when finished* is checked in *Classification process* (page 94) settings, a sound is played when the process is finished.

We can remove all the bands loaded in QGIS layers except the ones whose name begin with RT\_.

## Define the Band set and create the Training Input File

Now we need to define the *Band set* which is the input image for *SCP*. Open the tab *Band set* (page 37) clicking the button  in the *SCP menu* (page 21) or the *SCP dock* (page 23).

In *Band set definition* click the button  to clear all the bands from *active band set* created during the previous



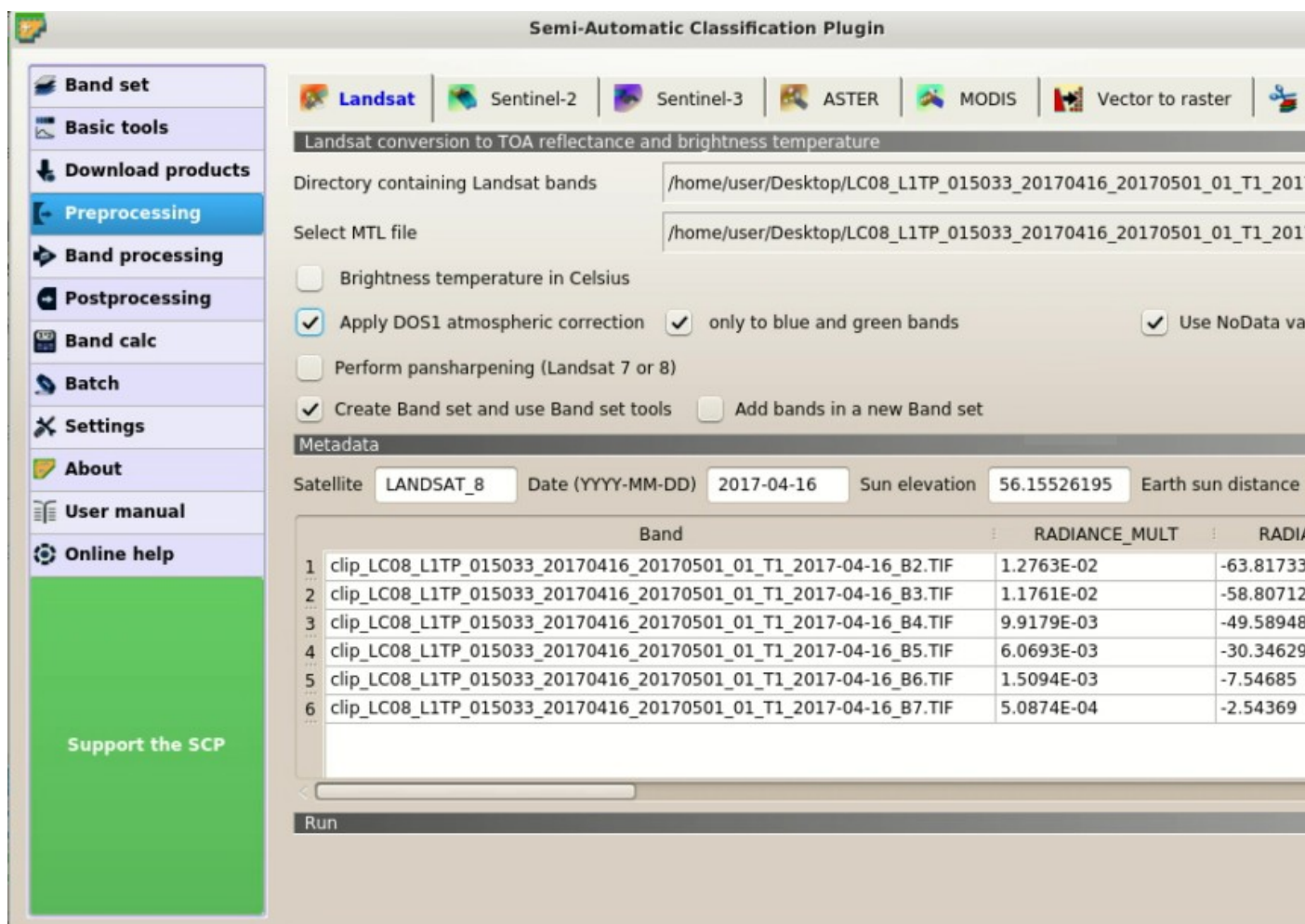
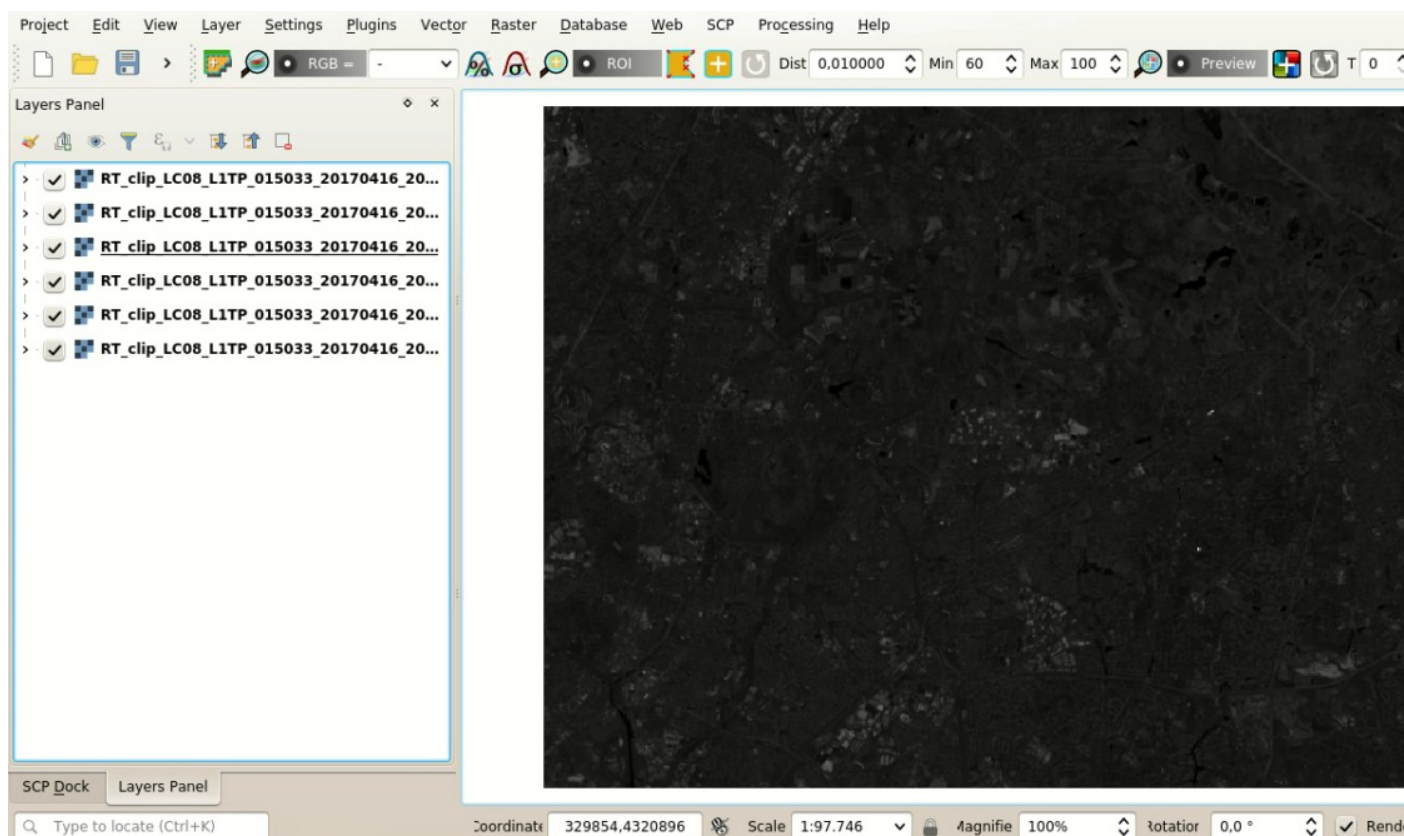





Fig. 9: Landsat 8 conversion to reflectance

Fig. 10: *Converted Landsat 8 bands*

steps.


Click the button  to refresh the layer list, and select all the converted bands; then click  to add selected rasters to the *Band set*.

In the table *Band set definition* order the band names in ascending order (click  to sort bands by name automatically). Finally, select *Landsat 8 OLI* from the list *Quick wavelength settings*, in order to set automatically the *Center wavelength* of each band and the *Wavelength unit* (required for spectral signature calculation).

We can display a *Color Composite* (page 116) of bands: Near-Infrared, Red, and Green: in the *Working toolbar* (page 34), click the list *RGB=* and select the item 4-3-2 (corresponding to the band numbers in *Band set* (page 37)). You can see that image colors in the map change according to the selected bands, and vegetation is highlighted in red (if the item 3-2-1 was selected, natural colors would be displayed).

**TIP :** If a *Band set* (page 37) is defined, a temporary virtual raster (named Virtual Band Set 1) is created automatically, which allows for the display of *Color Composite* (page 116). In order to speed up the visualization, you can show only the virtual raster and hide all the layers in the QGIS Layers.

Now we need to create the *Training input* (page 24) in order to collect *Training Areas* (page 117) (ROIs) and calculate the *Spectral Signature* (page 112) thereof (which are used in classification).

In the *SCP dock* (page 23) select the tab *Training input* (page 24) and click the button  to create the *Training input* (define a name such as `training.scp`). The path of the file is displayed and a vector is added to QGIS layers with the same name as the *Training input* (in order to prevent data loss, you should not edit this layer using QGIS functions).

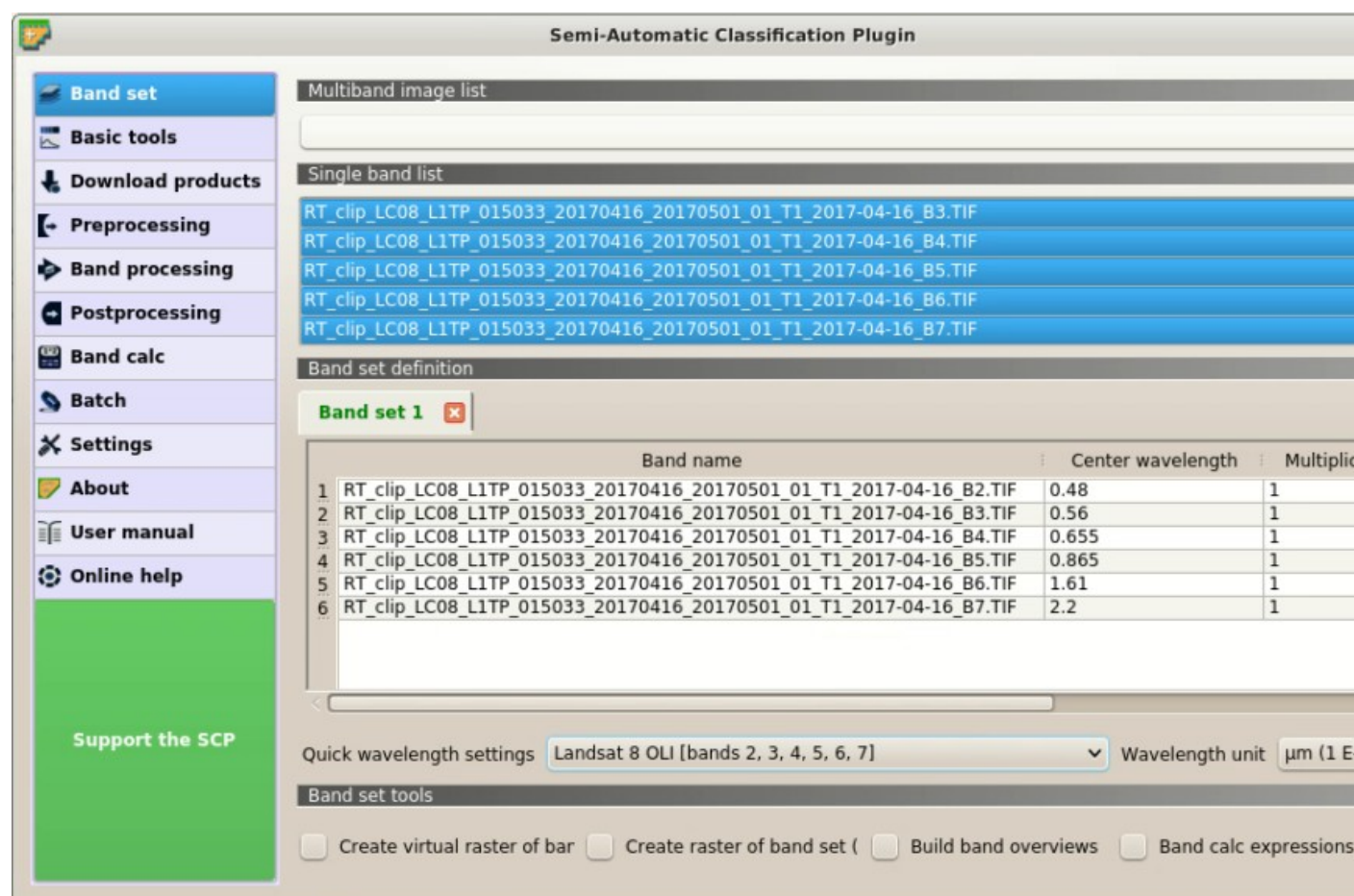


Fig. 11: Definition of a band set



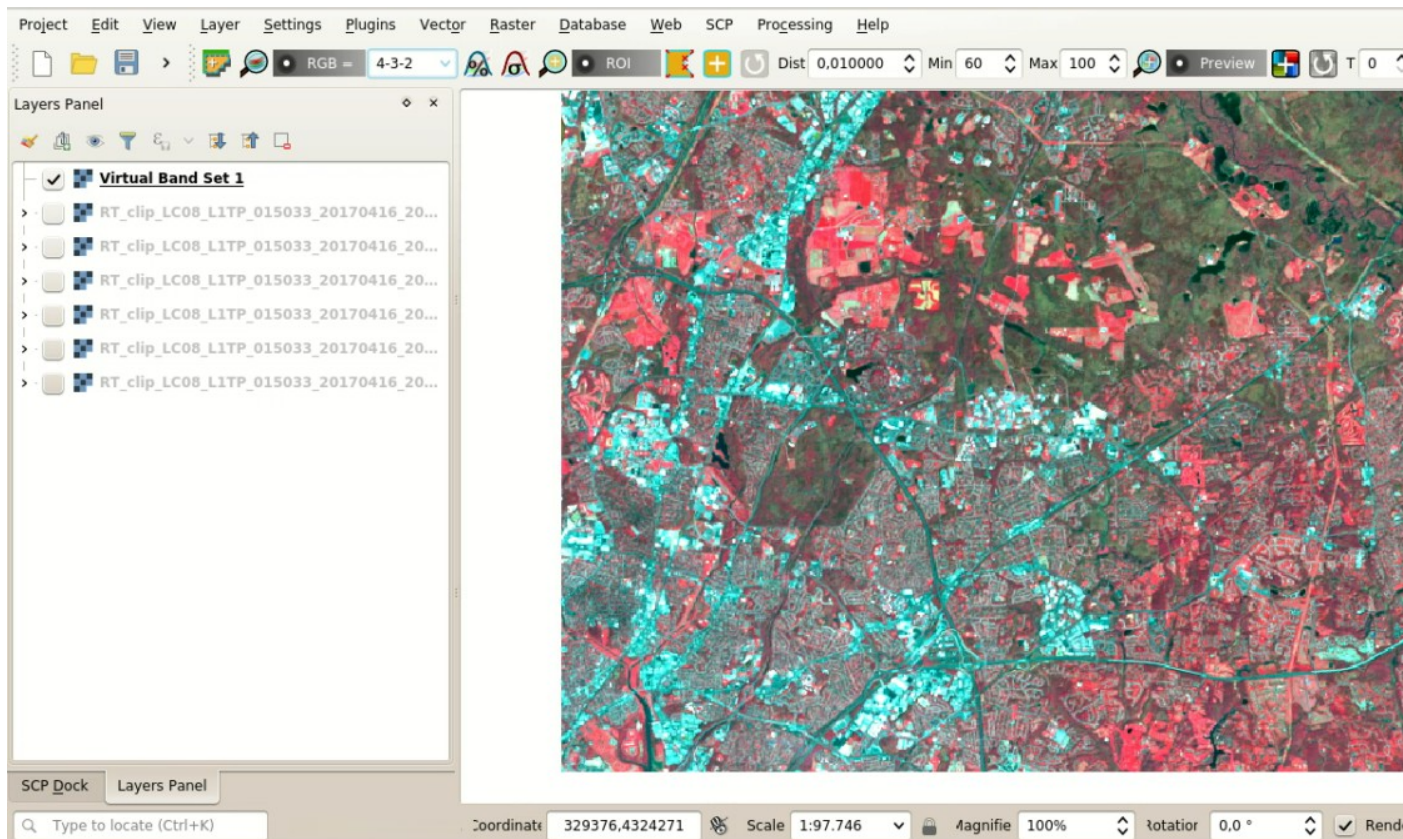


Fig. 12: Color composite RGB=4-3-2

## Create the ROIs

We are going to create ROIs defining the *Classes and Macroclasses* (page 118). Each ROI is identified by a Class ID (i.e. C ID), and each ROI is assigned to a land cover class through a Macroclass ID (i.e. MC ID).


Macroclasses are composed of several materials having different spectral signatures; in order to achieve good classification results we should separate spectral signatures of different materials, even if belonging to the same macroclass. Thus, we are going to create several ROIs for each macroclass (setting the same *MC ID*, but assigning a different *C ID* to every ROI).

We are going to use the Macroclass IDs defined in the following table.

### Macroclasses

| Macroclass name            | Macroclass ID |
|----------------------------|---------------|
| Water                      | 1             |
| Built-up                   | 2             |
| Vegetation                 | 3             |
| Bare soil (low vegetation) | 4             |

ROIs can be created by manually drawing a polygon or with an automatic region growing algorithm.

Zoom in the map over the dark area in the upper right corner of the image which is a water body. In order to create manually a ROI inside the dark area, click the button  in the *Working toolbar* (page 34). Left click on the map to define the ROI vertices and right click to define the last vertex closing the polygon. An orange semi-transparent polygon is displayed over the image, which is a temporary polygon (i.e. it is not saved in the *Training input*).

**TIP :** You can draw temporary polygons (the previous one will be overridden) until the shape covers the intended area.





Fig. 13: *Definition of Training input in SCP*

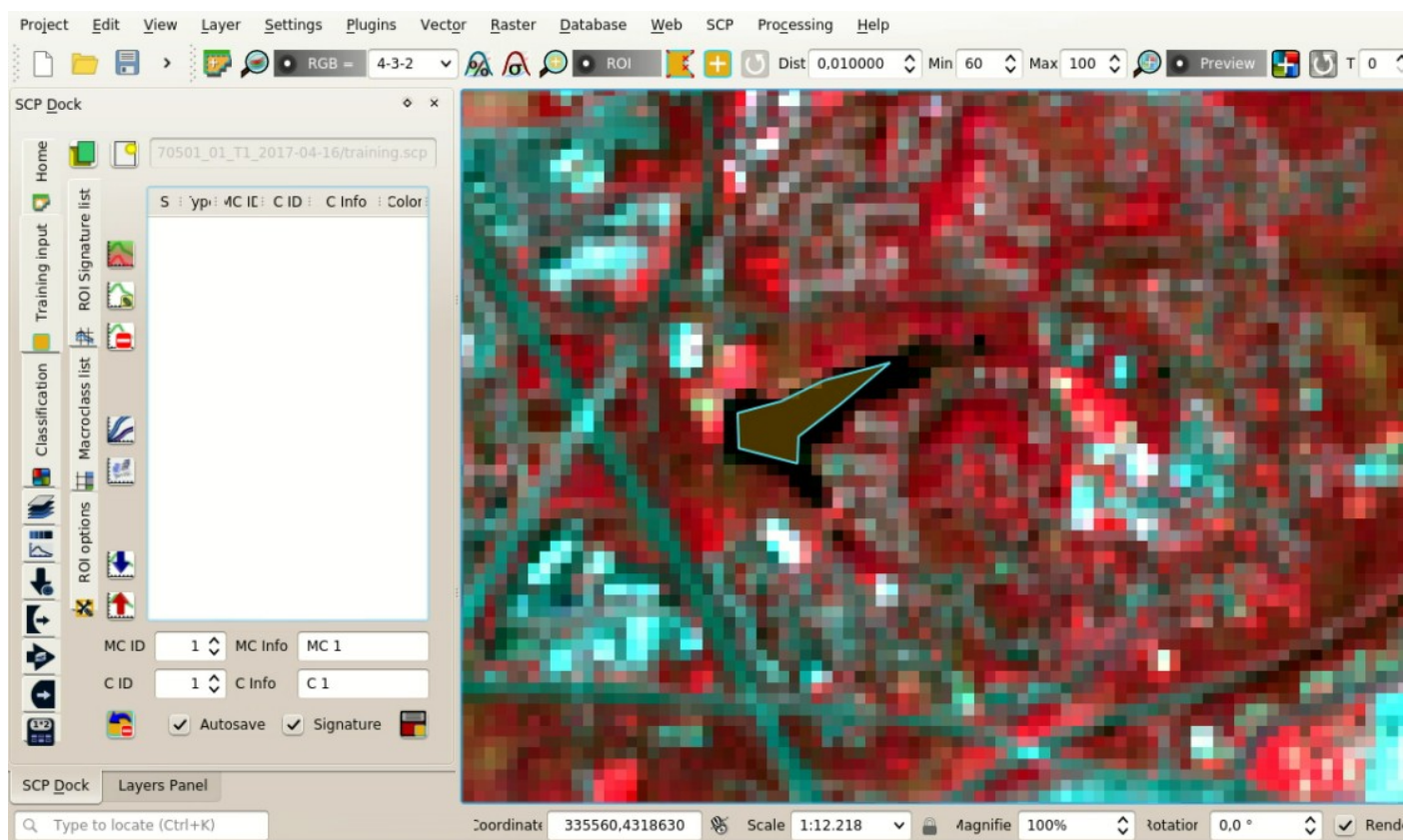




Fig. 14: A temporary ROI created manually


If the shape of the temporary polygon is good we can save it to the *Training input*.

Open the *Training input* (page 24) to define the *Classes and Macroclasses* (page 118). In the *ROI Signature list* (page 27) set *MC ID* = 1 and *MC Info* = Water; also set *C ID* = 1 and *C Info* = Lake. Now click  to save the ROI in the *Training input*.

After a few seconds, the ROI is listed in the *ROI Signature list* (page 27) and the spectral signature is calculated (because  *Signature* was checked).

As you can see, the *C ID* in *ROI Signature list* (page 27) is automatically increased by 1. Saved ROI is displayed as a dark polygon in the map and the temporary ROI is removed. Also, in the *ROI Signature list* (page 27) you can notice that the *Type* is *B*, meaning that the ROI spectral signature was calculated and saved in the *Training input*.

You can also see in the tab *Macroclasses* (page 28) that the first macroclass has been added to the table *Macroclasses*.

Now we are going to create a second ROI for the built-up class using the automatic region growing algorithm. Zoom in the lower region of the image. In *Working toolbar* (page 34) set the *Dist* value to 0.08. Click the  button in the *Working toolbar* (page 34) and click over the purple area of the map. After a while the orange semi-transparent polygon is displayed over the image.

**TIP** : *Dist* value should be set according to the range of pixel values; in general, increasing this value creates larger ROIs.

In the *ROI Signature list* (page 27) set *MC ID* = 2 and *MC Info* = Built-up; also set *C ID* = 2 (it should be already set) and *C Info* = Buildings.

Again, the *C ID* in *ROI Signature list* (page 27) is automatically increased by 1.

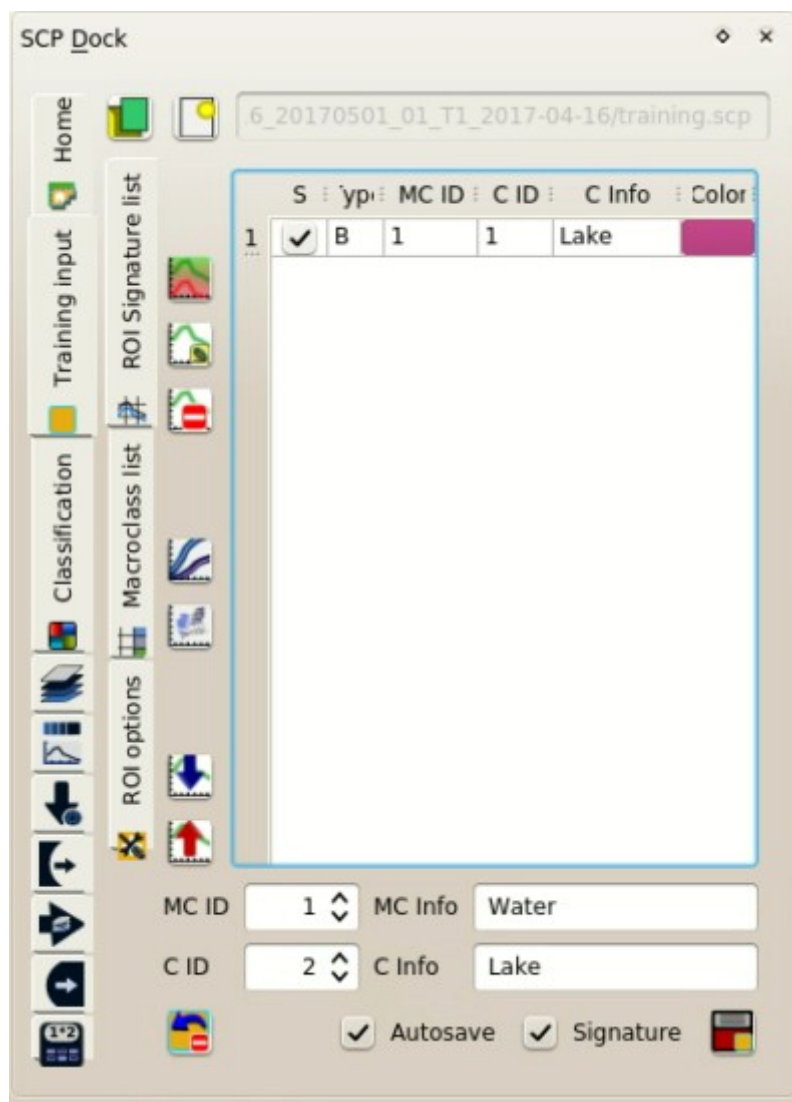
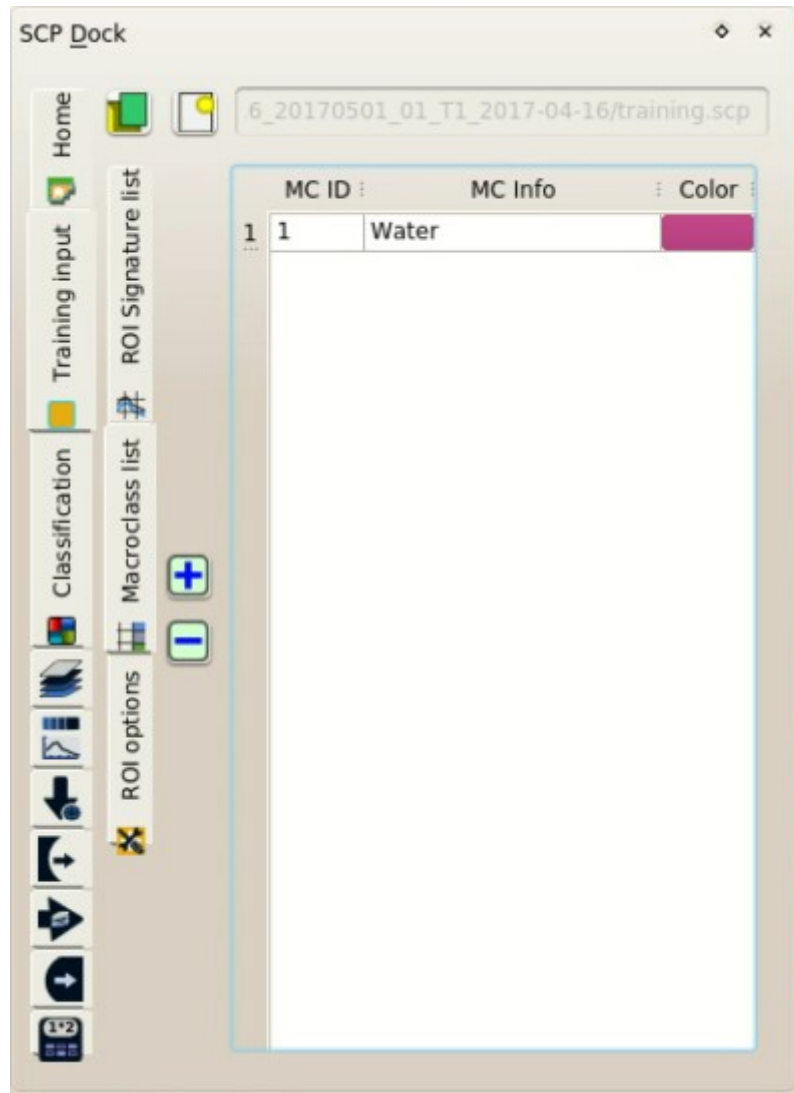


Fig. 15: The ROI saved in the Training input

Fig. 16: *Macroclasses*

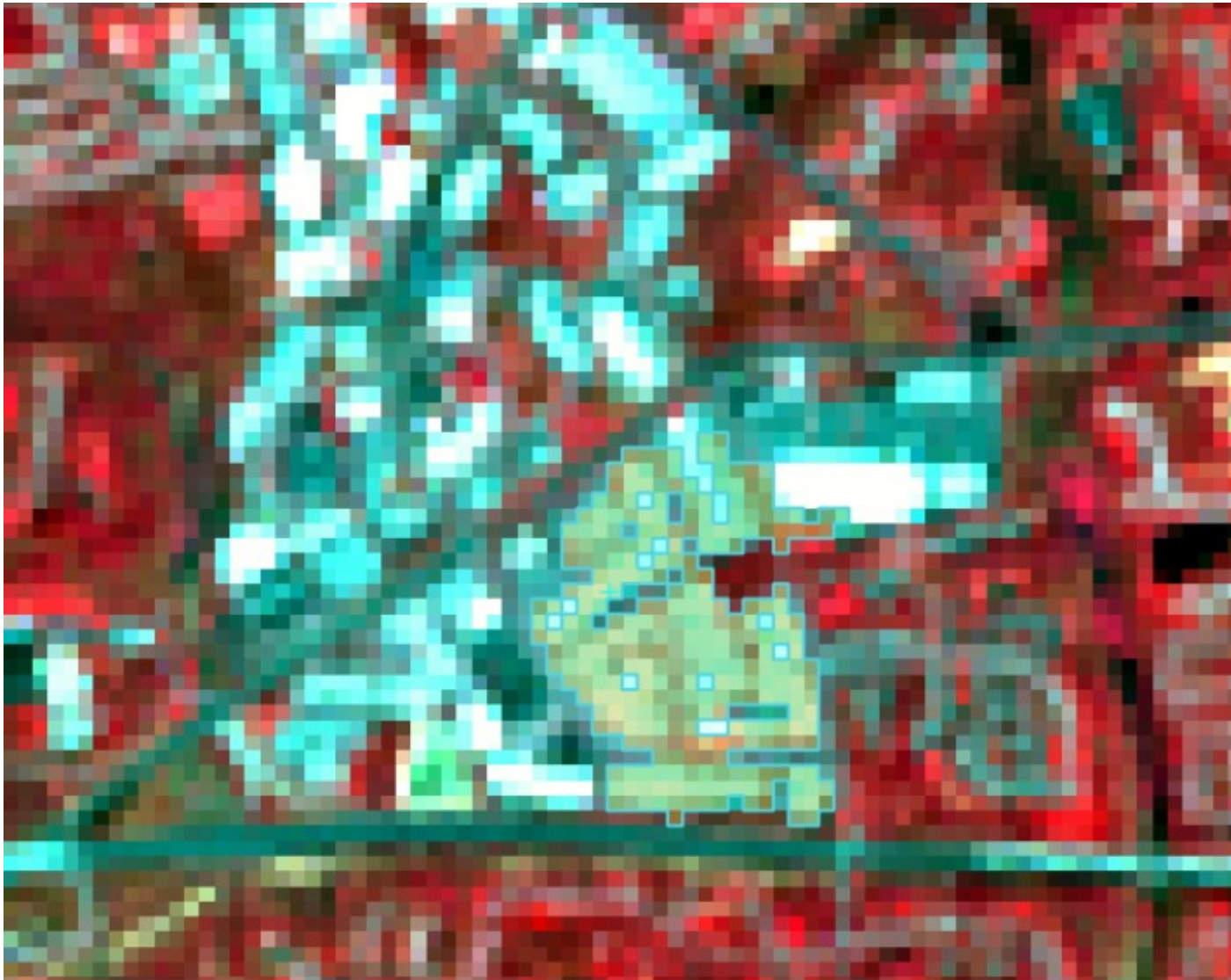


Fig. 17: A temporary *ROI* created with the automatic region growing algorithm



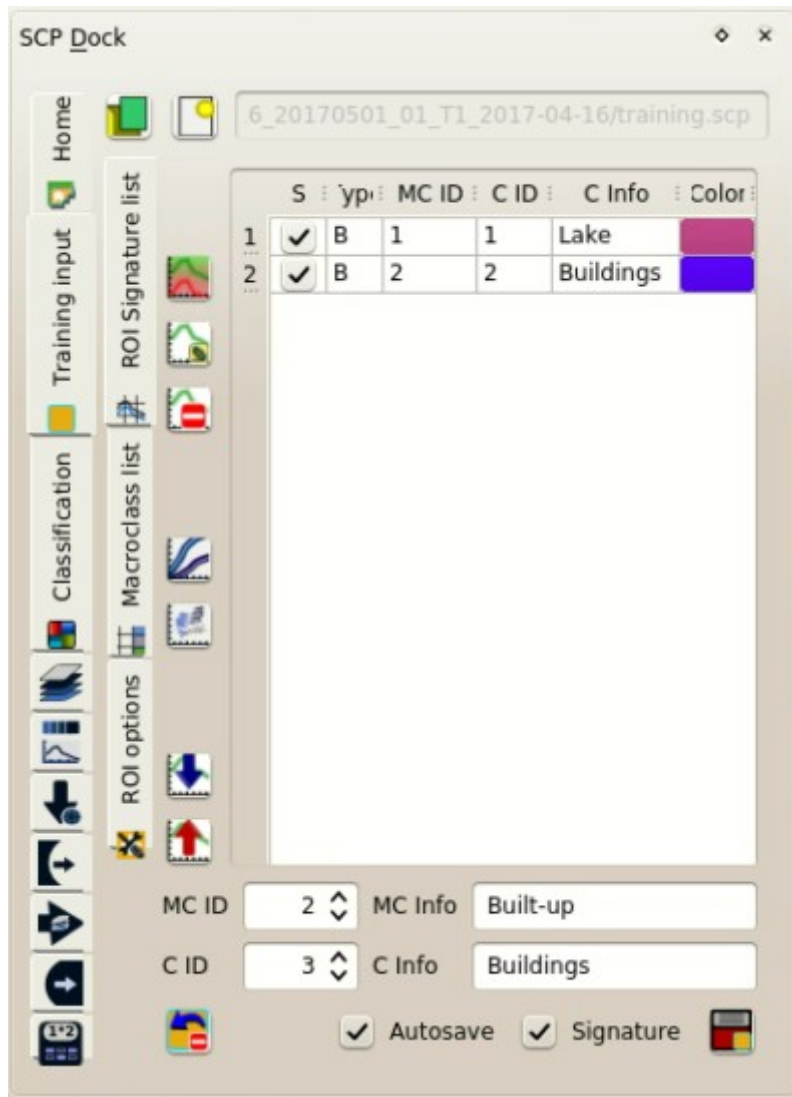




Fig. 18: The ROI saved in the Training input

After clicking the button  in the *Working toolbar* (page 34) you should notice that the cursor in the map displays a value changing over the image. This is the NDVI value of the pixel beneath the cursor (NDVI is displayed because the function  *Display* is checked in *Training input* (page 24)). The NDVI value can be useful for identifying spectrally pure pixels, in fact vegetation has higher NDVI values than soil.

For instance, move the mouse over a vegetation area and left click to create a ROI when you see a local maximum value. This way, the created ROI and the spectral signature thereof will be particularly representative of healthy vegetation.



Fig. 19: NDVI value of vegetation pixel displayed in the map. Color composite RGB = 4-3-2

Create a ROI for the class Vegetation (red pixels in color composite RGB=4-3-2) and a ROI for the class Bare soil (low vegetation) (green pixels in color composite RGB=4-3-2) following the same steps described previously. The following images show a few examples of these classes identified in the map.



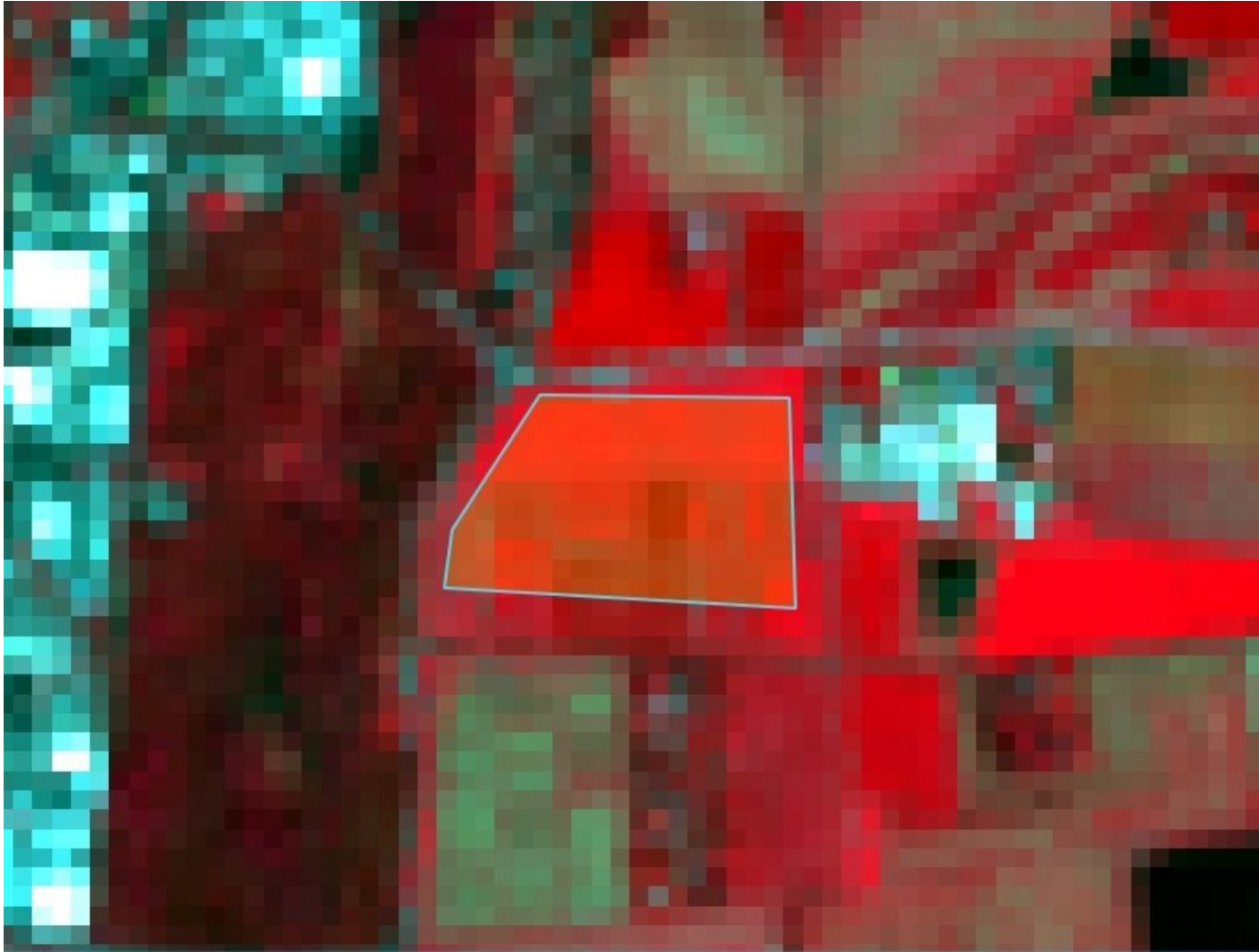


Fig. 20: *Vegetation. Color composite RGB = 4-3-2*




Fig. 21: *Bare soil (low vegetation). Color composite RGB = 4-3-2*

## Assess the Spectral Signatures

Spectral signatures are used by *Classification Algorithms* (page 118) for labelling image pixels. Different materials may have similar spectral signatures (especially considering multispectral images) such as built-up and soil. If spectral signatures used for classification are too similar, pixels could be misclassified because the algorithm is unable to discriminate correctly those signatures. Thus, it is useful to assess the *Spectral Distance* (page 124) of signatures to find similar spectral signatures that must be removed. Of course the concept of distance vary according to the algorithm used for classification.

One can simply assess spectral signature similarity by displaying a signature plot. In order to display the signature plot, in the *ROI Signature list* (page 27) highlight two or more spectral signatures (with click in the table), then

click the button . The *Spectral Signature Plot* (page 98) is displayed in a new window. Move and zoom inside the *Plot* (page 100) to see if signatures are similar (i.e. very close). Double click the color in the *Plot Signature list* (page 98) to change the line color in the plot.

We can see in the following figure a signature plot of different materials.

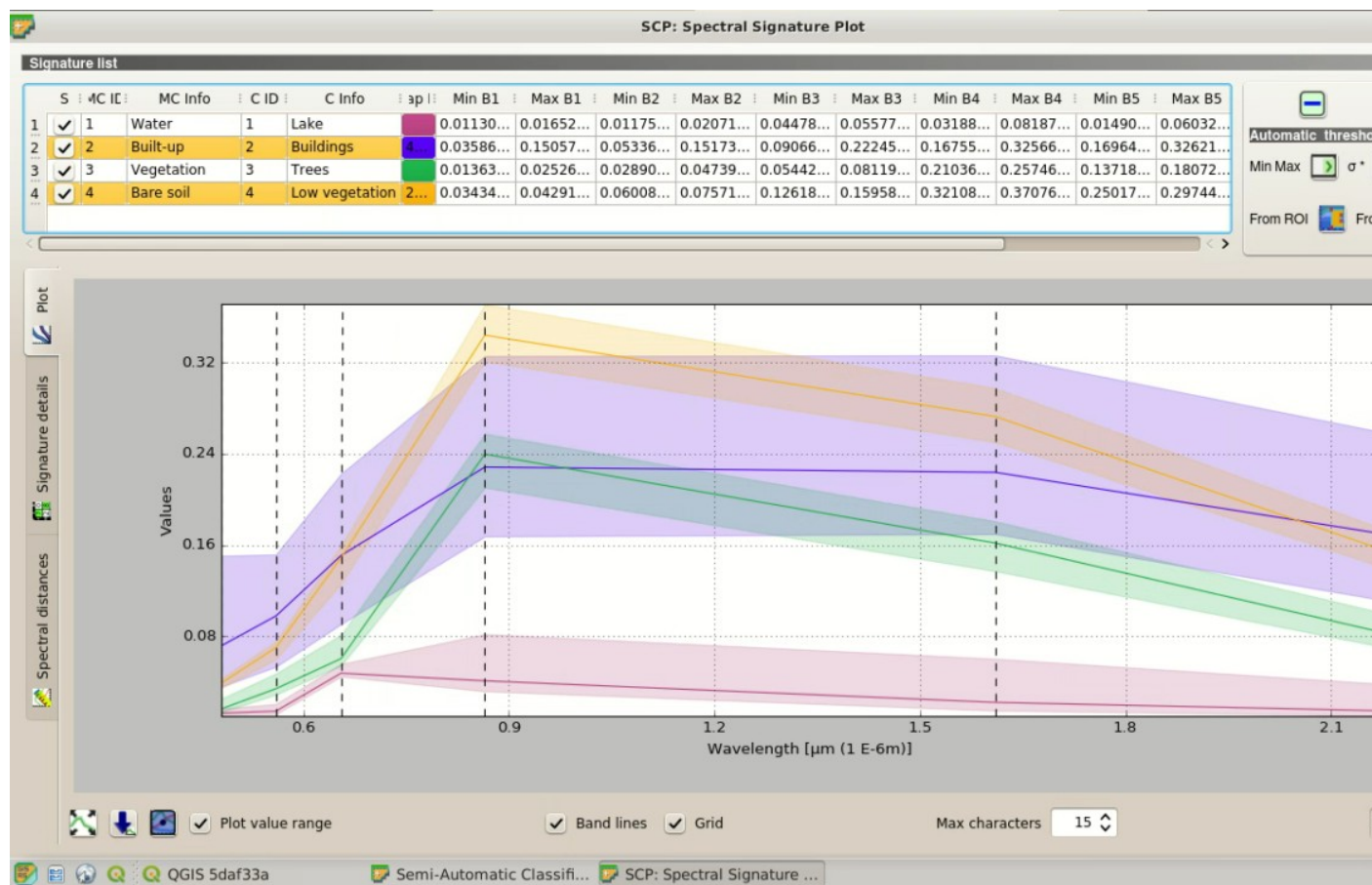



Fig. 22: *Spectral plot*

In the plot we can see the line of each signature (with the color defined in the *ROI Signature list* (page 27)), and the spectral range (minimum and maximum) of each band (i.e. the semi-transparent area colored like the signature line). The larger is the semi-transparent area of a signature, the higher is the standard deviation, and therefore the heterogeneity of pixels that composed that signature. Spectral similarity between spectral signatures is highlighted in orange in the *Plot Signature list* (page 98).

Additionally, we can calculate the spectral distances of signatures (for more information see *Spectral Distance* (page 124)). Highlight two or more spectral signatures with click in the table *Plot Signature list* (page 98), then

click the button ; distances will be calculated for each pair of signatures. Now open the tab *Spectral distances* (page 101); we can notice that similarity between signatures vary according to considered algorithm.

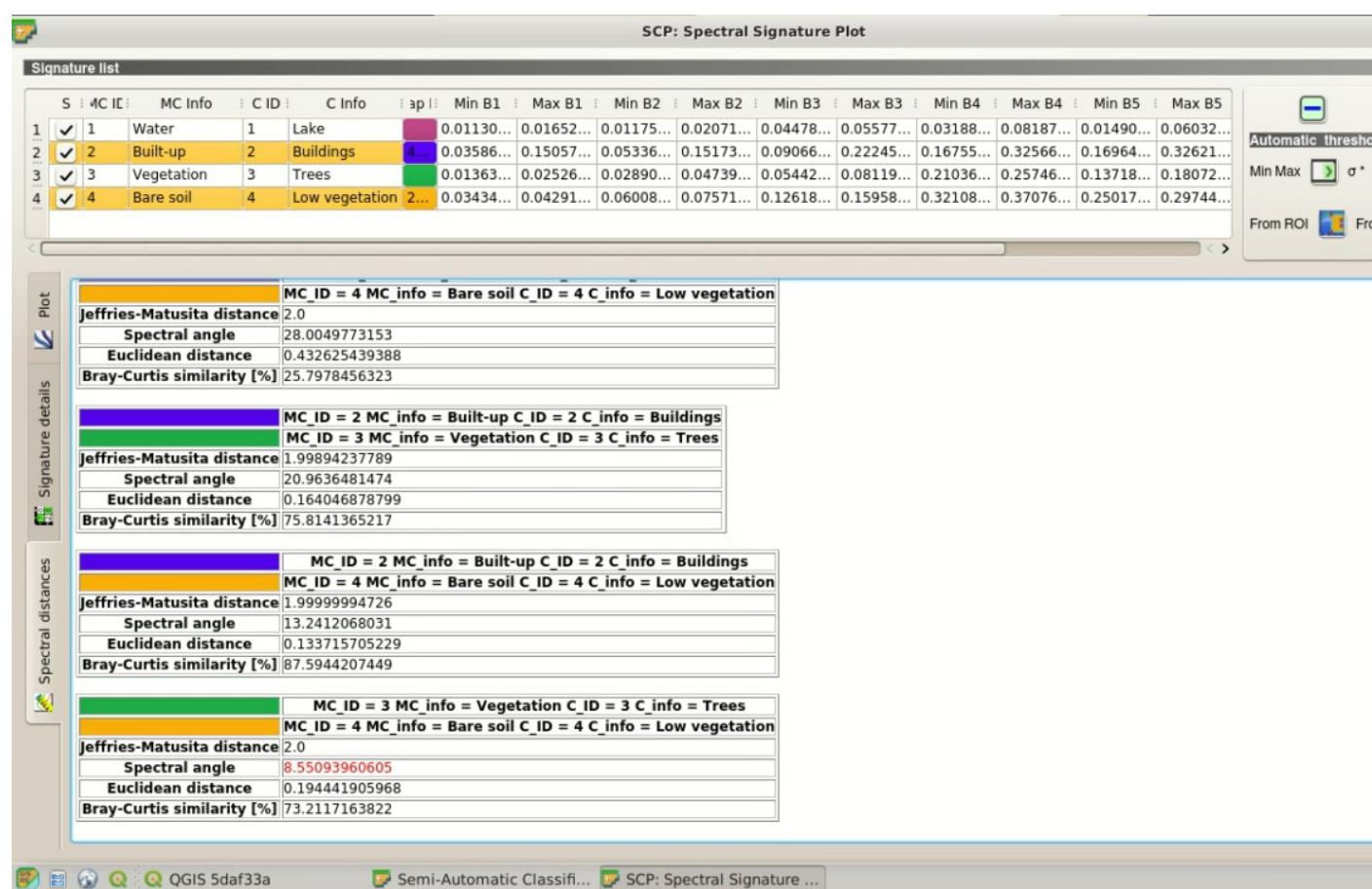


Fig. 23: Spectral distances



For instance, two signatures can be very similar for *Spectral Angle Mapping* (page 121) (very low *Spectral Angle* (page 125)), but quite distant for the *Maximum Likelihood* (page 120) (*Jeffries-Matusita Distance* (page 124) value near 2). The similarity of signatures is affected by the similarity of materials (in relation to the number of spectral bands available); also, the way we create ROIs influences the signatures.

Spectral signature values, standard deviation and other details such as the number of ROI pixels are displayed in the *Signature details* (page 101).

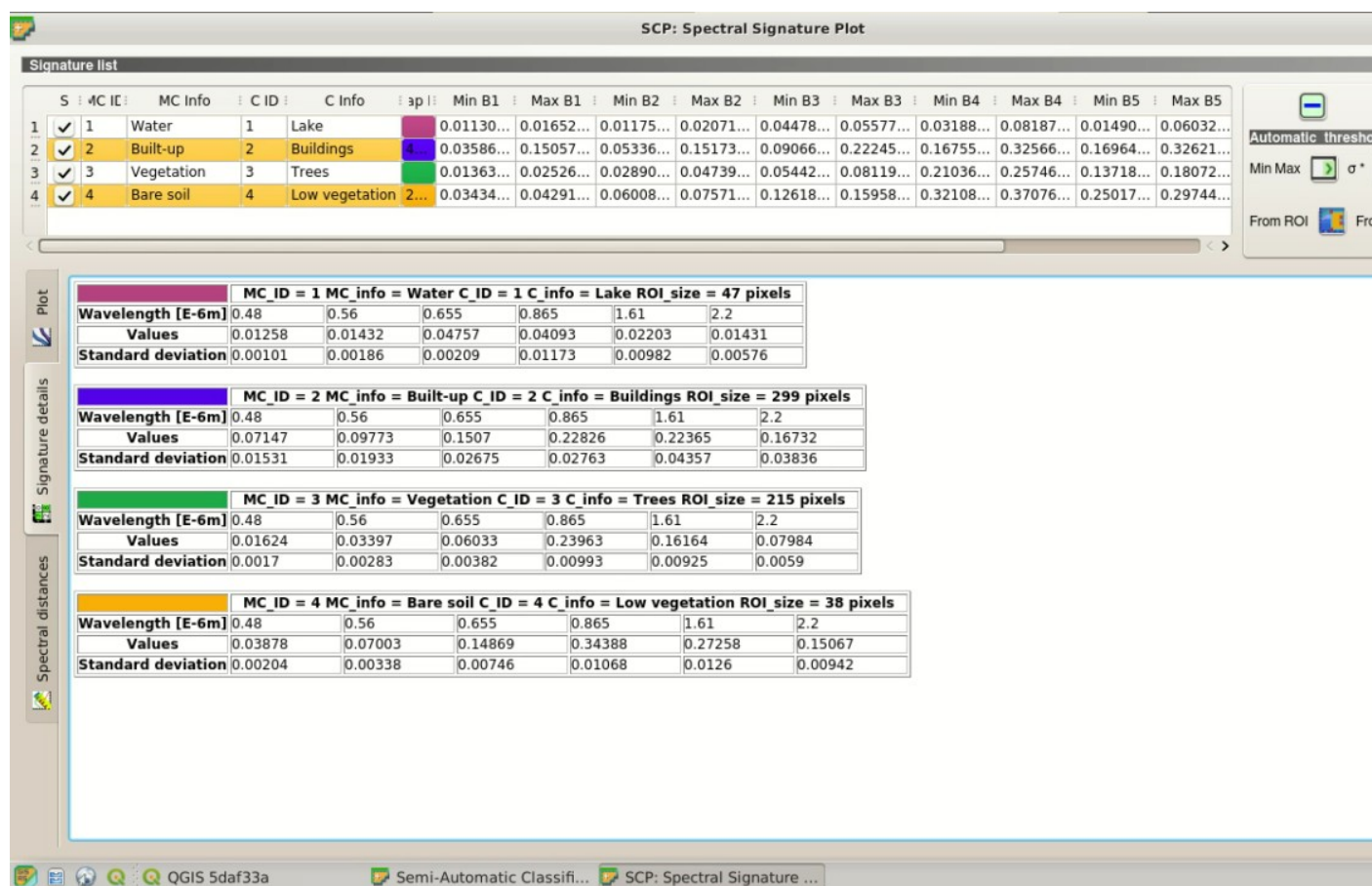




Fig. 24: Spectral signature values


We need to create several ROIs (i.e. spectral signatures) for each macroclass (repeating the steps in *Create the ROIs* (page 151)), assigning a unique C ID to each spectral signature, and assess the spectral distance thereof in order to avoid the overlap of spectral signatures belonging to different macroclasses.

In the list *RGB=* of the *Working toolbar* (page 34) type 3-4-6 (you can also use the tool *RGB list* (page 40)). Using this color composite, urban areas are purple and vegetation is green. You can notice that this color composite *RGB = 3-4-6* highlights roads more than natural color (*RGB = 3-2-1*).

The following examples display a few RGB color composites of Landsat images.

**TIP** : Change frequently the *Color Composite* (page 116) in order to clearly identify the materials at the ground; use the mouse wheel on the list *RGB=* of the *Working toolbar* (page 34) for changing the

color composite rapidly; also use the buttons  and  for better displaying the *Input image* (i.e. image stretching).

It is worth mentioning that you can show or hide the temporary ROI clicking the button  *ROI* in *Working toolbar* (page 34).

**TIP** : Install the plugin *QuickMapServices* in QGIS, and add a map (e.g. *OpenStreetMap*) in order to facilitate the identification of ROIs using high resolution data.

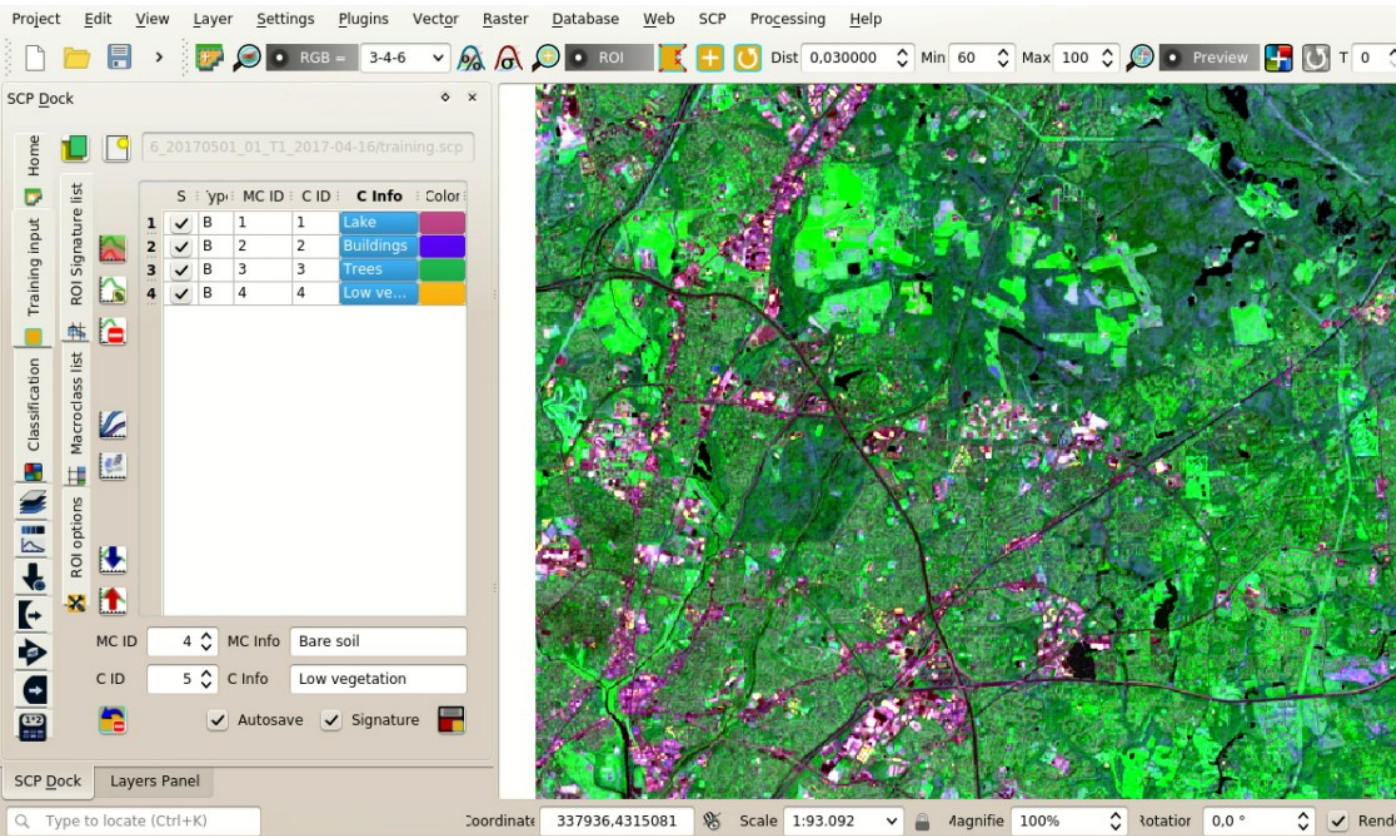


Fig. 25: Color composite RGB = 3-4-6

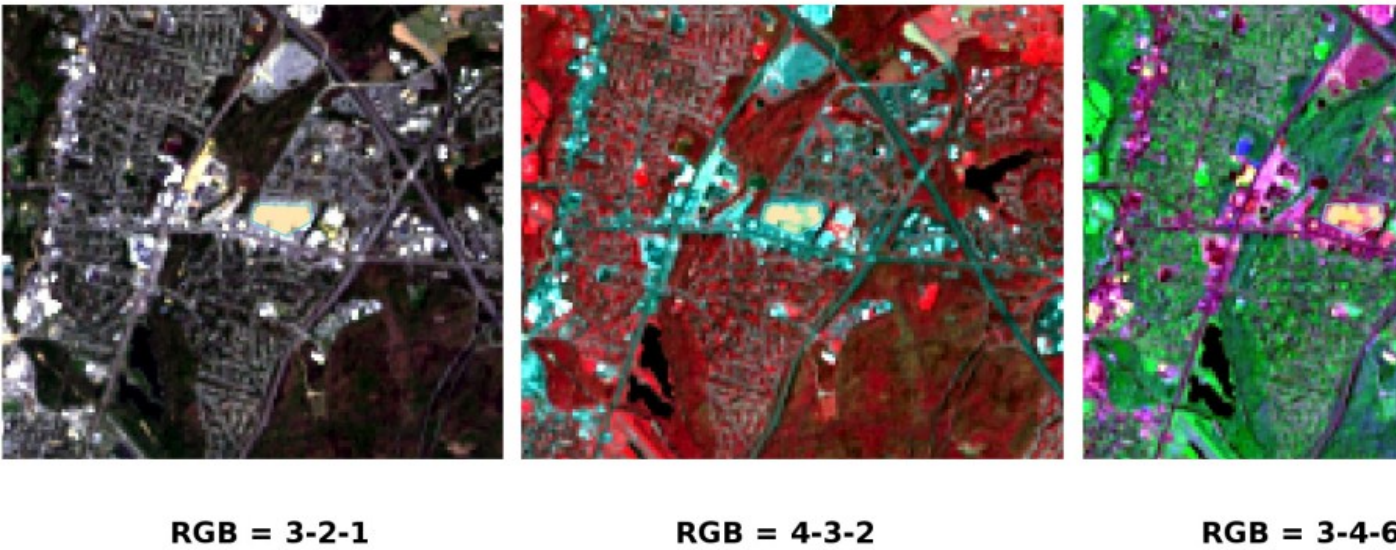


Fig. 26: Built-up ROI: large buildings

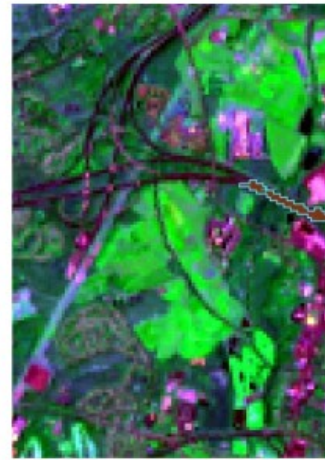




**RGB = 3-2-1**



**RGB = 4-3-2**

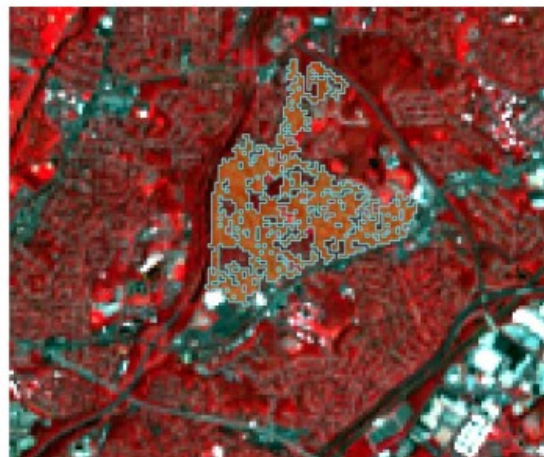


**RGB = 3-4-6**

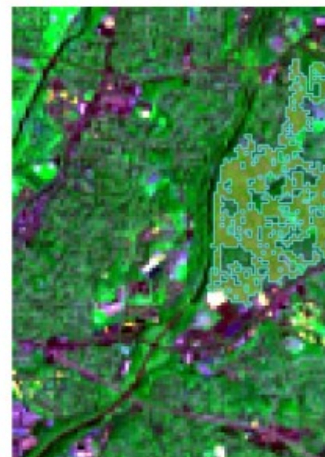
Fig. 27: *Built-up ROI: road*



**RGB = 3-2-1**



**RGB = 4-3-2**



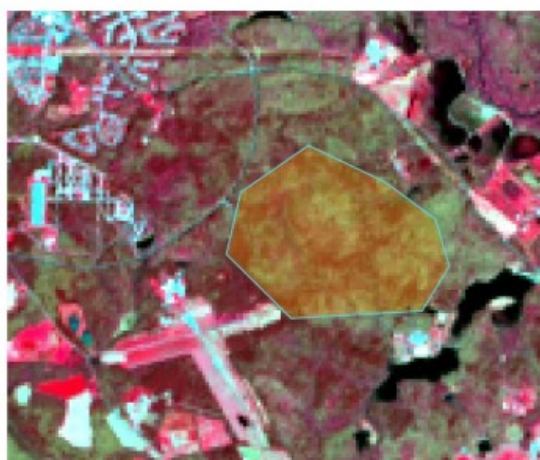
**RGB = 3-4-6**

Fig. 28: *Built-up ROI: buildings, narrow roads*





**RGB = 3-2-1**



**RGB = 4-3-2**

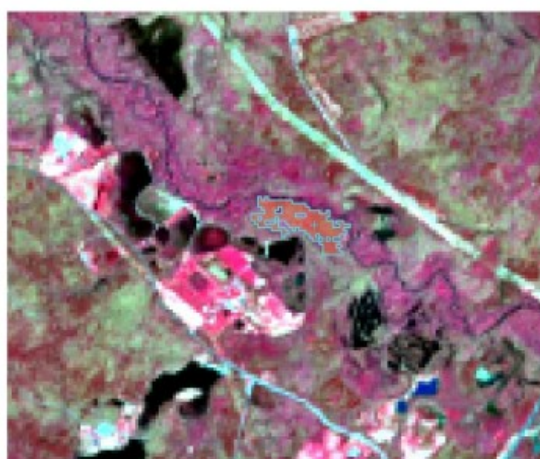


**RGB = 3-4-6**

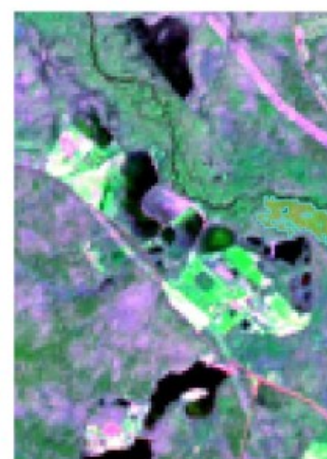
Fig. 29: *Vegetation ROI: deciduous trees*



**RGB = 3-2-1**



**RGB = 4-3-2**



**RGB = 3-4-6**

Fig. 30: *Vegetation ROI: riparian vegetation*


## Create a Classification Preview


The classification process is based on collected ROIs (and spectral signatures thereof). It is useful to create a *Classification preview* (page 35) in order to assess the results (influenced by spectral signatures) before the final classification. In case the results are not good, we can collect more ROIs to better classify land cover.



Before running a classification (or a preview), set the color of land cover classes that will be displayed in the classification raster. In the *ROI Signature list* (page 27), double click the color (in the column *Color*) of each ROI to choose a representative color of each class.

Also, we need to set the color for macroclasses in table *Macroclasses* (page 28).

Now we need to select the classification algorithm. In this tutorial we are going to use the *Maximum Likelihood* (page 120).

Open the *Classification* (page 31) to set the use of classes or macroclasses. Check *Use*  *C ID* and in *Algorithm* (page 31) select the *Maximum Likelihood*.

In *Classification preview* (page 35) set *Size* = 300; click the button  and then left click a point of the image in the map. The classification process should be rapid, and the result is a classified square centered in clicked point.

Previews are temporary rasters (deleted after QGIS is closed) placed in a group named *Class\_temp\_group* in the QGIS panel Layers. Now in *Classification* (page 31) check *Use*  *MC ID* and click the button  in *Classification preview* (page 35).

We can see that now there are only 4 colors representing the macroclasses.

**TIP :** When loading a previously saved QGIS project, a message could ask to handle missing layers, which are temporary layers that SCP creates during each session and are deleted afterwards; you can click *Cancel* and ignore these layers; also, you can delete these temporary layers clicking the button






in *Working toolbar* (page 34).

In general, it is good to perform a classification preview every time a ROI (or a spectral signature) is added to the *ROI Signature list* (page 27). Therefore, the phases *Create the ROIs* (page 151) and *Create a Classification Preview* (page 167) should be iterative and concurrent processes.

## Create the Classification Output

Assuming that the results of classification previews were good (i.e. pixels are assigned to the correct class defined in the *ROI Signature list* (page 27)), we can perform the actual land cover classification of the whole image.

In *Classification* (page 31) check *Use*  *MC ID*. In the *Classification output* (page 33) click the button 

and define the path of the classification output, which is a raster file (.tif). If  *Play sound when finished* is checked in *Classification process* (page 94) settings, a sound is played when the process is finished.

**Well done!** You have just performed your first land cover classification.

However, you can see that there are several classification errors, because the number of ROIs (spectral signatures) is insufficient.

We can improve the classification using some of the tools that will be described in other tutorials.

## 5.2 Tutorial 2

The following is a tutorial about the functions of the Semi-Automatic Classification Plugin (SCP). It is assumed that you have a basic knowledge of QGIS.

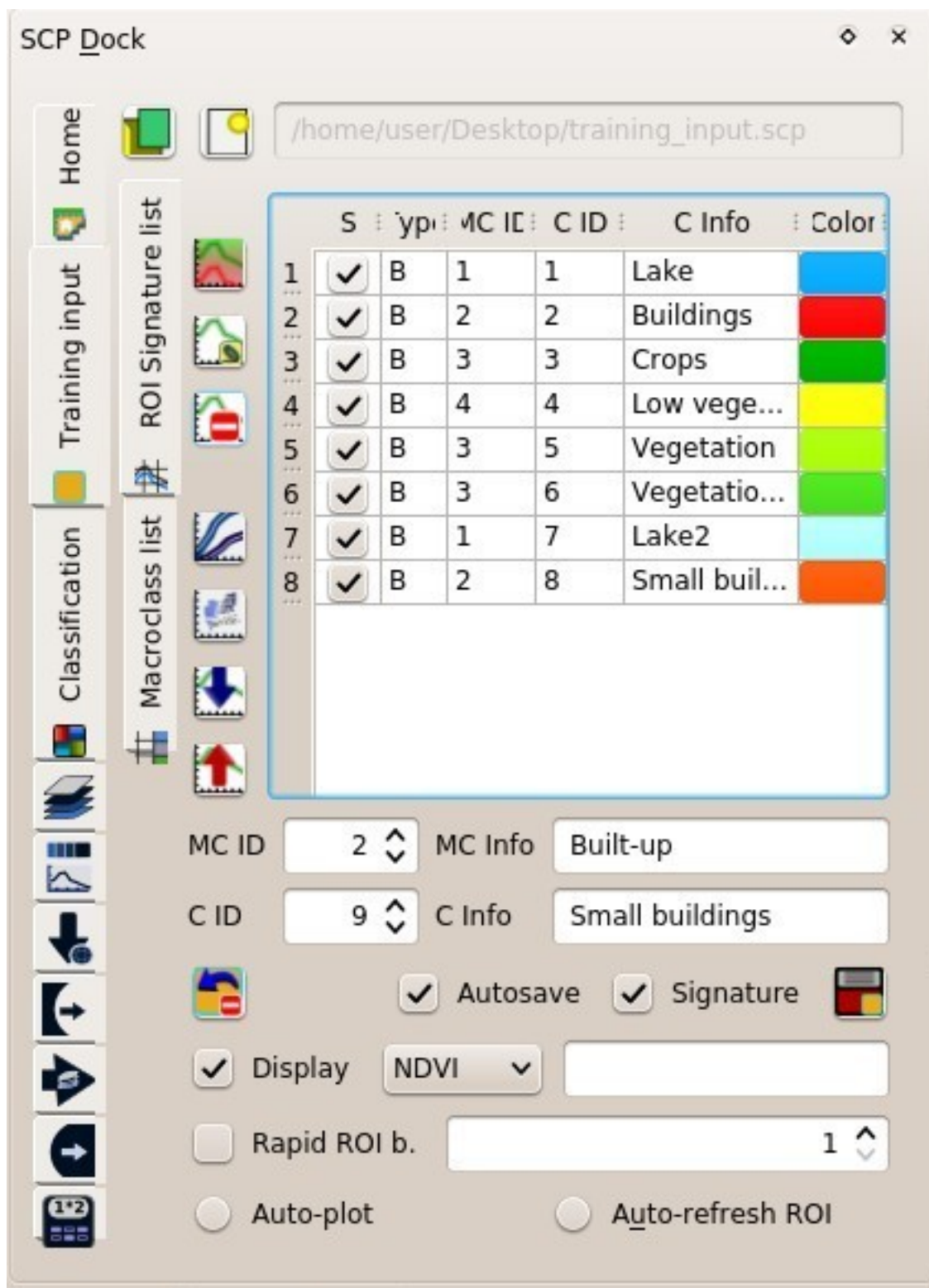


Fig. 31: Definition of class colors

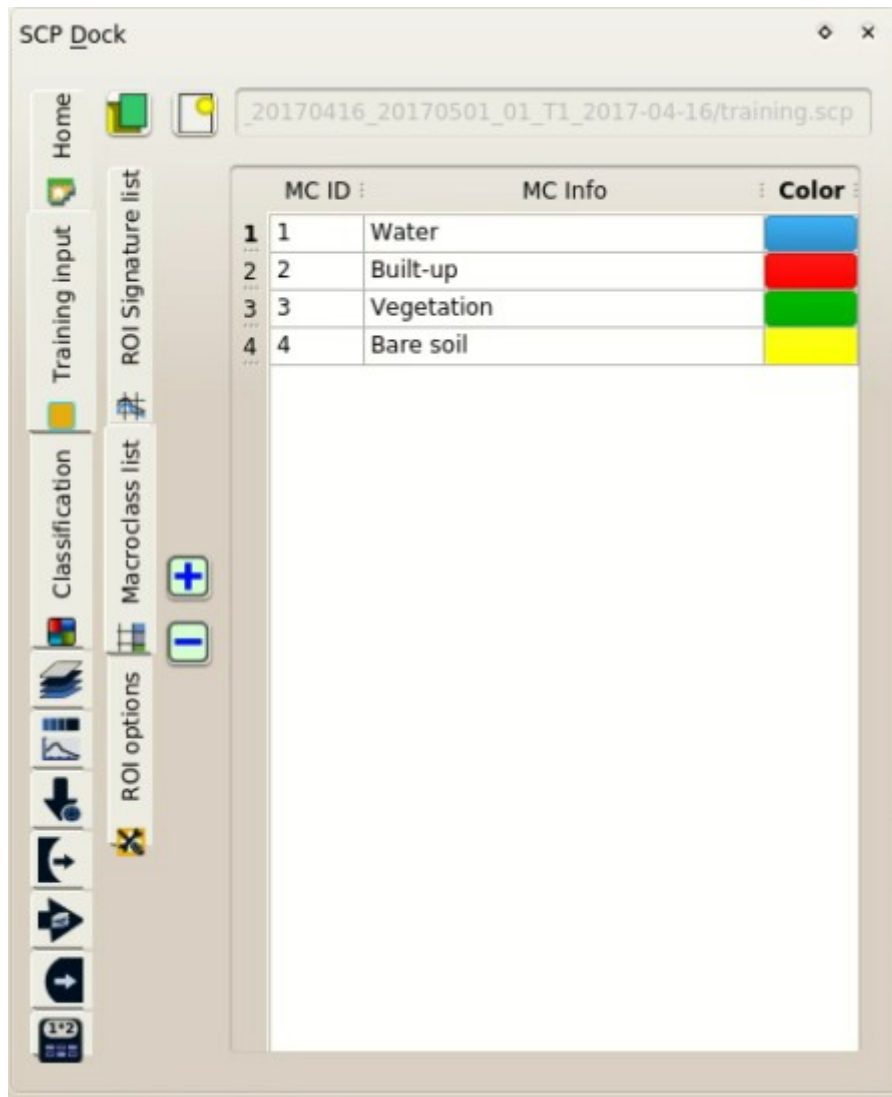


Fig. 32: Definition of macroclass colors





Fig. 33: *Setting the algorithm and using C ID*

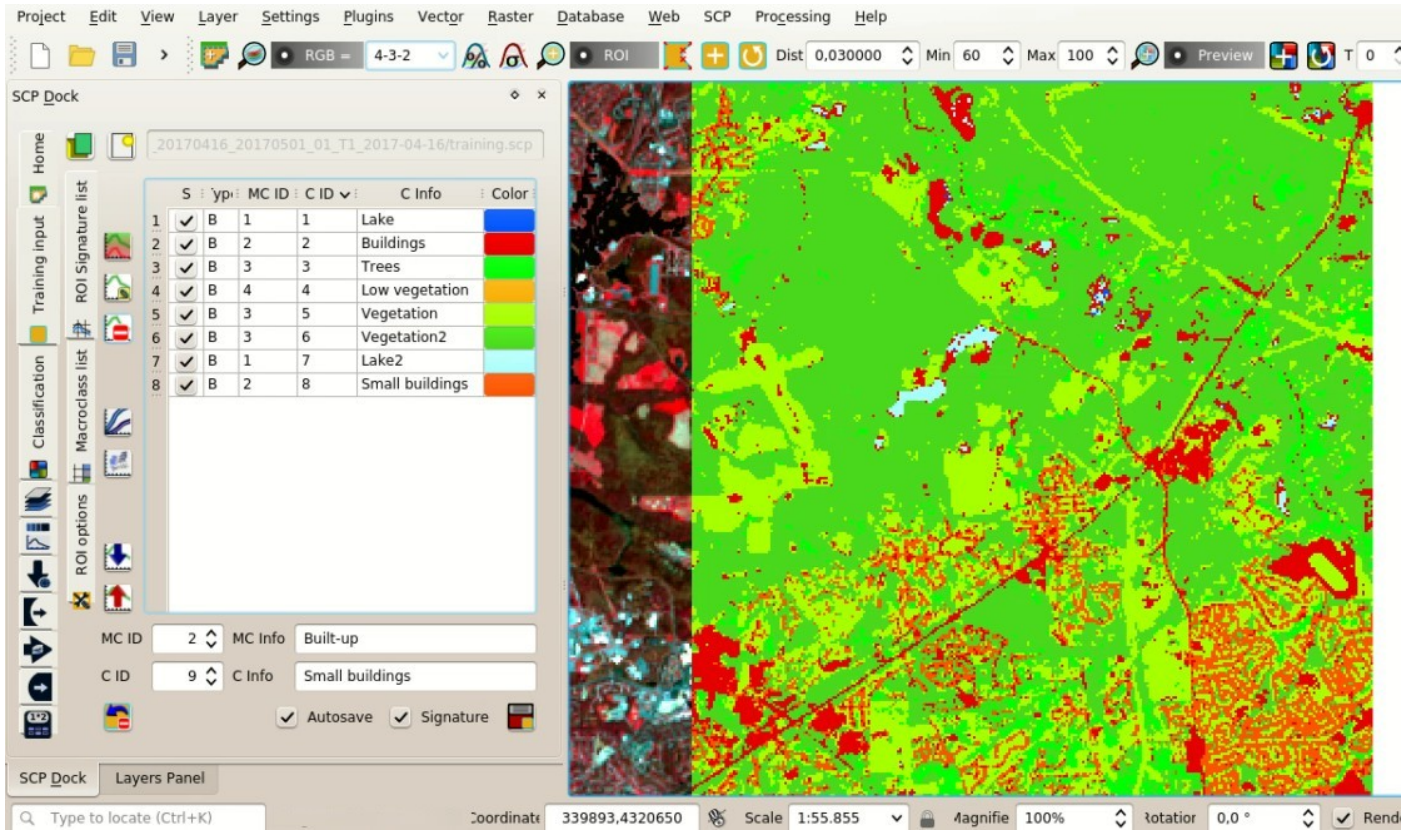


Fig. 34: Classification preview displayed over the image using C ID

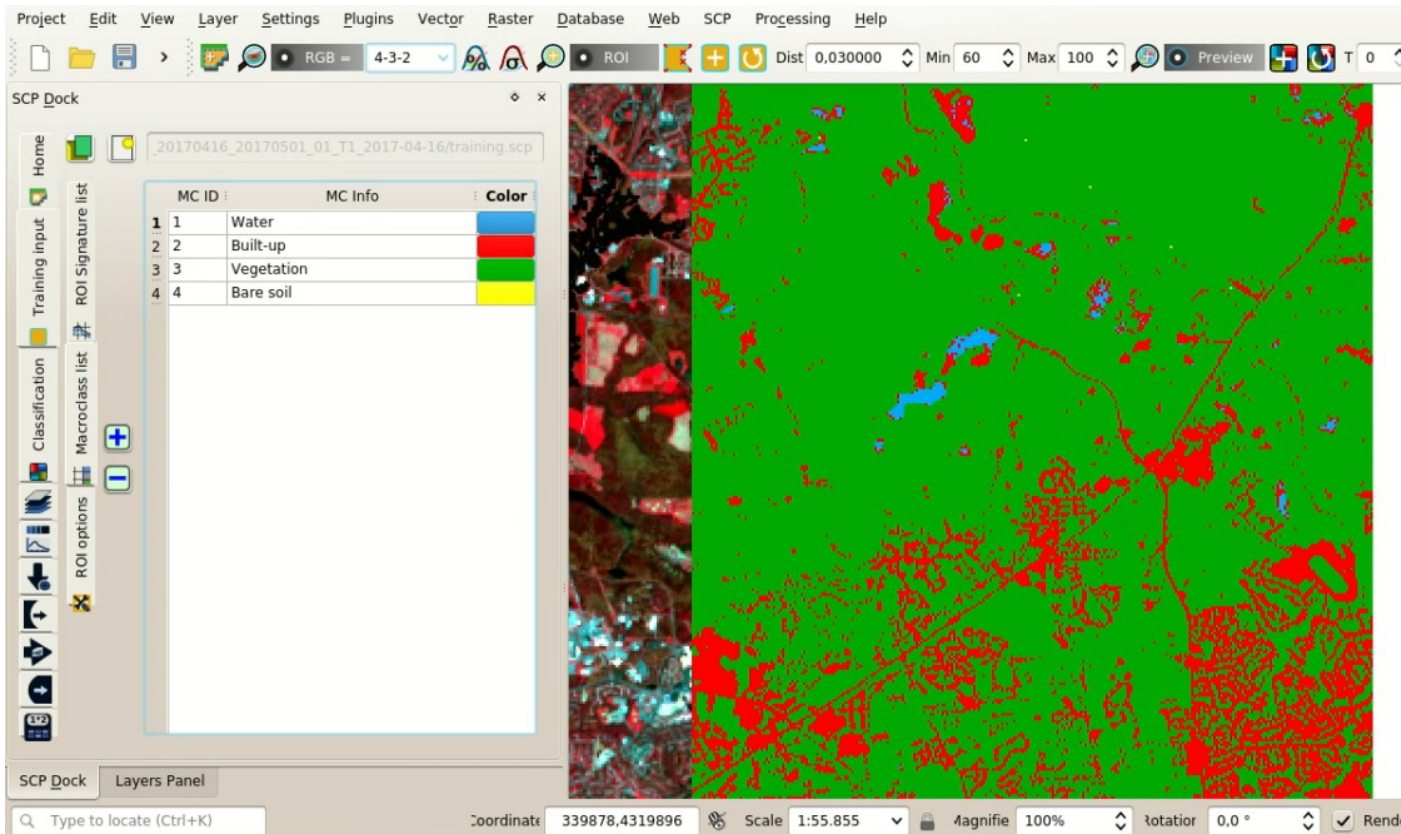


Fig. 35: Classification preview displayed over the image using MC ID



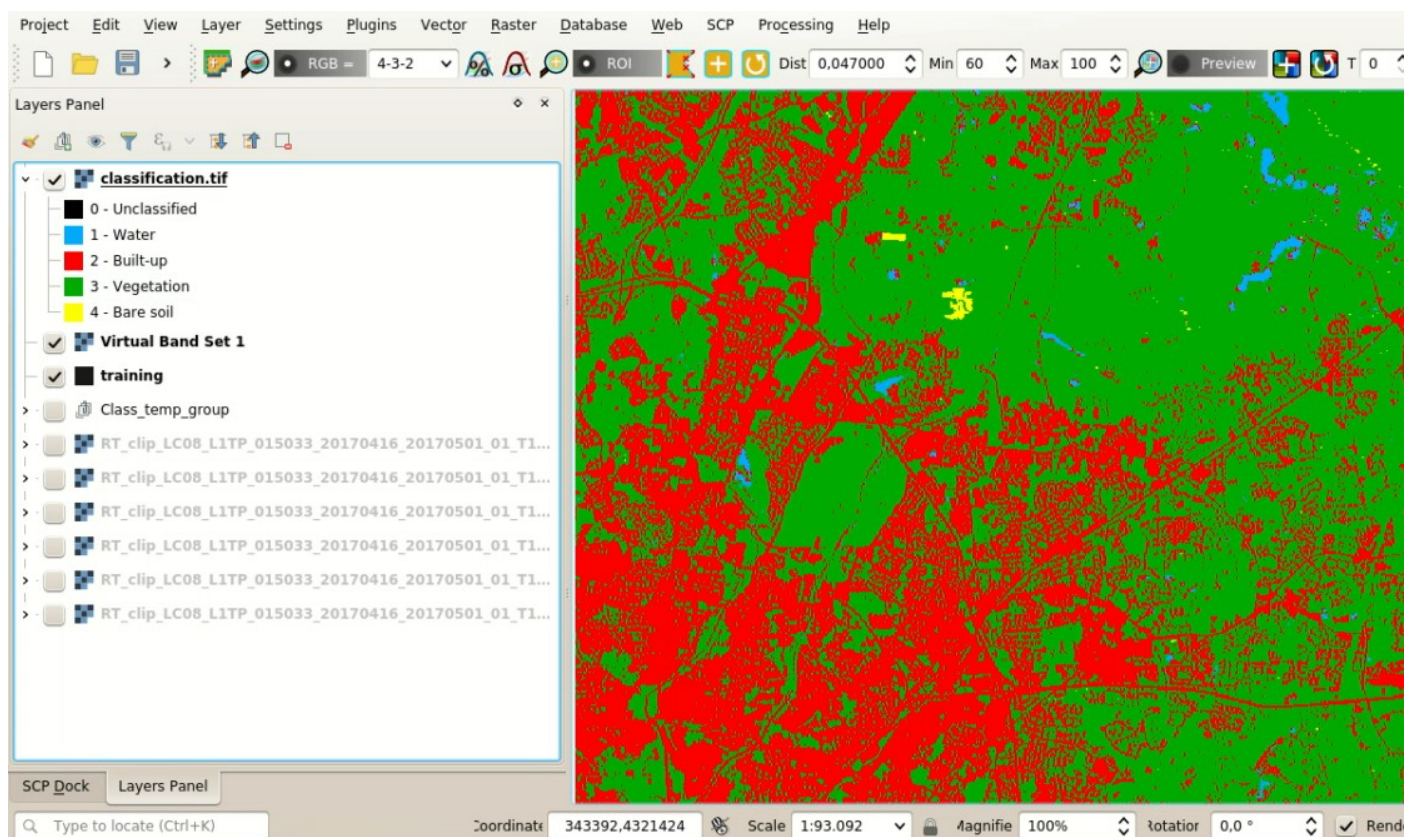
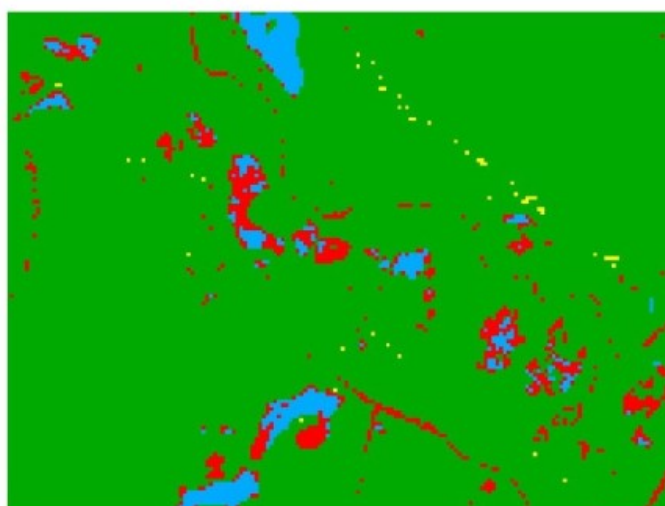


Fig. 36: Result of the land cover classification



**Classification**



**RGB = 3-2-1**

Fig. 37: Example of error: Water bodies classified as Built-up

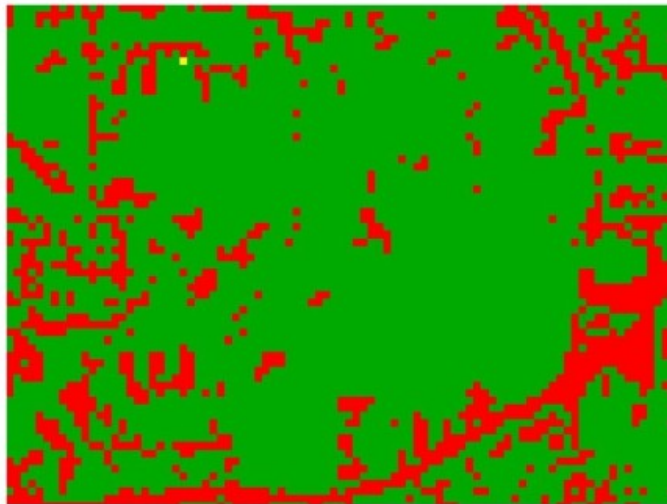
**Classification****RGB = 3-2-1**

Fig. 38: Example of error: Built-up classified as vegetation

- *Tutorial 2: Cloud Masking, Image Mosaic, and Land Cover Change Location* (page 173)
  - *Download the Data* (page 173)
  - *Create the cloud cover mask* (page 181)
  - *Mask clouds in the Sentinel-2 image* (page 182)
  - *Mosaic the Sentinel-2 images* (page 182)
  - *Land cover change* (page 186)

### 5.2.1 Tutorial 2: Cloud Masking, Image Mosaic, and Land Cover Change Location

This tutorial is about the use of *SCP* for the assessment of land cover change of a multispectral image. It is recommended to complete the *Tutorial 1: Your First Land Cover Classification* (page 139) before this tutorial.

The purpose of this tutorial is to locate land cover change over one year (between 2017 and 2018), using free Sentinel-2 images.

Following the video of this tutorial.

<http://www.youtube.com/watch?v=xm9s97GPs0Y>

#### Download the Data

We are going to download a *Sentinel-2 Satellite* (page 114) image (Copernicus land monitoring services) and use the bands illustrated in the following table.

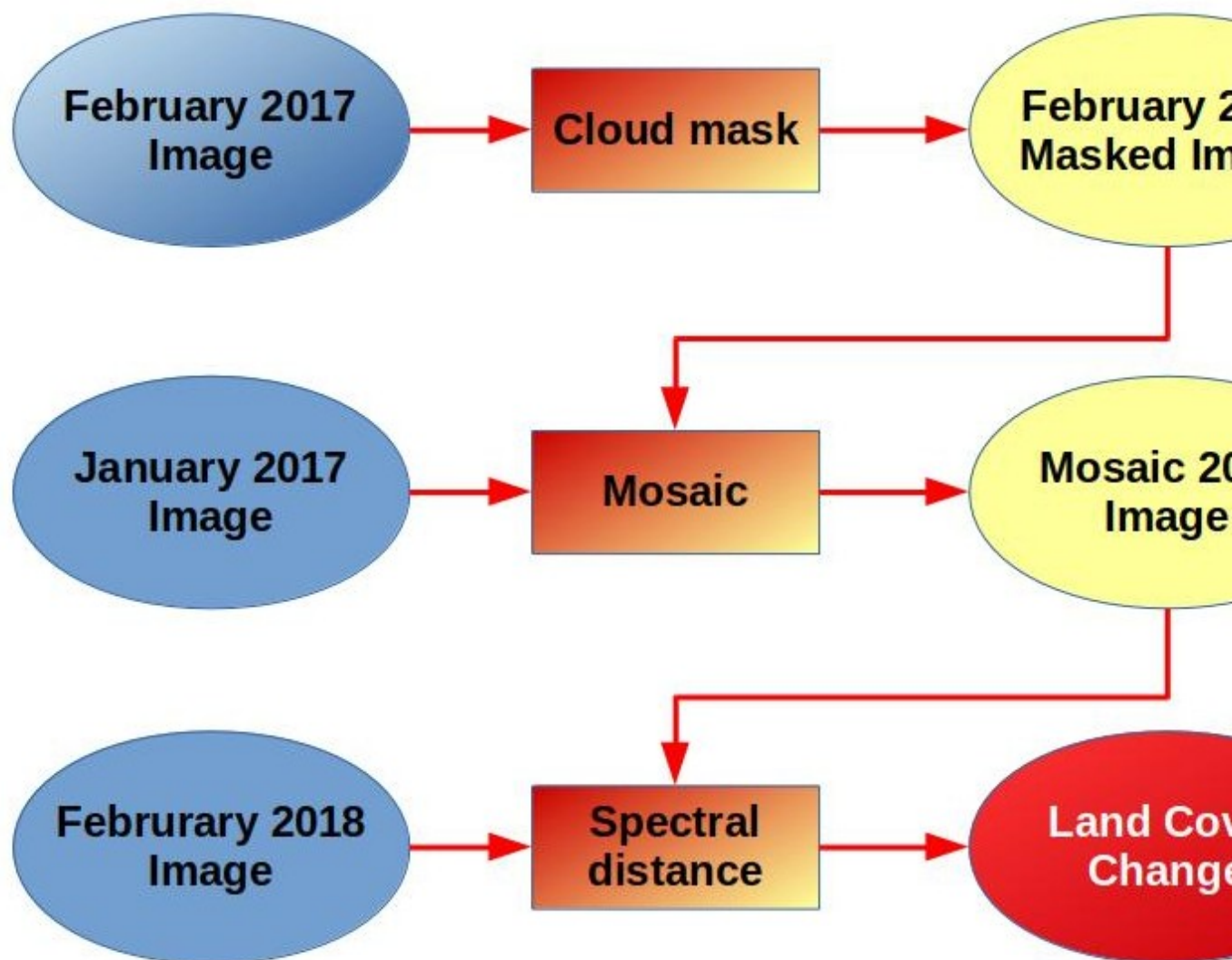





Fig. 39: *Workflow*



| Sentinel-2 Bands              | Central Wavelength [micrometers] | Resolution [meters] |
|-------------------------------|----------------------------------|---------------------|
| Band 2 - Blue                 | 0.490                            | 10                  |
| Band 3 - Green                | 0.560                            | 10                  |
| Band 4 - Red                  | 0.665                            | 10                  |
| Band 5 - Vegetation Red Edge  | 0.705                            | 20                  |
| Band 6 - Vegetation Red Edge  | 0.740                            | 20                  |
| Band 7 - Vegetation Red Edge  | 0.783                            | 20                  |
| Band 8 - NIR                  | 0.842                            | 10                  |
| Band 8A - Vegetation Red Edge | 0.865                            | 20                  |
| Band 11 - SWIR                | 1.610                            | 20                  |
| Band 12 - SWIR                | 2.190                            | 20                  |

Start QGIS and the SCP . Open the tab *Download products* (page 51) clicking the button  in the *Home* (page 24), or in the *SCP menu* (page 21). In the tab *Download products* (page 51) click the button  to display the OpenStreetMap tiles (© OpenStreetMap contributors) in the QGIS map, licensed as CC BY-SA (*Tile Usage Policy* ).

In general it is possible to define the area coordinates clicking the button , then left click in the map for the UL point and right click in the map for the LR point. In this tutorial the study area is Rome (Italy), therefore click in the map to define the search area, or alternatively, enter these point coordinates in *Search parameters* (page 53):

- *UL*: 12.4 / 41.9
- *LR*: 12.5 / 41.8


The purpose of this tutorial is to map the land cover change between 2017 and 2018, therefore we need to download at least two images. Because of cloud cover, we are going to download an additional image for 2016, which will be used to replace pixels covered by clouds in the first image. We are searching for three images (tile 33TTG) acquired on:

- 01 January 2017
- 10 February 2017
- 10 February 2018

Therefore, we need to perform three searches. Select *Sentinel-2* from the *Products*  and set:

- *Date from*: 2017-01-01
- *to*: 2017-01-01

In this case, enter L1C\_T33TTG in *Filter* to filter the results only for the tile 33TTG.

Now click the button *Find*  and after a few seconds the image will be listed in the *Product list* (page 54). Click the item in the table to display a preview that is useful for assessing the quality of the image and the cloud cover.

Repeat the date definition and the search also for the 2017-02-10 image. You can notice that there are a few clouds over the area, therefore we are going to mosaic this image with the one acquired on 2017-01-01.

Finally, repeat the search for the 2018-02-10 image.

We can also select the bands to be downloaded according to our purpose. In particular, select the tab *Download options* (page 55) and check only the Sentinel-2 bands that will be used in this tutorial and the ancillary data.

For the purpose of this tutorial, uncheck the option  *Only if preview in Layers* because we want to download and preprocess all the images listed in the table.

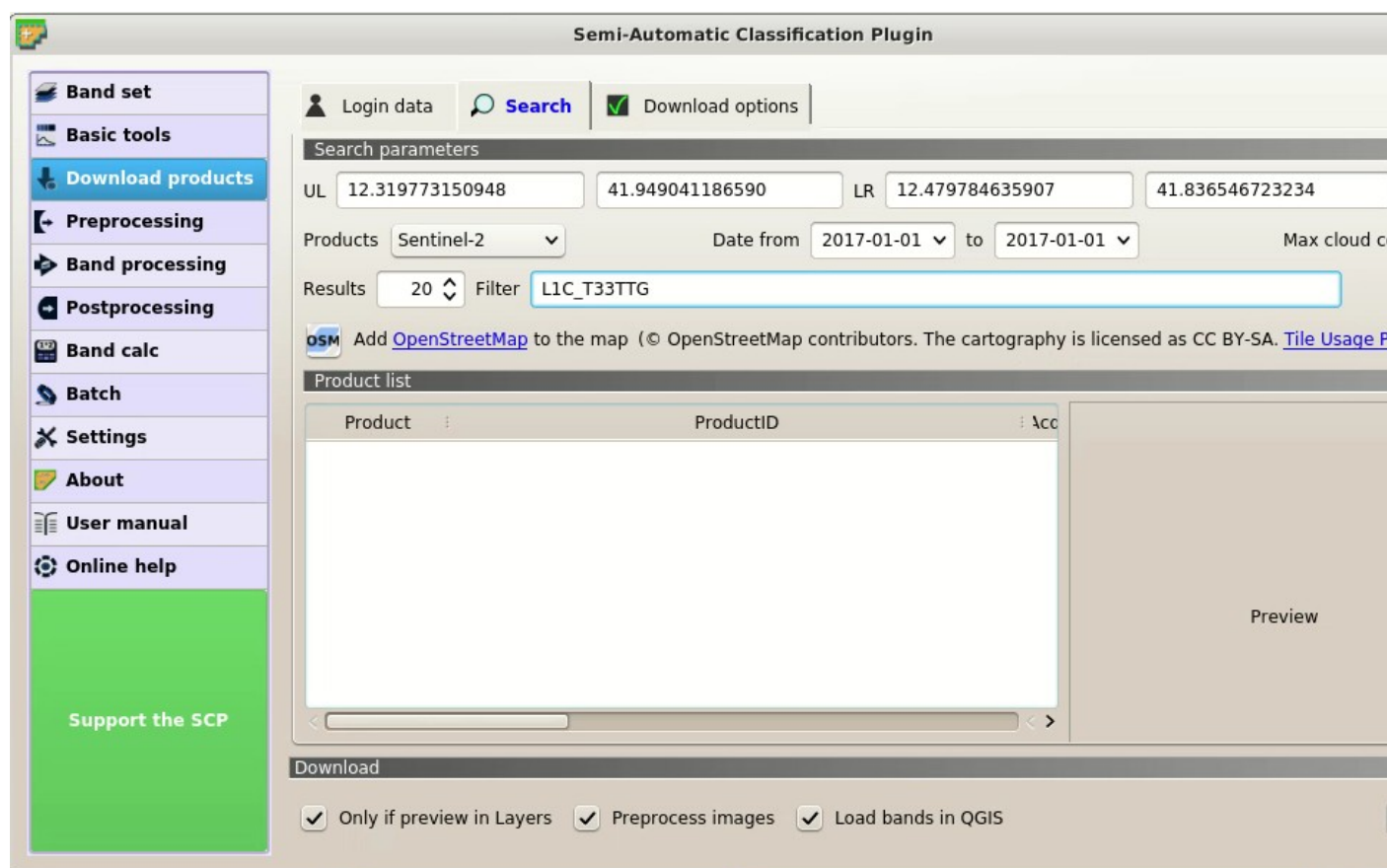


Fig. 40: Search products

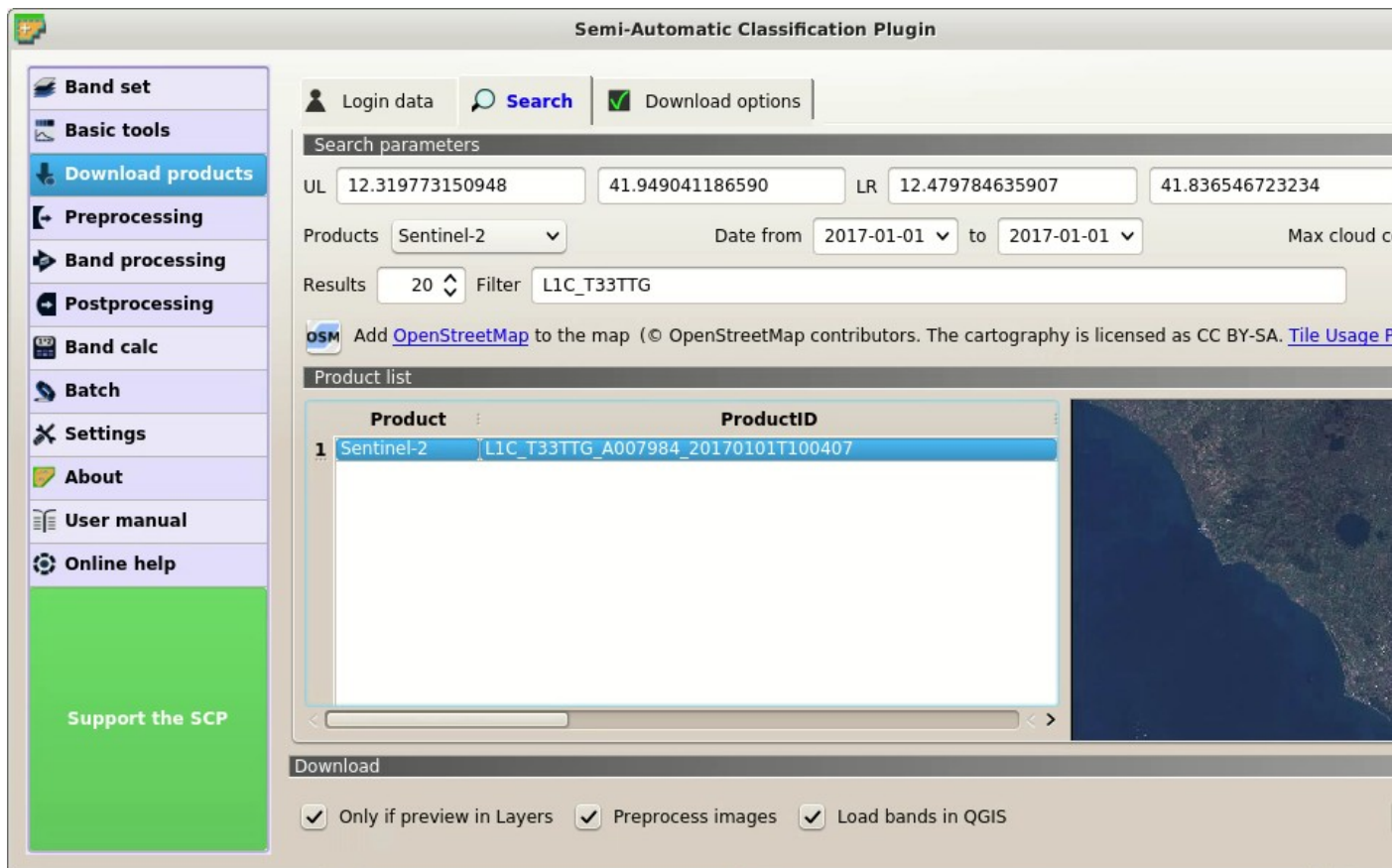


Fig. 41: Search result



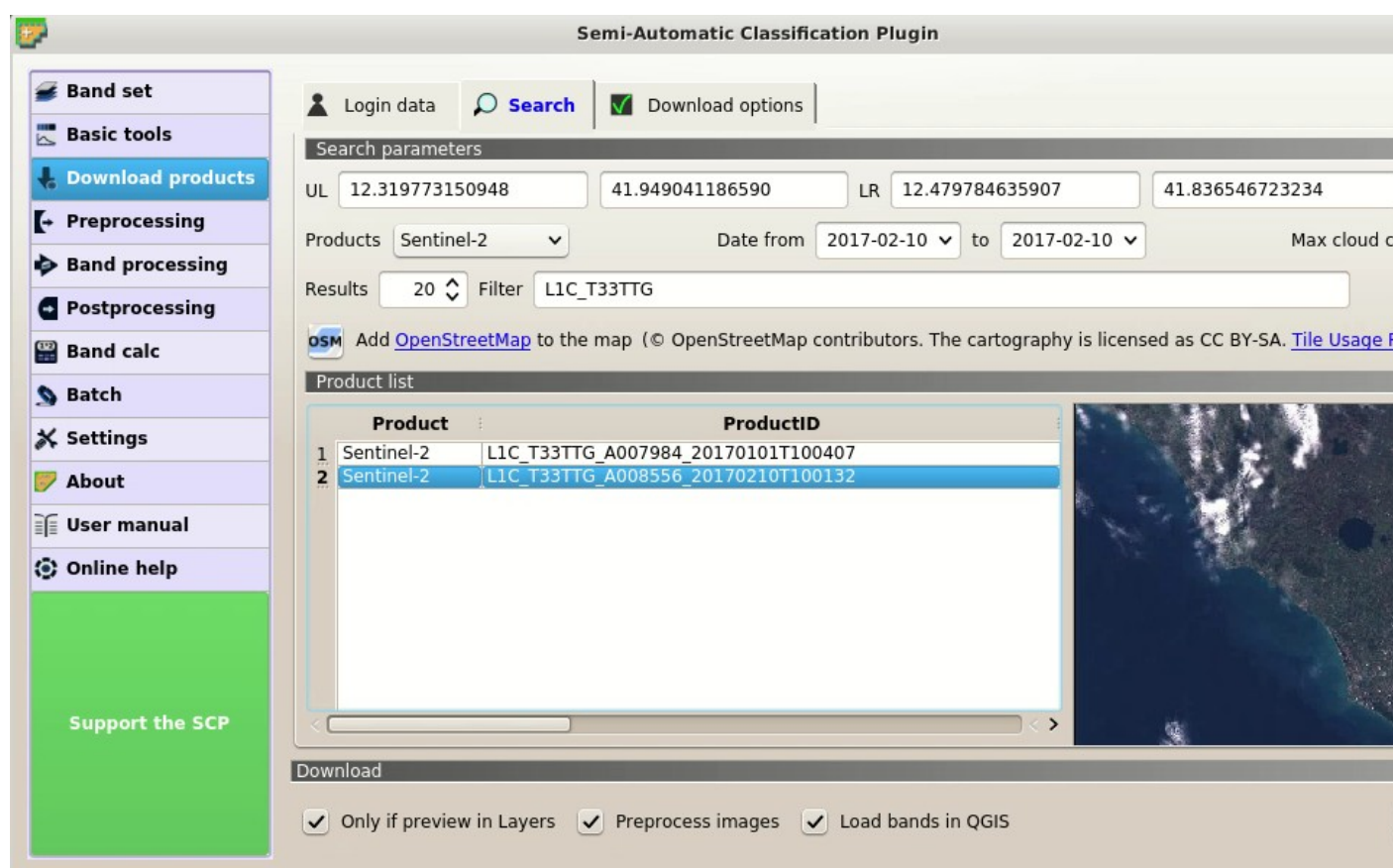


Fig. 42: Search result of second image

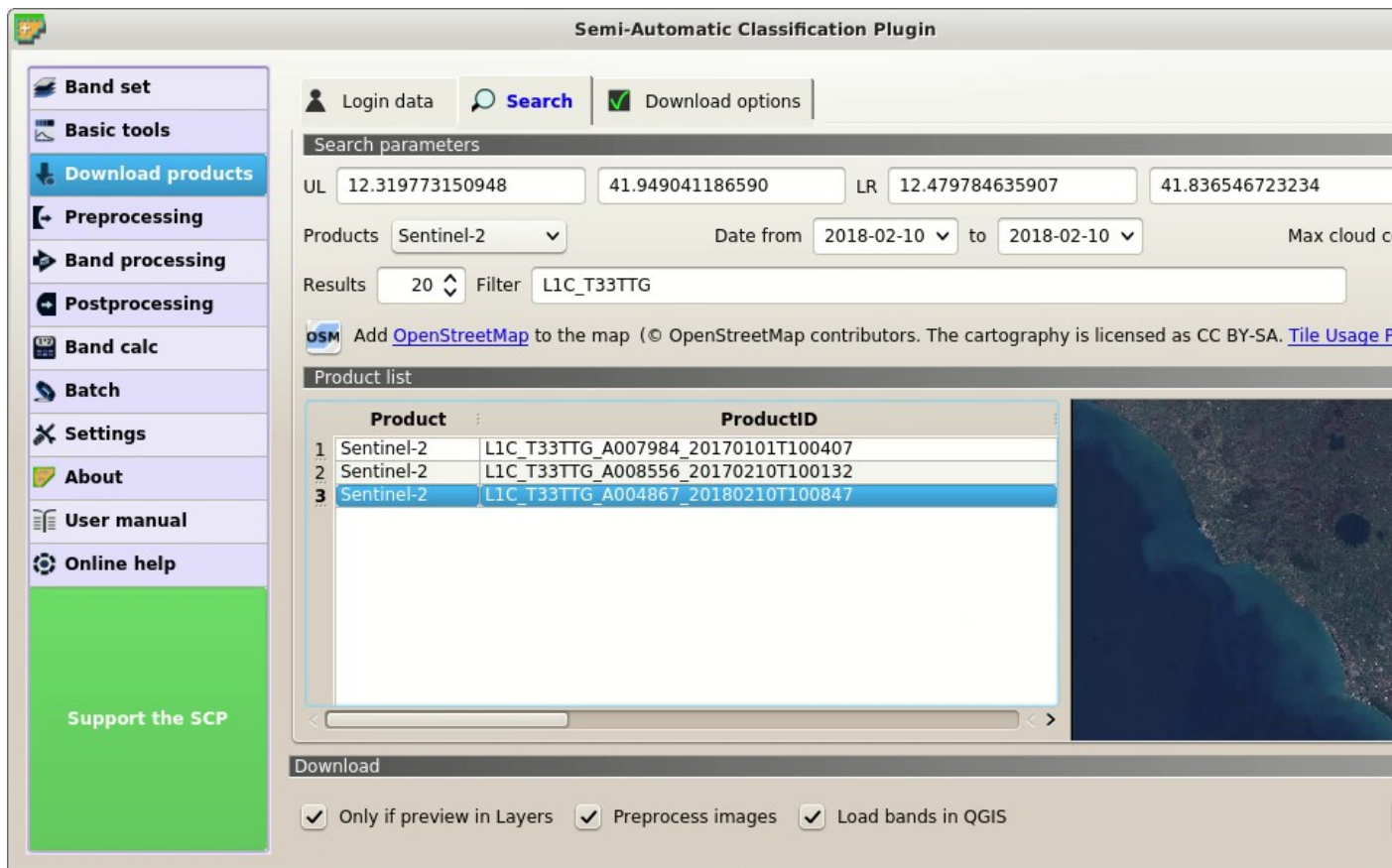
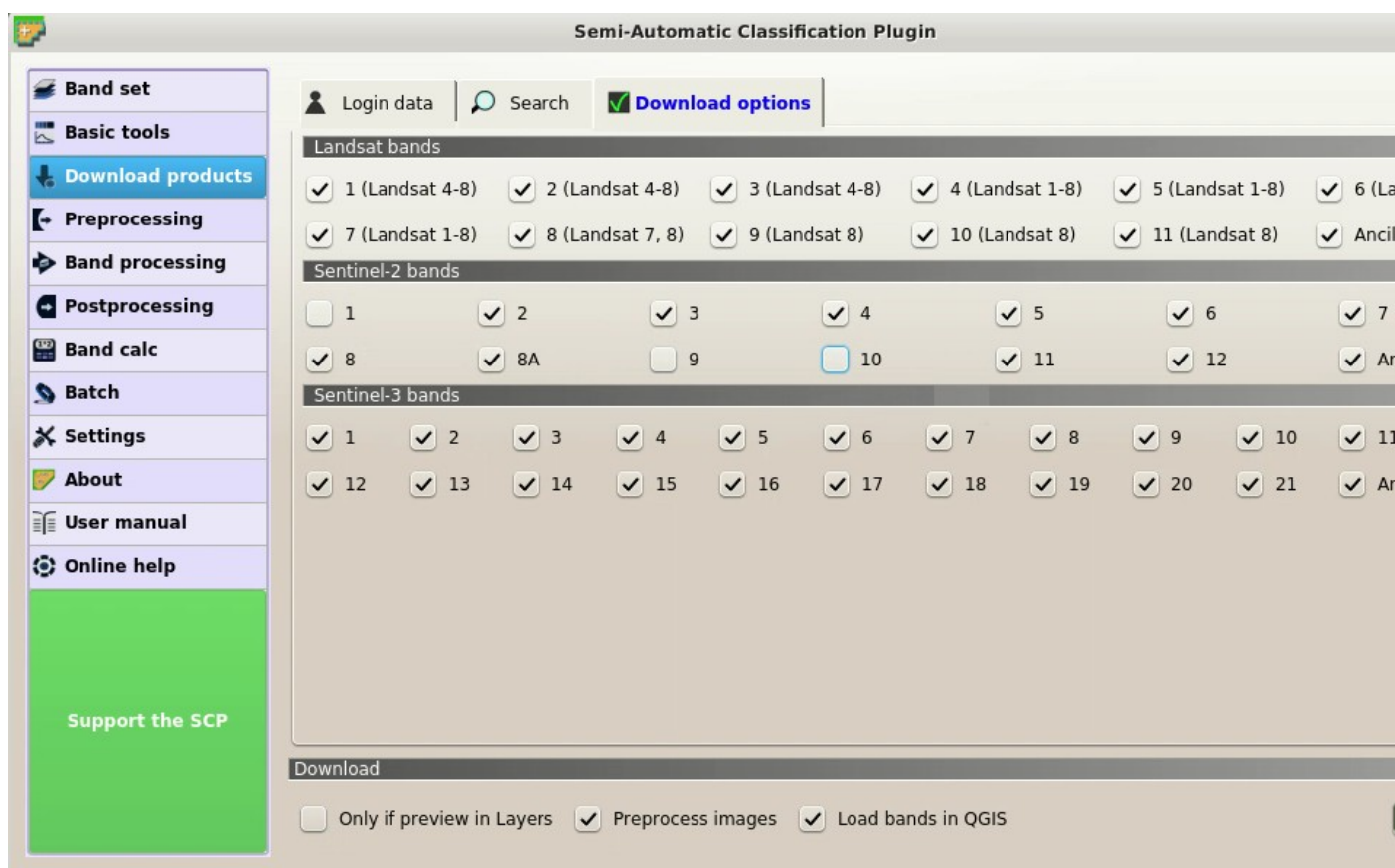


Fig. 43: Search results

Fig. 44: *Download options*

Before starting the download we need to set the preprocessing options in the tab *Sentinel-2* (page 58) for performing the *DOS1 Correction* (page 132). Check the options ☒ *Apply DOS1 atmospheric correction* and ☒ *Add bands in a new Band set* to automatically create a *Band set* for each image.

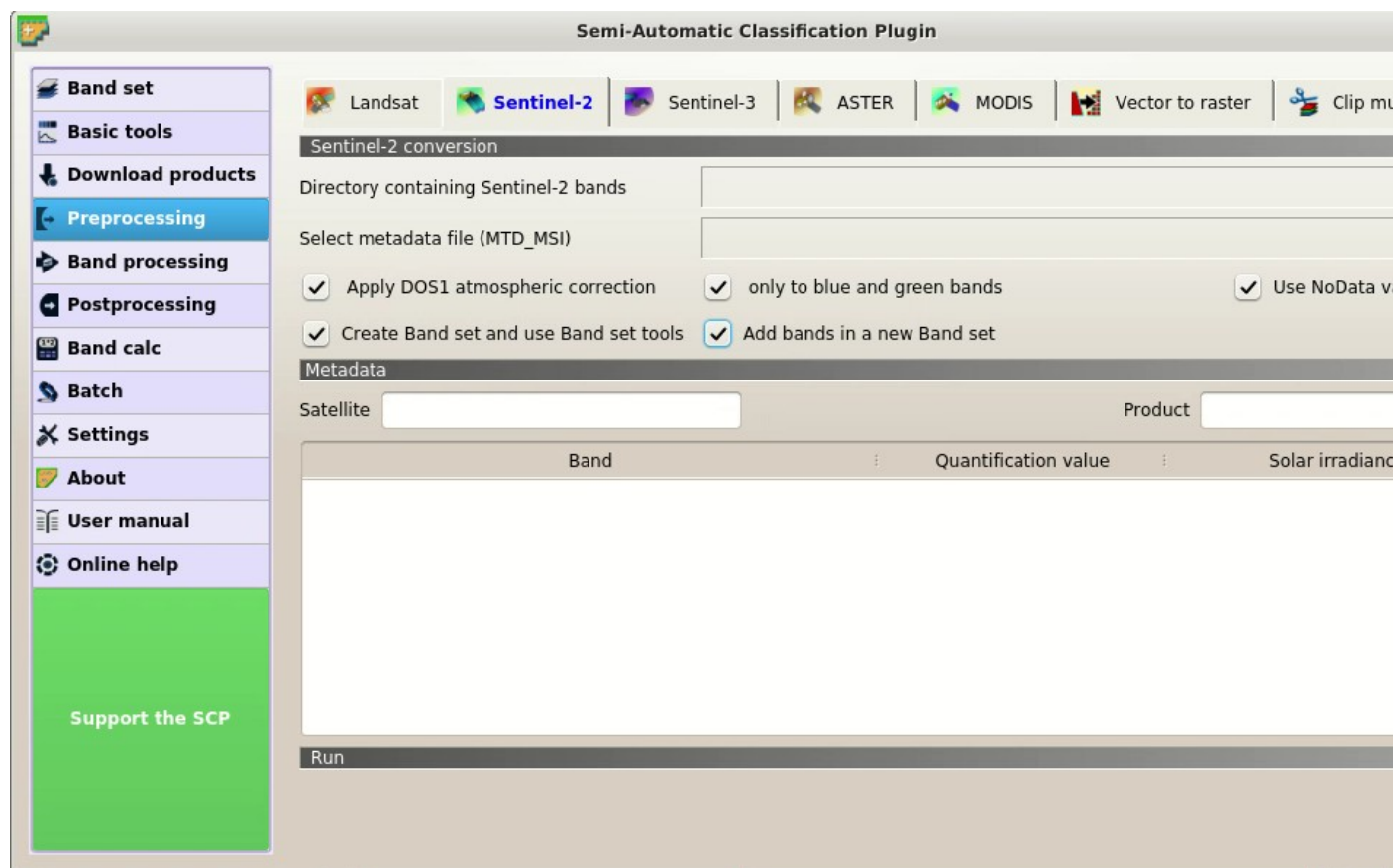



Fig. 45: Preprocessing options

To start the image download, in the tab *Download products* (page 51) click the button *RUN*  and select a directory where bands are saved (a new directory will be created for each image). The download could last a few minutes according to your internet connection speed. The download progress is displayed in a bar.


After the download, all the bands of all the Sentinel-2 images (© Copernicus Sentinel data 2018) are automatically loaded in the map. We can also display the RGB color composite of the *Band sets* clicking the list *RGB=* in the *Working toolbar* (page 34), and selecting the item 3-2-1.

### Create the cloud cover mask

Before the land cover change assessment, we need to remove cloud cover pixels in the image acquired on 2017-02-10. Of course we could perform the same process for all the other images.

In QGIS, load the file `MSK_CLOUDS_B00.gml` that should be inside the directory `L1C_T33TTG_A008556_20170210T100132_2017-02-10`. This vector file represents most of the cloud cover in the image. In QGIS Layers Panel, left click the vector `MSK_CLOUDS_B00 MaskFeature` and select `Export > Save Feature as` to save this gml file to shapefile (e.g. `clouds.shp`).

We can convert this vector file to raster using the tab *Vector to raster* (page 64).

Click the button  to refresh the layer list, and select the vector `clouds`. Check the ☒ *Use constant value* to set the raster value 1 for clouds. Also, in *Select the reference raster* select the name of a band. This will create



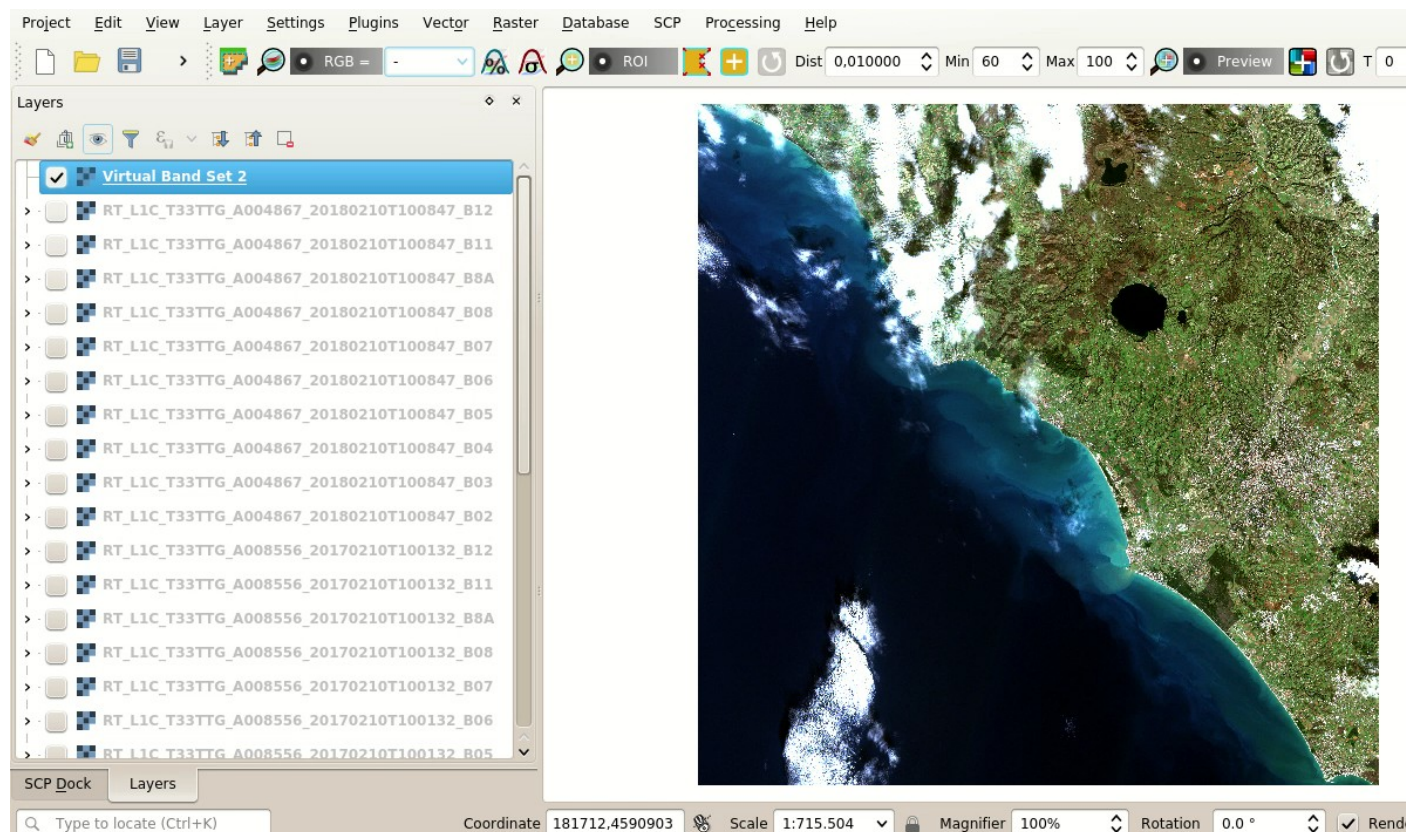



Fig. 46: Download of Sentinel-2 bands

a raster with the same size and aligned to the Sentinel-2 image. Finally click the button **RUN**  to create the mask.


We could also improve the mask by manually editing the pixel of the raster using the tool *Edit raster* (page 82) or creating a semi-automatic classification of clouds.

### Mask clouds in the Sentinel-2 image

We are going to mask all the pixels covered by clouds in all the bands composing the *Band set* of the image acquired on 2017-02-10.


In the tab *Cloud masking* (page 69), set the number of the 2017-02-10 *Band set* in *Select input band set*. In *Select the classification* we select the mask created at the previous step. Enter 1 in *Mask class values*. Finally, uncheck

☒ *Use buffer of pixel size* to speed up the masking process.

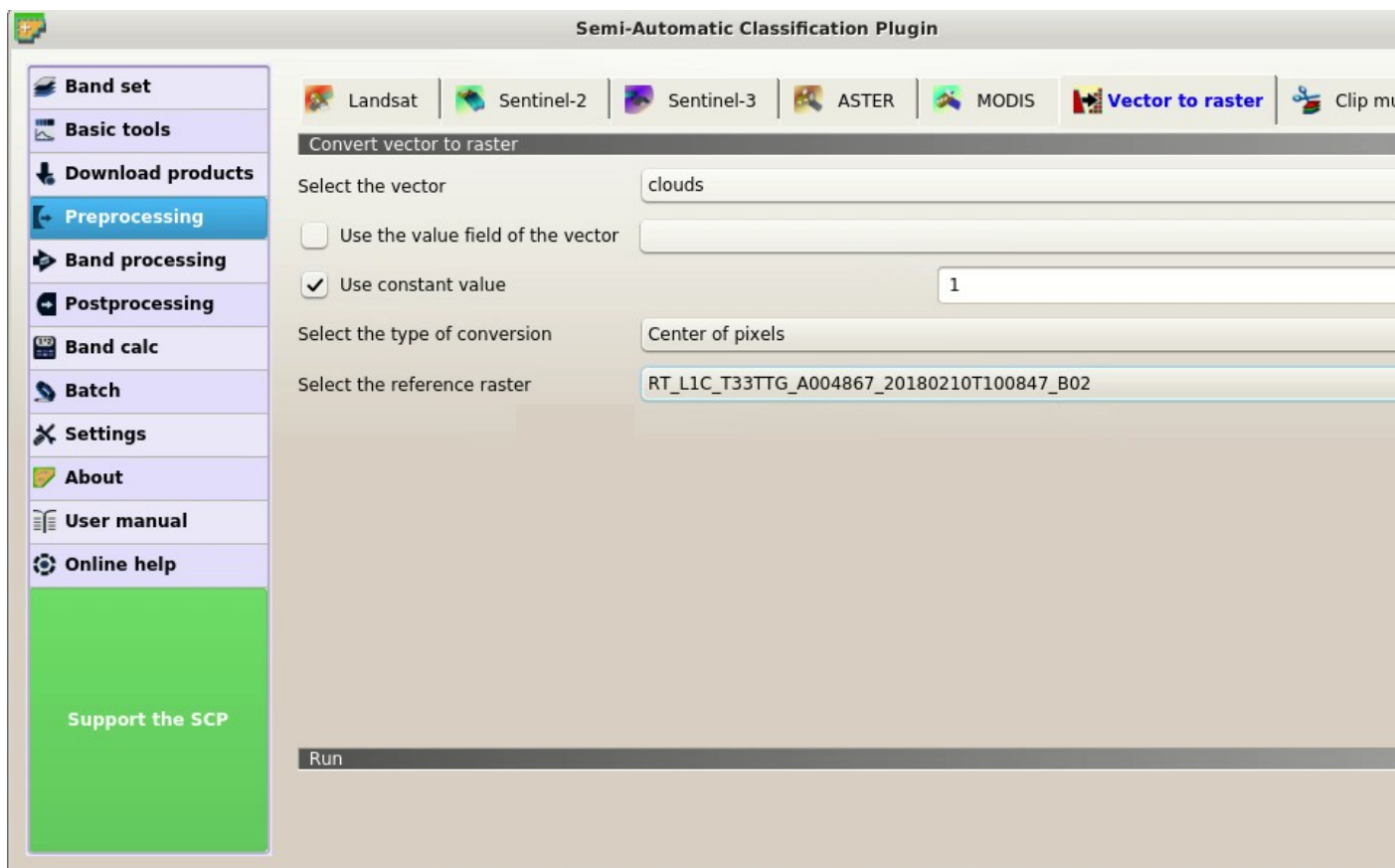
Now click the button **RUN**  to select the output directory and start the masking process.

### Mosaic the Sentinel-2 images

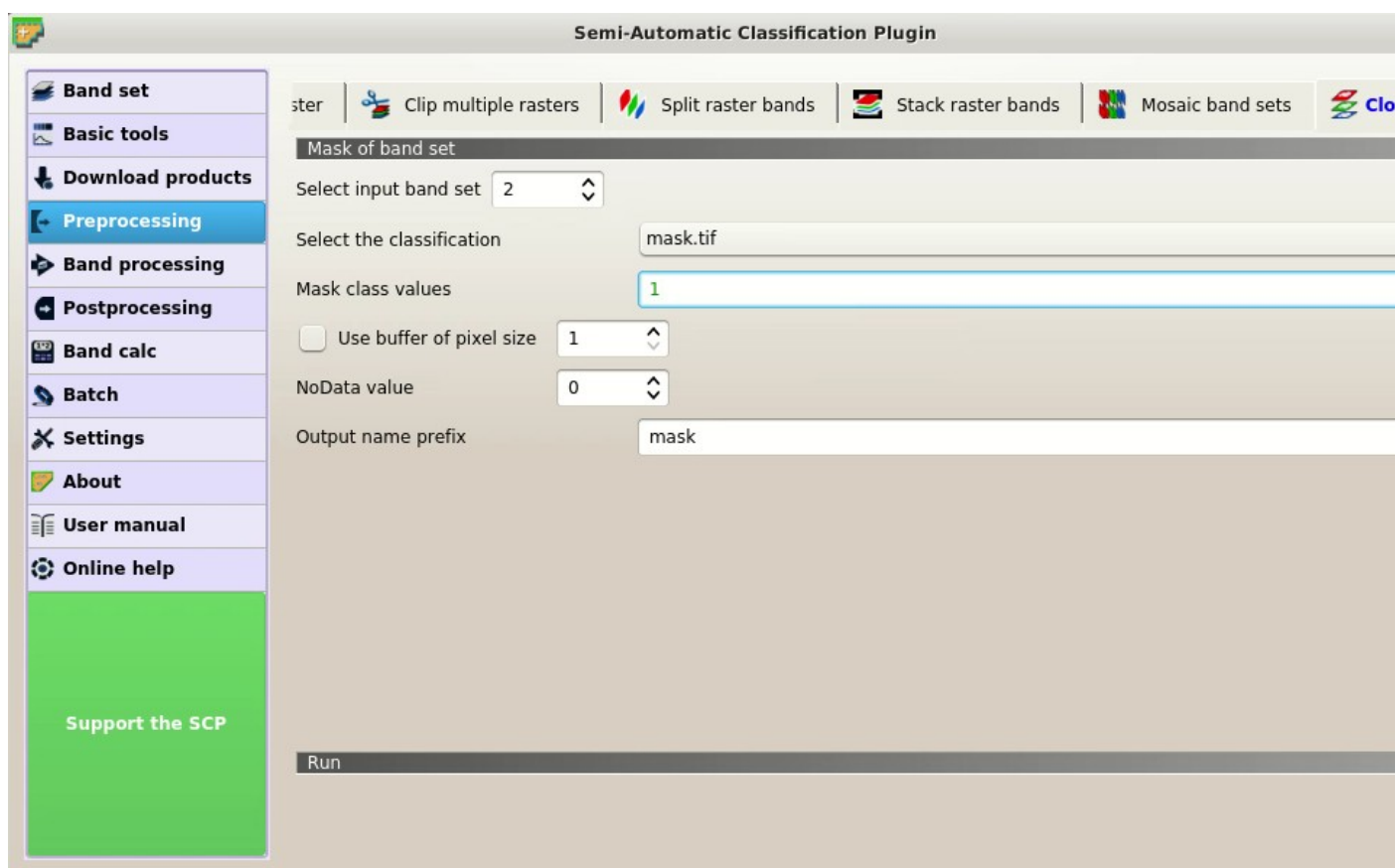
We are going to mosaic the 2017 images in order to create a cloud free image to be used for land cover change.

We use the image acquired on 2017-01-01 to fill the gaps in the 2017-02-10 image. In the tab *Band set* (page 37), add a new *Band set* with the button  and add the masked bands.

Now we can mosaic the 2017 images.

Fig. 47: *Vector to raster mask*



Fig. 48: *Mask clouds*

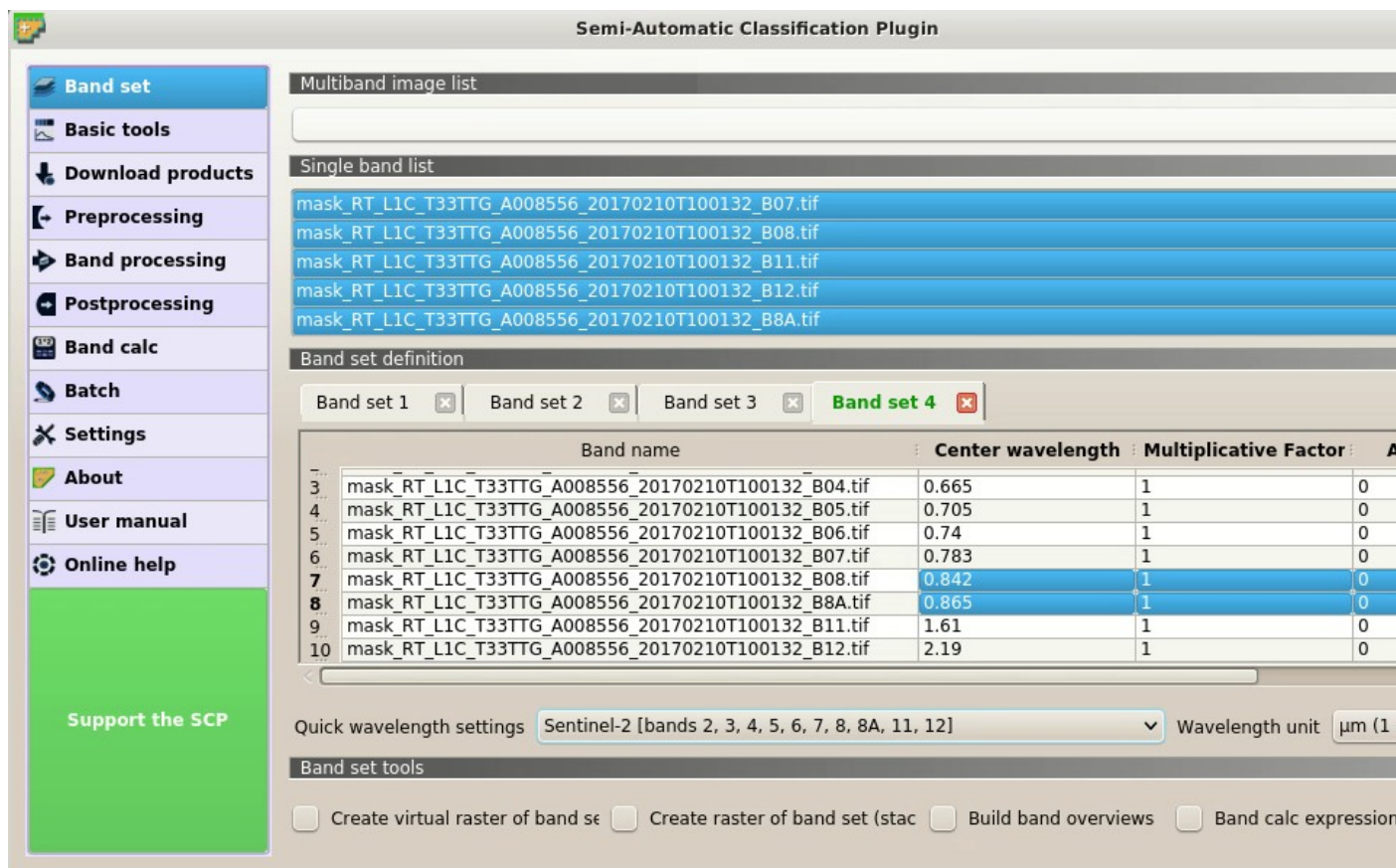



Fig. 49: New Band set

In the tab *Mosaic of band sets* (page 69), in the *Band set list* enter the number of the 2017-02-10 masked *Band set*, followed by comma, followed by the number of the 2017-01-01 *Band set*. Now click the button *RUN*  to select the output directory and start the masking process.

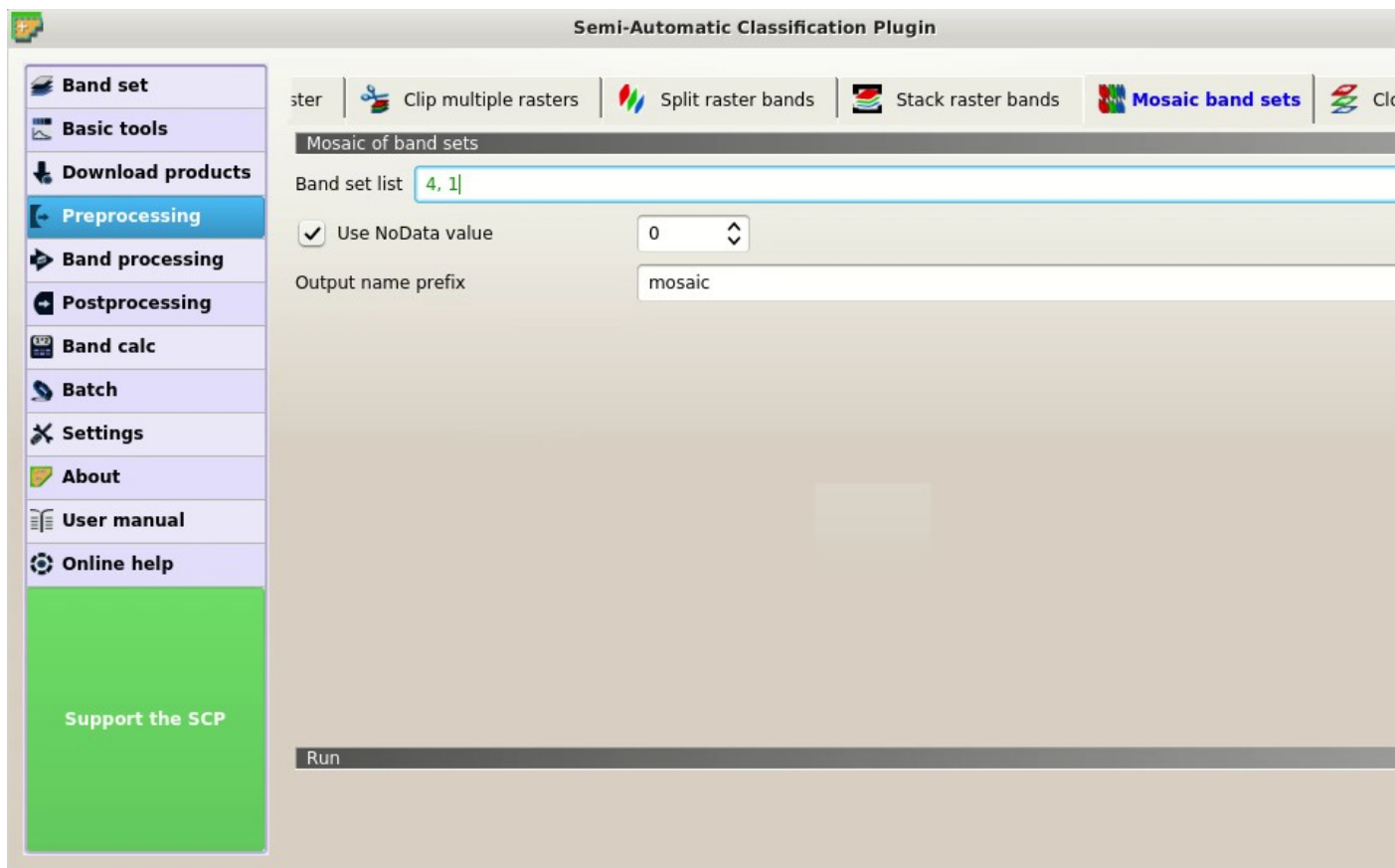




Fig. 50: *Mosaic Band sets*


We could have used more than 2 *Band sets*. The process automatically mosaic the corresponding bands of the input *Band sets* filling the NoData gaps of the first *Band set* with the pixels of the following *Band sets*. The mosaic bands are automatically added to the map.

## Land cover change

We are going to automatically locate the land cover change between the image mosaic of 2017 and the 2018 image. SCP includes a tool that allows for calculating the spectral distance between every corresponding pixel of two *Band sets*, and creating a raster of changes through a spectral distance threshold.

In the tab *Band set* (page 37), add a new *Band set* with the button  and add the mosaic bands.

In the tab *Spectral distance* (page 73), set the number of the 2017 mosaic *Band set* in *Select first input band set*, and set the number of the 2018 *Band set* in *Select second input band set*. In *Distance algorithm* check the  *Spectral Angle Mapping*. Check the ☒ *Distance threshold* and set the value 10 that is the threshold used for creating the raster of changes.

Now click the button *RUN*  to select the output directory and start the masking process.

After a while, the spectral distance raster and the raster of changes are added to the map

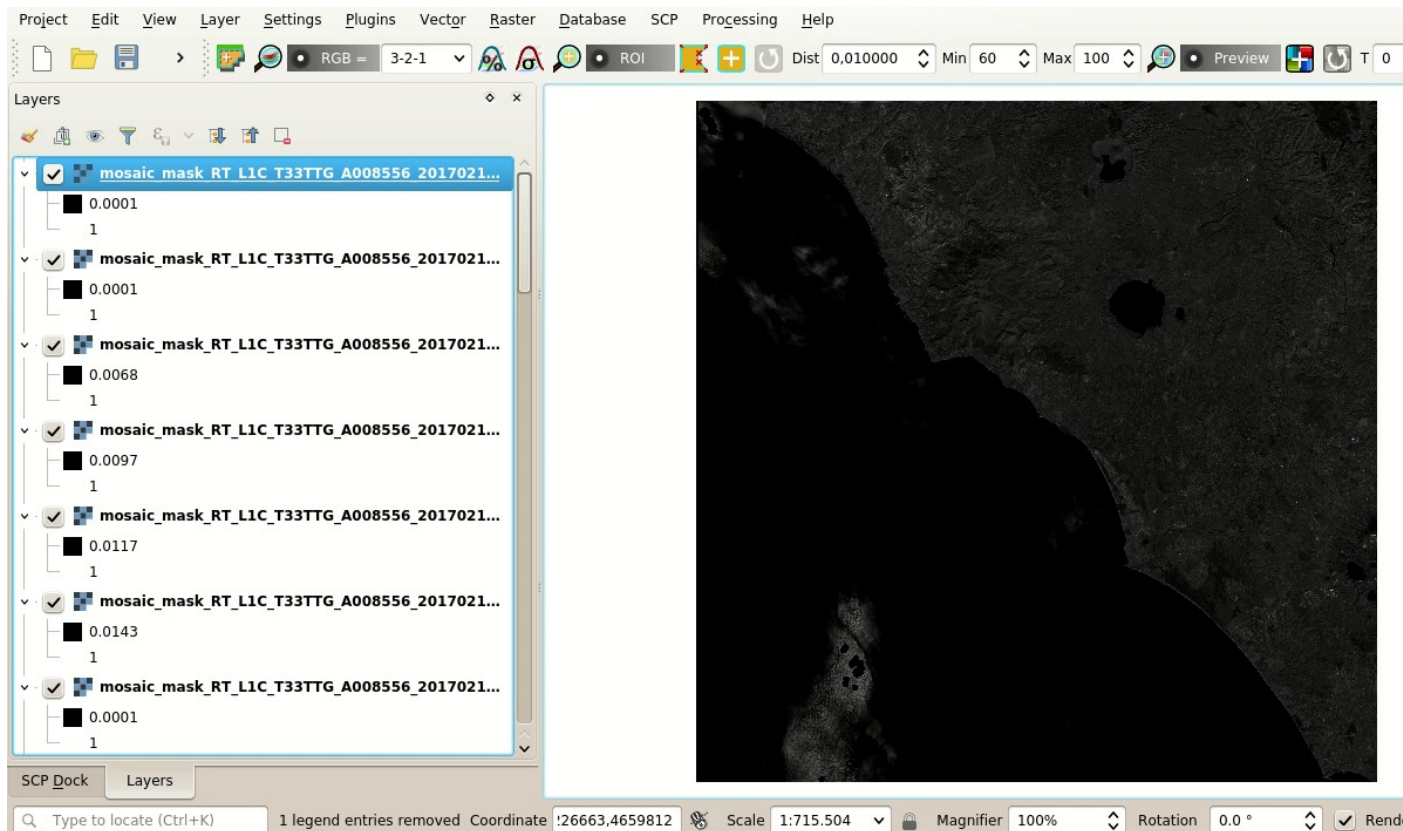


Fig. 51: Mosaic of 2017 images

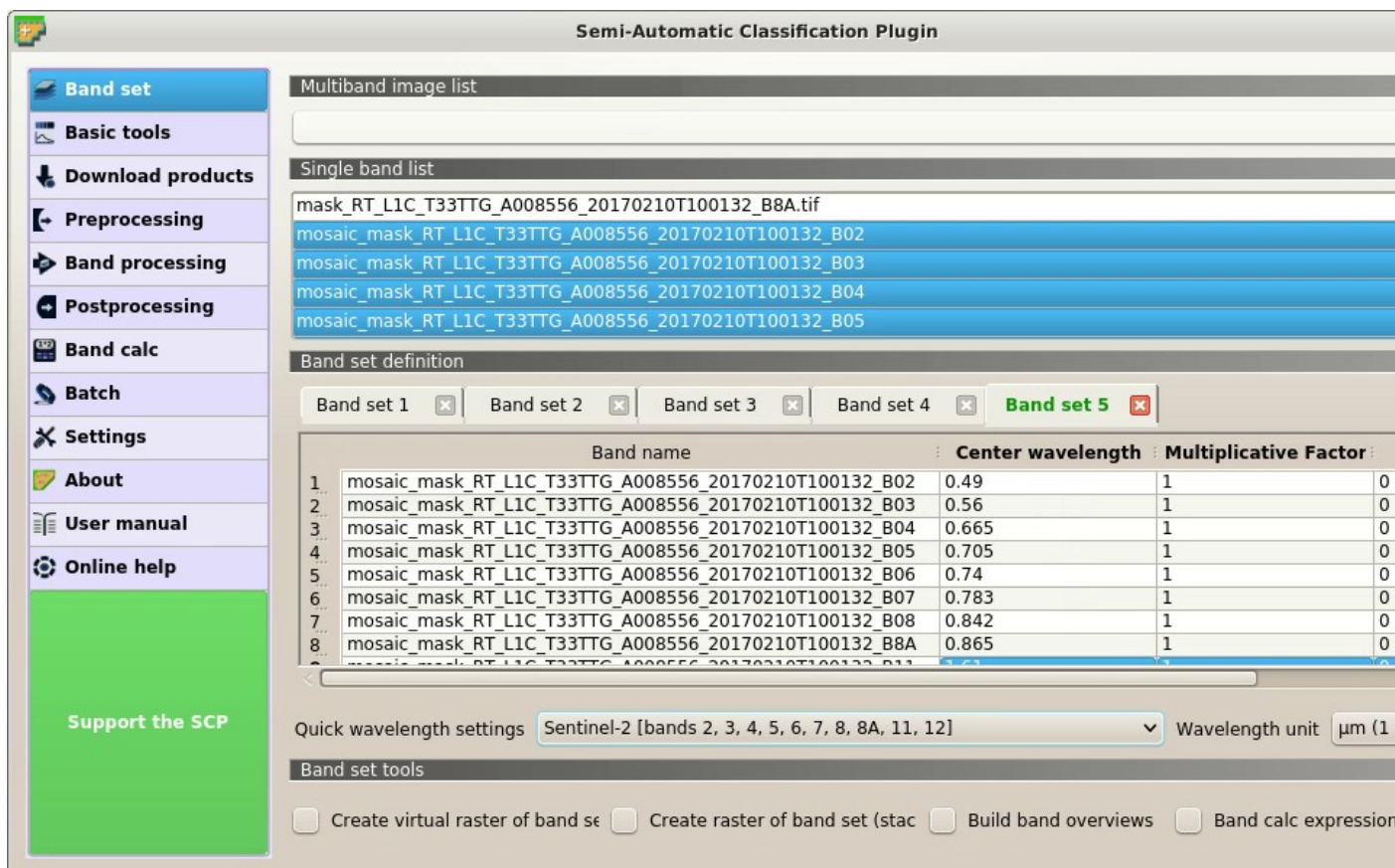


Fig. 52: New Band set

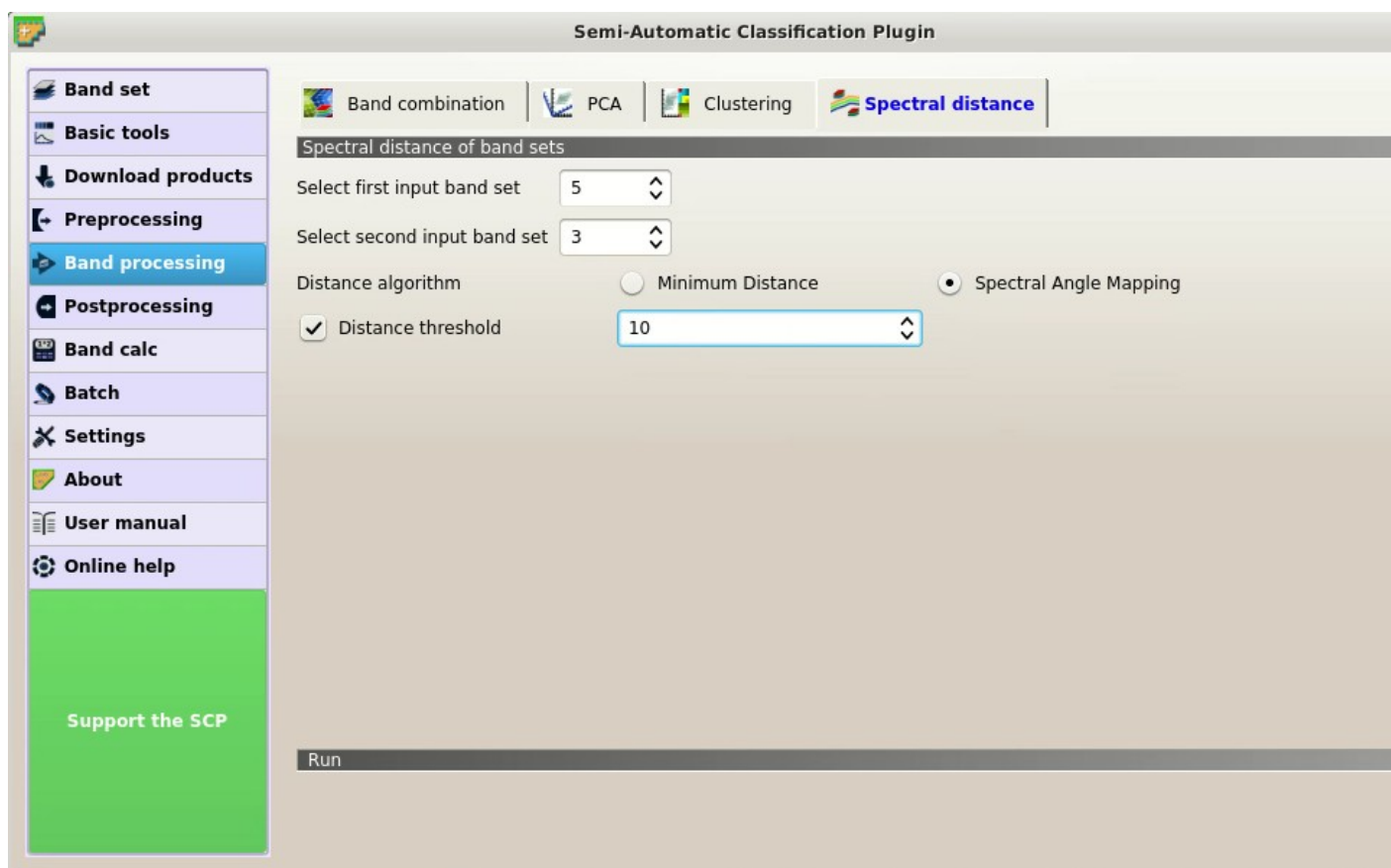
Fig. 53: *Spectral distance*





Fig. 54: *Raster of changes*



This is an automatic method for locating land cover changes. We can see that most land cover changes are due to crop variations.

For instance, this method could be useful to assess vegetation burnt area or forest logging. We could set a different threshold value for increasing or reducing the number of pixels identified as changes.

Of course, in order to identify the type of land cover change we should identify the land cover classes of the images through photo-interpretation or with semi-automatic classification.

The following are advanced tutorials using the Semi-Automatic Classification Plugin (SCP). It is assumed that you have already performed the *Basic Tutorials* (page 139).

### 6.1 Tutorial 3

The following is a tutorial about the functions of the Semi-Automatic Classification Plugin (SCP). It is assumed that you have a basic knowledge of QGIS.

- *Tutorial 3: Accuracy Assessment of a Land Cover Classification* (page 191)
  - *Sample Design* (page 192)
  - *Sample Collection and Photo-Interpretation* (page 194)
  - *Calculation of Accuracy Statistics* (page 200)

#### 6.1.1 Tutorial 3: Accuracy Assessment of a Land Cover Classification

Accuracy assessment is a fundamental step after land cover classification in order to evaluate errors, globally and for each class, and finally evaluate the reliability of the map.

This post is a tutorial about accuracy assessment of a land cover classification using the Semi-Automatic Classification Plugin (SCP) for QGIS. We are going to use the function of SCP to create ROIs using stratified random points (a new function of SCP 6.4.0), which will be photo-interpreted and used as reference for the accuracy assessment. The SCP tool *Accuracy* (page 75) will take care of the rest, providing the error matrix and the accuracy estimates.

The following is the video tutorial, and the following text illustrates the phases in detail.

<http://www.youtube.com/watch?v=H1cL0yhIygg>

Accuracy assessment is performed comparing a sample of points (ground truth) to the classification. There are several ways to choose the sample size and the allocation thereof (sample scheme). The sample should be designed in order to achieve low standard errors of accuracy estimates, and usually this is achieved by random selection of samples.

Sample design depends on several variables such as the proportions of land cover classes and the standard errors that we expect for the overall land cover classification and single classes. In order to reduce standard errors of class specific estimates, it is recommended to stratify the sample. For further details about how to determine the sample size and the stratification, please refer to “Olofsson, et al., 2014. Good practices for estimating area and assessing accuracy of land change. Remote Sensing of Environment, 148, 42 – 57”.

## Sample Design

This tutorial assumes that you have already performed the classification of a Landsat image following the instructions of this previous [Tutorial 1: Your First Land Cover Classification](#) (page 139). You can download the classification raster from [this archive](#).

The land cover classes are described in the following table.

*Classes*

| Macroclass name            | Class ID |
|----------------------------|----------|
| Water                      | 1        |
| Built-up                   | 2        |
| Vegetation                 | 3        |
| Bare soil (low vegetation) | 4        |

Basically, the main requirement is to provide an adequate number of samples for each class, even if the class area proportion ( $W_i$ ) is low. The number of samples ( $N$ ) should be calculated as (Olofsson, et al., 2014):



$$N = \left( \sum_{i=1}^c (W_i - S_i) / S_o \right)^2$$



where:


- $W_i$  = mapped area proportion of class  $i$ ;
- $S_i$  = standard deviation of stratum  $i$ ;
- $S_o$  = expected standard deviation of overall accuracy;
- $c$  = total number of classes;

This requires some conjectures about overall accuracy and user’s accuracy of each class. We should base these conjectures on previous studies. One can hypothesize that user’s accuracy is lower and standard deviations  $S_i$  is higher for classes having low area proportion, but of course these values should be carefully evaluated.

To get  $W_i$  start QGIS and load the classification raster.

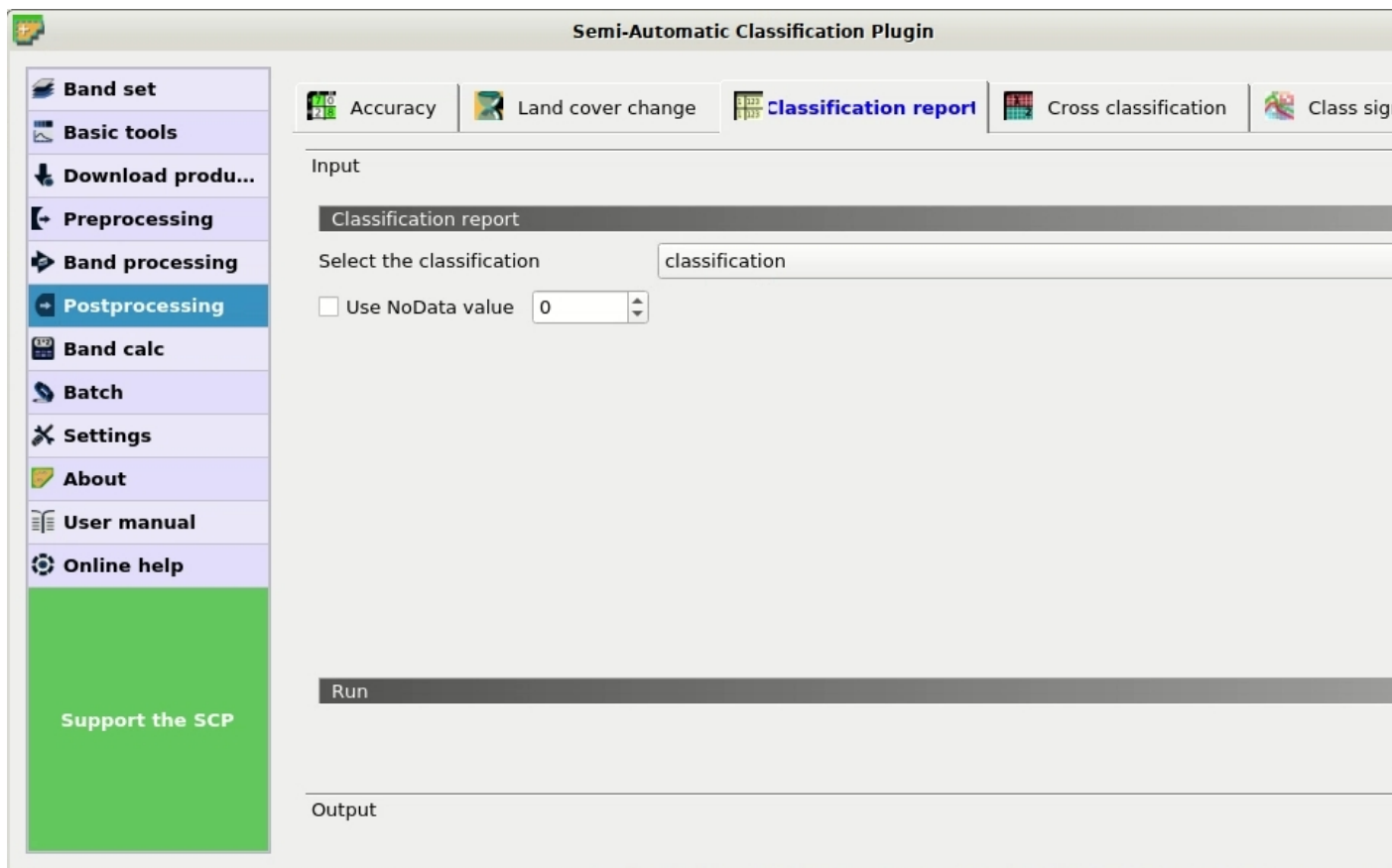
Open the [SCP menu](#) (page 21) and click the tab  [Classification report](#) (page 77) under the submenu  [Postprocessing](#). This tool allows for estimating class area and class percentage.

Click the button  to refresh the layer list, and select the classification raster in *Select the classification* 

; next click  *RUN* to start the calculation; the output report is saved in a text file and displayed in the tab *Output*.

The report table contains the percentage of each class, which we divide by 100 to get the required  $W_i$ . In this tutorial we assume  $S_o = 0.01$  and conjecture the  $S_i$  values reported in the following table (of course, these assumptions are specific of this classification, other assumptions should be made for other classifications).

*Conjectured standard deviations*

Fig. 1: *Classification report*

| Land Cover Class | Area $m^2$  | $W_i$  | $S_i$ | $W_i * S_i$ |
|------------------|-------------|--------|-------|-------------|
| 1                | 976,500     | 0.0033 | 0.4   | 0.0013      |
| 2                | 111,267,000 | 0.3713 | 0.3   | 0.1114      |
| 3                | 187,018,200 | 0.6240 | 0.2   | 0.1248      |
| 4                | 438,300     | 0.0015 | 0.5   | 0.0007      |
| Total            |             |        |       | 0.2382      |

Therefore,  $N = (0.2382/0.01)^2 = 567$  is the number of samples that we should distribute among classes.

To stratify the sample we should conjecture user's accuracy and standard deviations of strata (Olofsson, et al., 2014).

A rough approximation is considering the mean value between equal distribution ( $N_i = N/c$ ) and weighted distribution ( $N_i = N * W_i$ ), which is  $N_i = (N/c + N * W_i)/2$  as illustrated in the following table.

*Sample stratification*



| Land Cover Class | Weighted | Equal | Mean |
|------------------|----------|-------|------|
| 1                | 2        | 142   | 72   |
| 2                | 210      | 142   | 176  |
| 3                | 354      | 142   | 248  |
| 4                | 1        | 142   | 71   |
| Total            |          |       | 567  |

## Sample Collection and Photo-Interpretation


This phase involves the creation of (randomly selected) single pixel *Training Areas* (page 117) (ROIs), and the attribution of a land cover class based on photo-interpretation of each ROI.

First, we need to define a *Band set* containing the classification raster that is an input required by the other tools we are going to use.


Open the tab *Band set* (page 37) clicking the button  in the *SCP menu* (page 21) or the *SCP dock* (page 23).

Click the button  to refresh the layer list, and select the classification raster; then click  to add selected raster to the *Band set 1*.

We need to create the *Training input* (page 24) in order to collect ROIs that will be the actual samples.

In the *SCP dock* (page 23) select the tab *Training input* (page 24) and click the button  to create the *Training input* (define a name such as `sample.scp`). The path of the file is displayed and a vector is added to QGIS layers with the same name as the *Training input* (in order to prevent data loss, you should not edit this layer using QGIS functions).

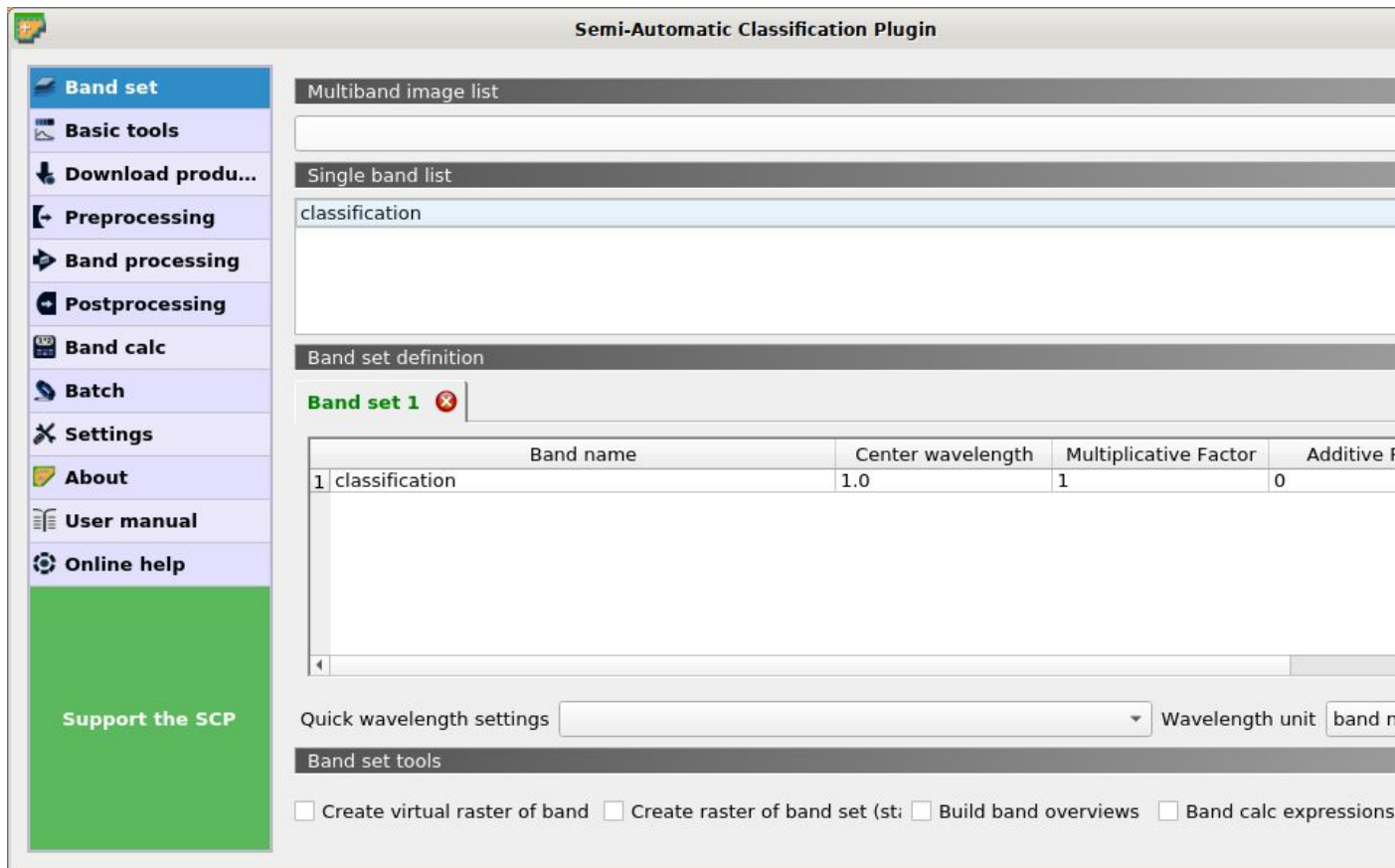
Now we are going to create the stratified random sample using the SCP tool Multiple ROI creation. This tool allows for the random creation of point coordinates according to the sample scheme previously defined.

**TIP :** In case you have already collected samples you can import (using the button ) a shapefile or a csv file containing the coordinates and the classification codes.

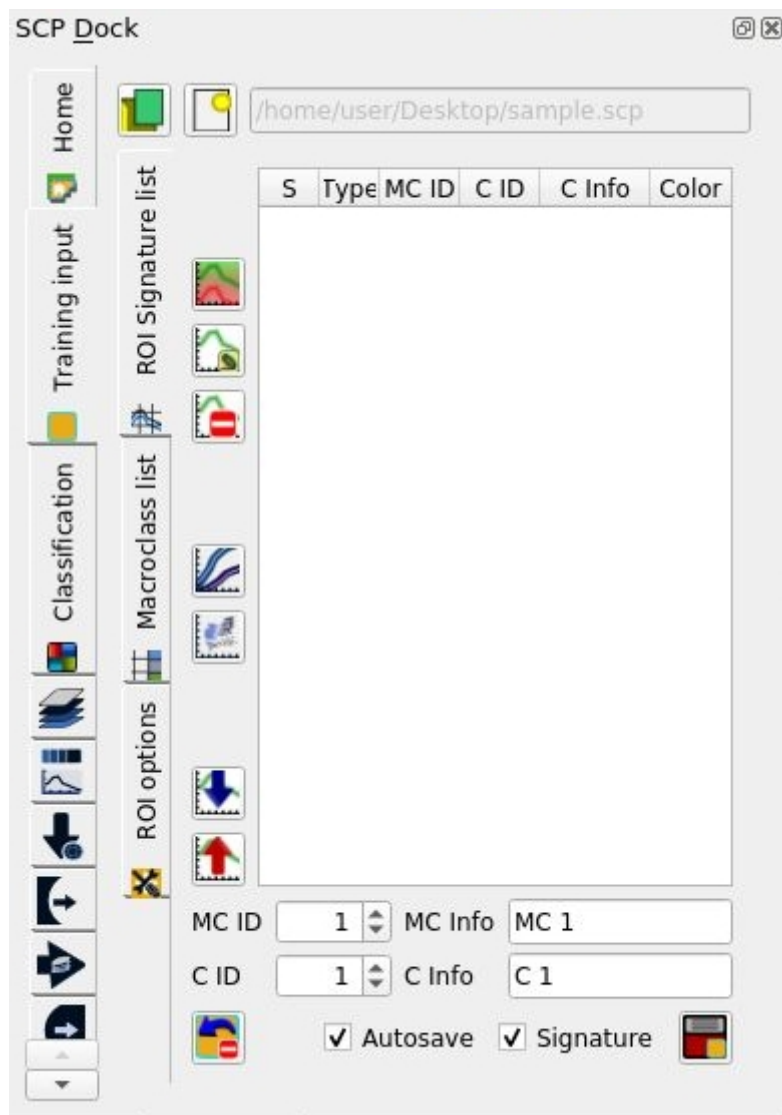
This tool works in two steps:

1. randomly select point coordinates defining ROI parameters;
2. actually create ROI polygons based on point coordinates;


During the first step, in addition to point coordinates, other fields are automatically filled in the table from the parameters set in the *Working toolbar* (page 34), such as the minimum and maximum ROI size. In this tutorial we use single pixel ROIs, although cluster sampling (several pixels per ROI) is also used for accuracy assessment. To

Fig. 2: *Band set definition*



Fig. 3: *Training input*

avoid manually editing these fields after the random point creation, in *Temporary ROI* (page 34) we need to set the parameters  $Min = 1$  and  $Max = 1$ . Created random samples will have the size of 1 pixel.

Now, open the *SCP menu* (page 21) and click the tab  *Multiple ROI Creation* (page 43) under the submenu  Basic tools.

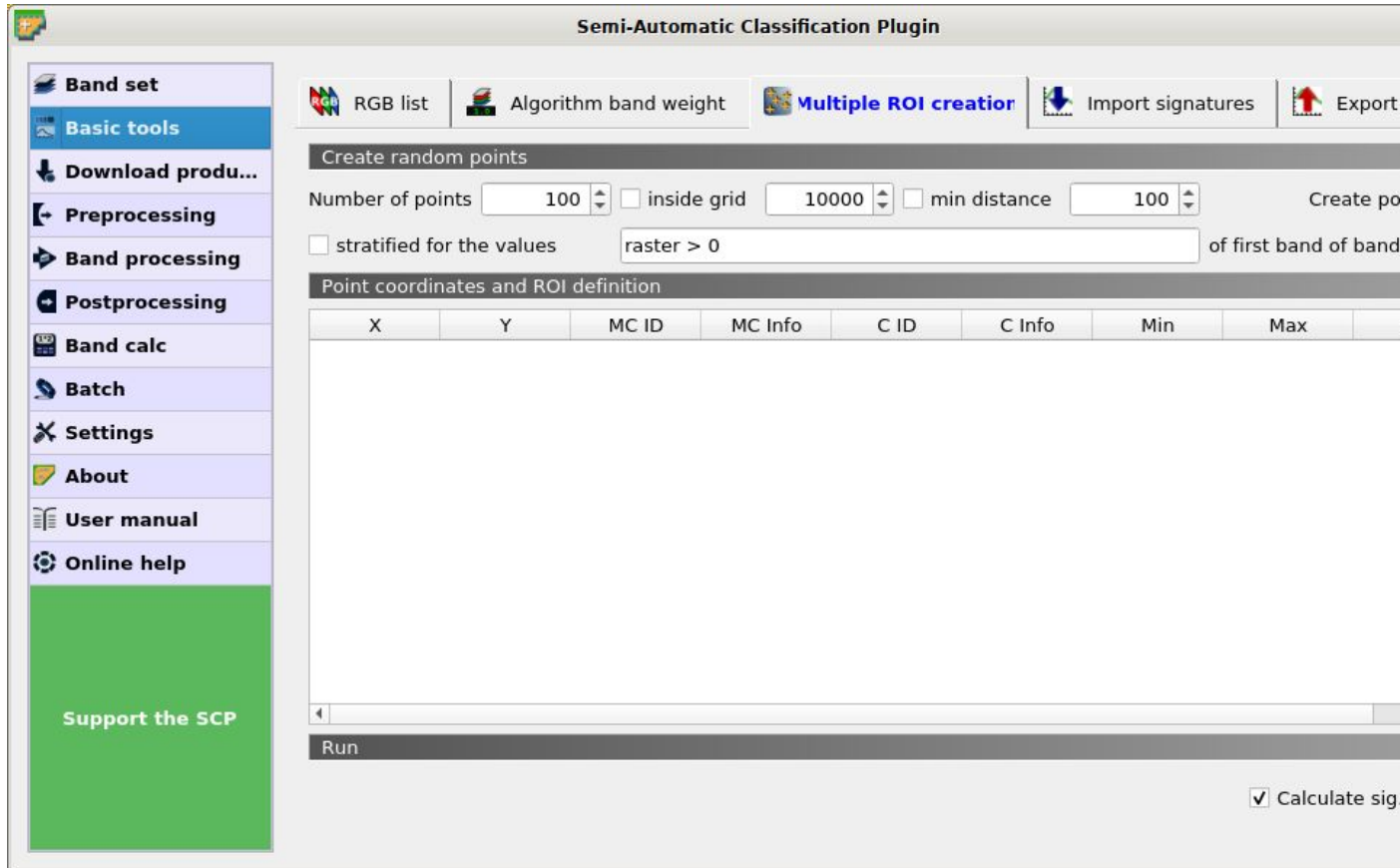





Fig. 4: Multiple ROI creation

To reduce the photo-interpretation time (considering the illustrative purpose of this tutorial and that the classification is a subset of a Landsat image), we are going to divide the number of samples by 10 according to the following table (of course, in real cases we must use all the samples as designed).

*Number of stratified samples*

| Land Cover Class | Samples |
|------------------|---------|
| 1                | 7       |
| 2                | 18      |
| 3                | 25      |
| 4                | 7       |
| Total            | 57      |

In *Number of points* enter 7 that is the number of samples designed for class 1. In the tab  *Multiple ROI Creation* (page 43) check the option  *stratified for the values* and enter the first expression `raster == 1` (notice the double “=”). This expression means that we are going to randomly select points that fall over pixels having value 1 of the classification (that is the first band of the Band set 1).

Therefore click *Create points*  to start the random creation. After a while point coordinates will be added to

the table *Point coordinates and ROI definition* (page 44).

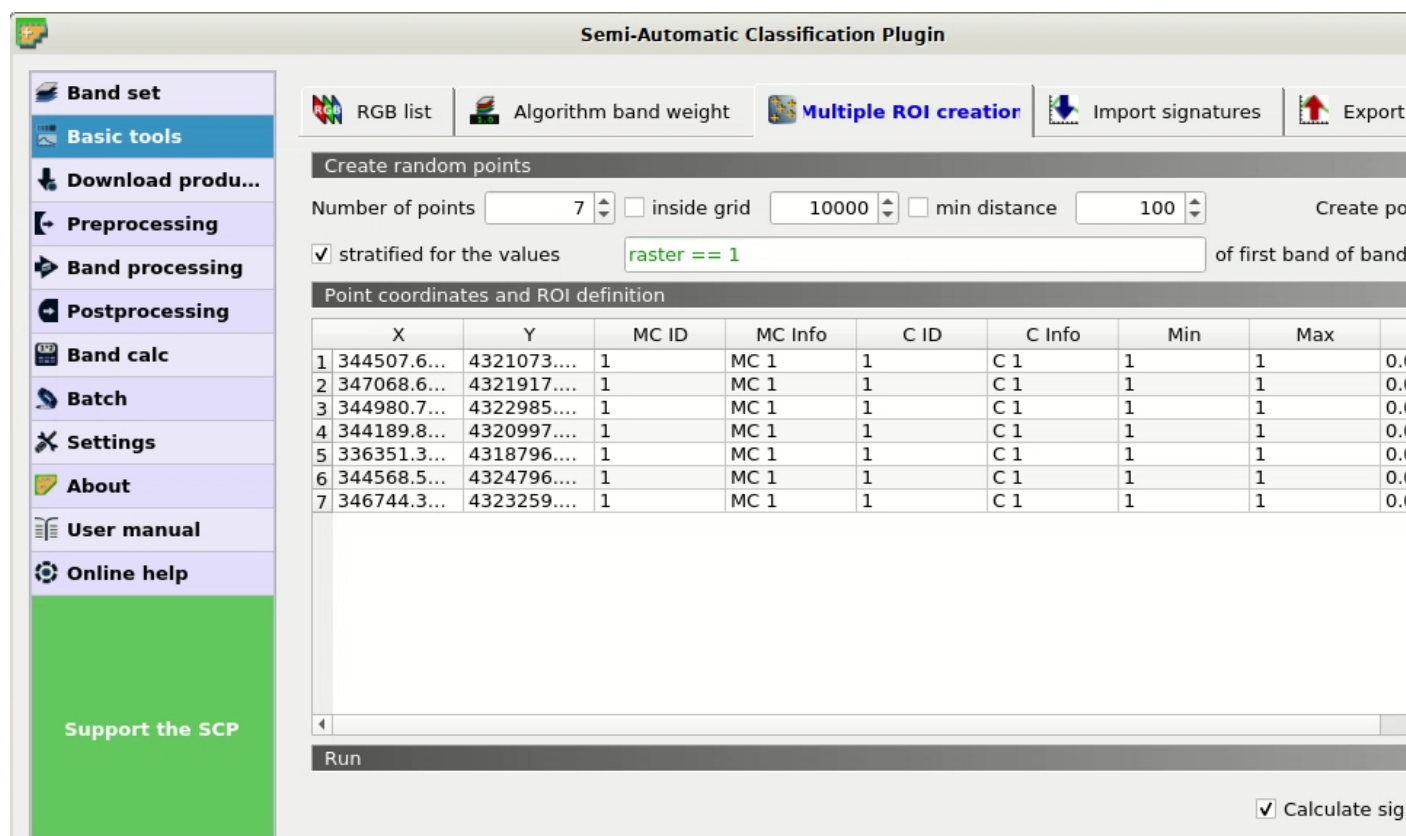





Fig. 5: Samples for class 1

Now we repeat the above steps for class 2. In *Number of points* enter 18 and in *stratified for the values* enter `raster == 2`. Click *Create points*  and the samples will be added to the table.

Repeat the same steps for class 3 (25 points and `raster == 3`) and for class 4 (57 points and `raster == 4`). Now that we have all the required samples we can create the ROIs (the single pixel polygons that will be photo-interpreted).

Uncheck the option  *Calculate sig.* because we don't need the spectral signature of ROIs and click *RUN* . After a while the ROIs will be added to the *Training input*.

The type R means that, of course, spectral signatures were not calculated. All the created ROIs have the same MC ID (i.e. macroclass ID) and C ID (i.e. class ID); now we can assign the correct class (MC ID) to each ROI with photo-interpretation using images with resolution higher than the classification, or other services such as [OpenStreetMap](#)).

In the *ROI Signature list* (page 27), double click on the first ROI in order to zoom to the ROI; after photo-interpreting the class we can assign the correct MC ID and C ID with a click on the corresponding field in the ROI list.

Of course we need to perform the photo-interpretation of all the samples, assigning the correct code. The photo-interpretation should be performed without considering the classification raster. It is worth highlighting that spatial resolution (i.e. 30m) implies mixed pixels (i.e. pixels made of multiple materials at ground); therefore, during the photo-interpretation we must consider the most prevalent land cover in the ROI area.

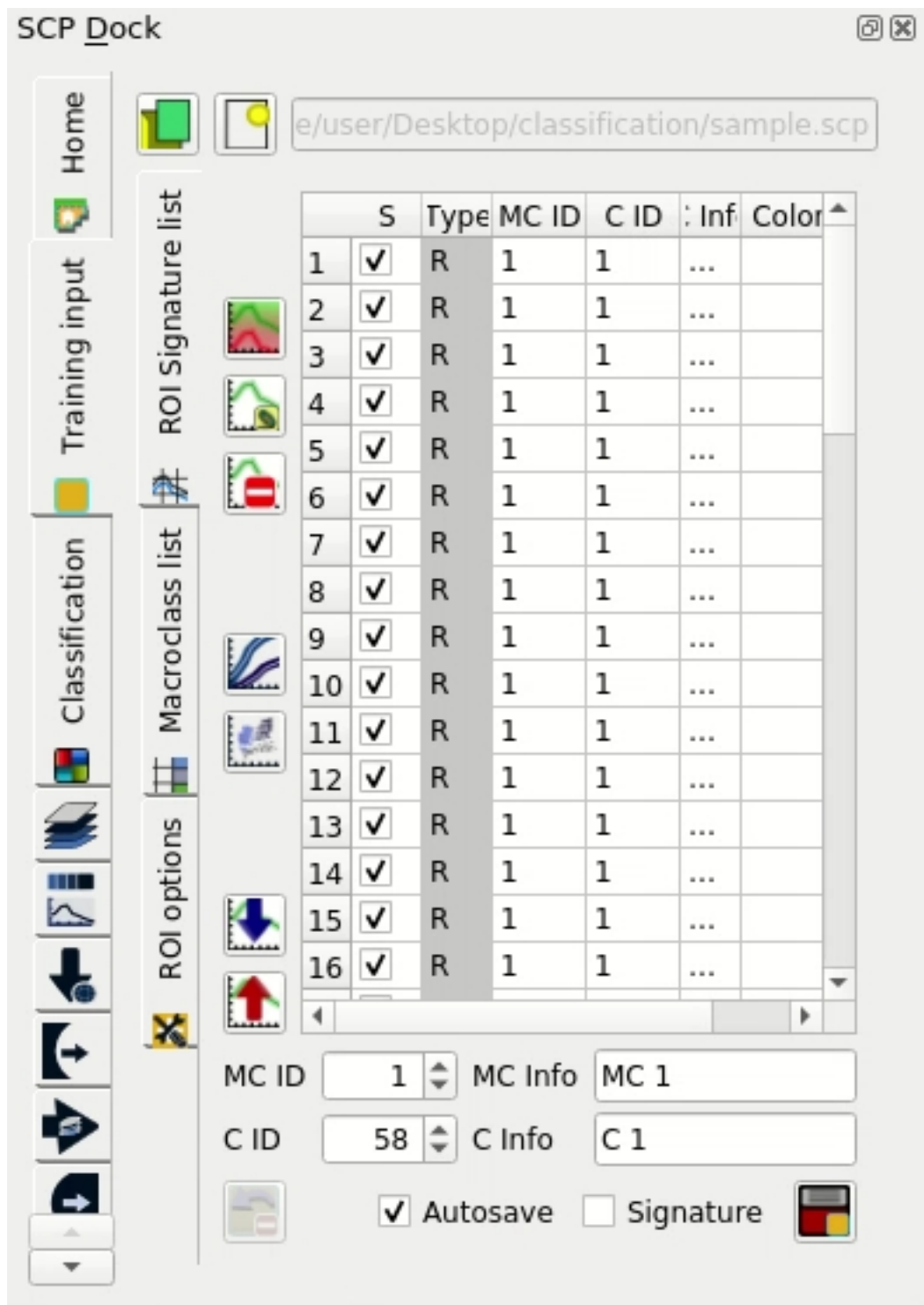


Fig. 6: Samples added to the training input

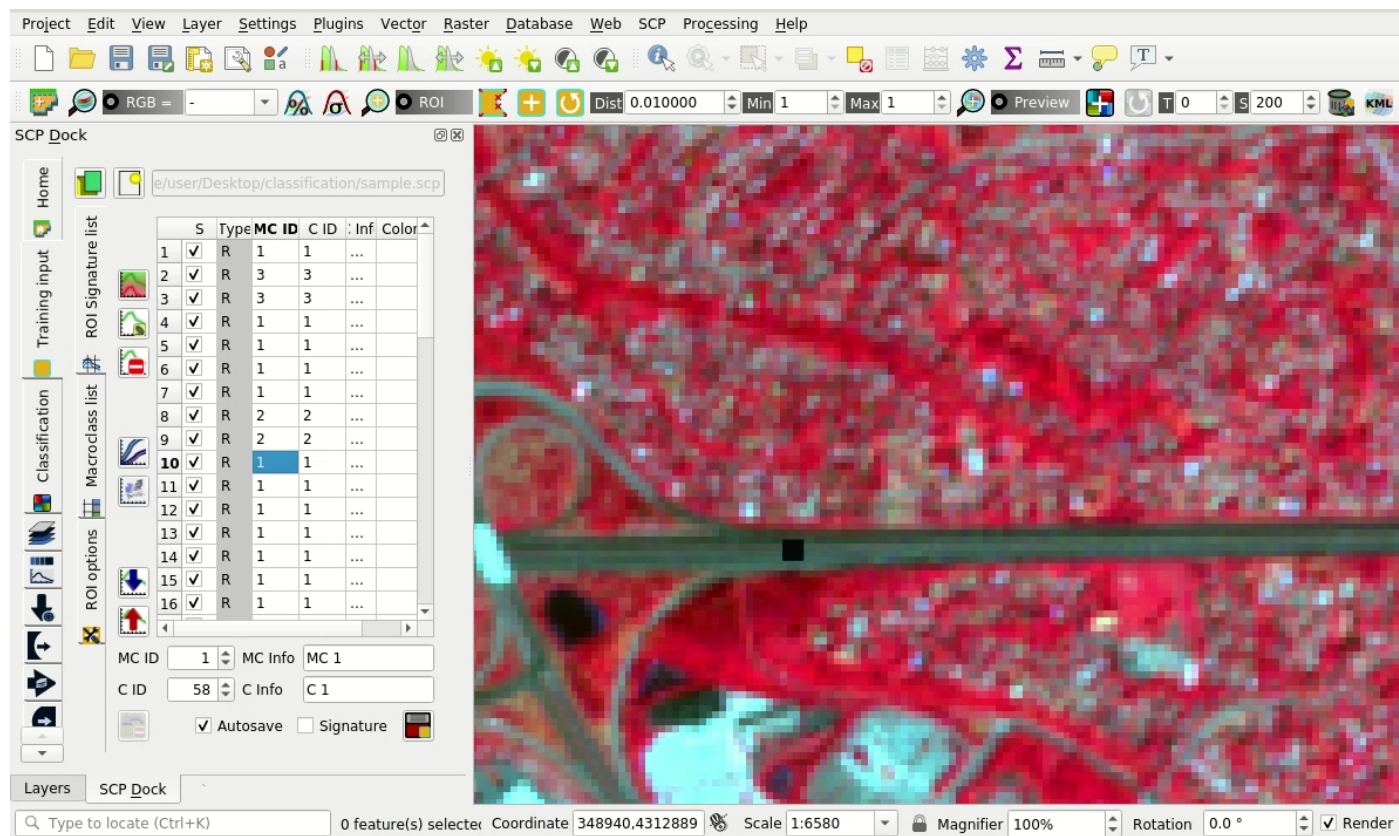




Fig. 7: A sample over a road photo-interpreted using a Copernicus Sentinel-2 image



## Calculation of Accuracy Statistics

After the photo-interpretation of all the samples, we can perform the accuracy assessment by comparing the ROIs to the classification. If you have skipped the previous step, you can download the photo-interpreted sample from [here](#).

The process will produce an error raster (a .tif file showing the errors in the map, where pixel values represent the combinations between the classification and reference identified by the `ErrorMatrixCode` in the error matrix) and a text file (i.e. a .csv file separated by tab) containing the error matrix and the accuracy statistics.

Open the [SCP menu](#) (page 21) and click the tab  [Accuracy](#) (page 75) under the submenu  [Postprocessing](#).

In *Select the classification to assess*  select the classification (click the button  if the raster isn't in the list).

In *Select the reference vector or raster*  select the sample vector that is the [Training input](#) (page 24), and in *Vector field*  select MC\_ID that is the vector field containing the class values.

Now we can click **RUN**  to start the raster processing.

After the calculation the accuracy statistics are displayed in the output interface and the error raster is loaded in QGIS.

Several statistics are calculated such as overall accuracy, user's accuracy, producer's accuracy, and Kappa hat. In particular, these statistics are calculated according to the area based error matrix (Olofsson, et al., 2014) where each element represents the estimated area proportion of each class. This allows for estimating the unbiased user's accuracy and producer's accuracy, the unbiased area of classes according to reference data, and the standard error



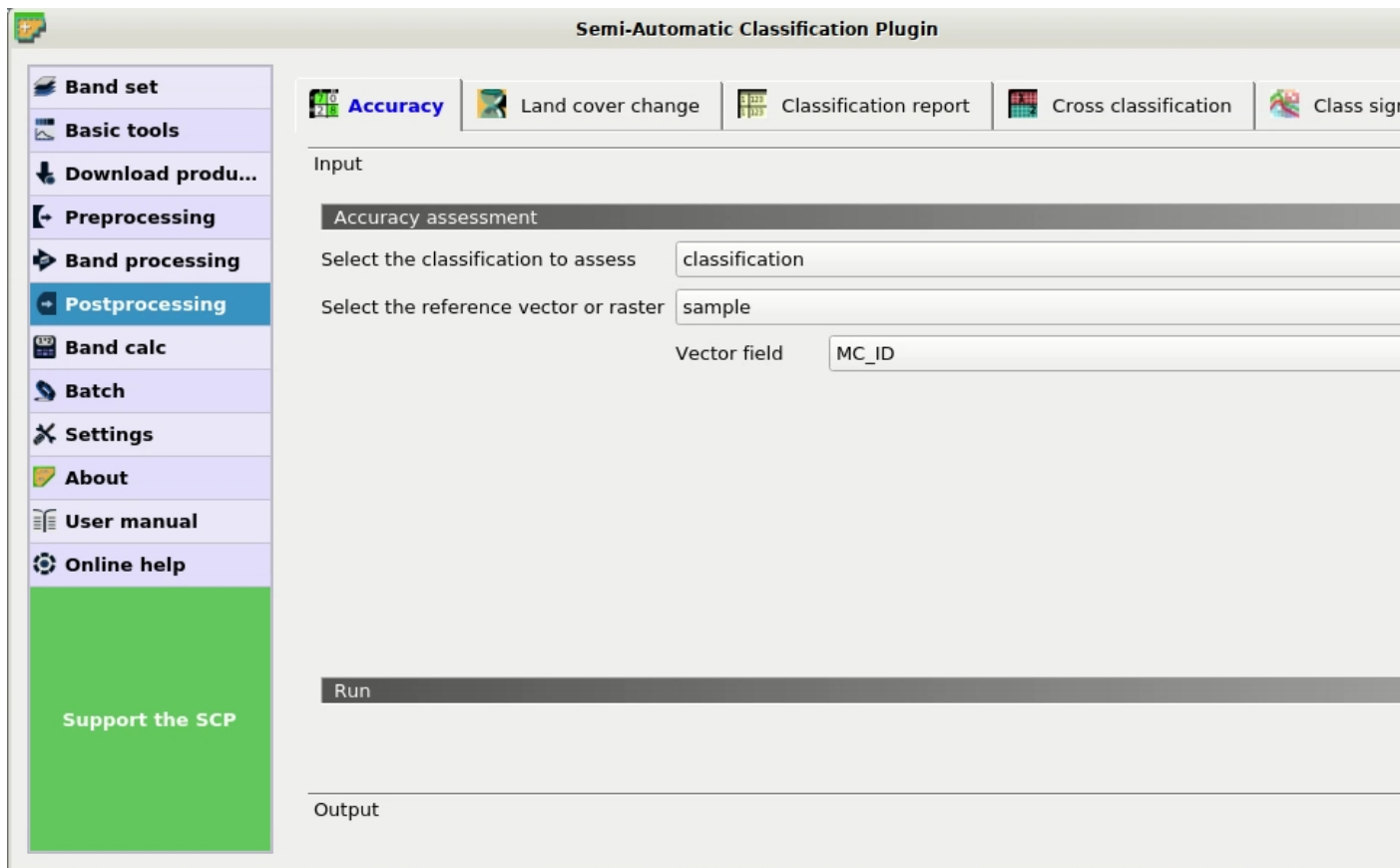


Fig. 8: The tool Accuracy

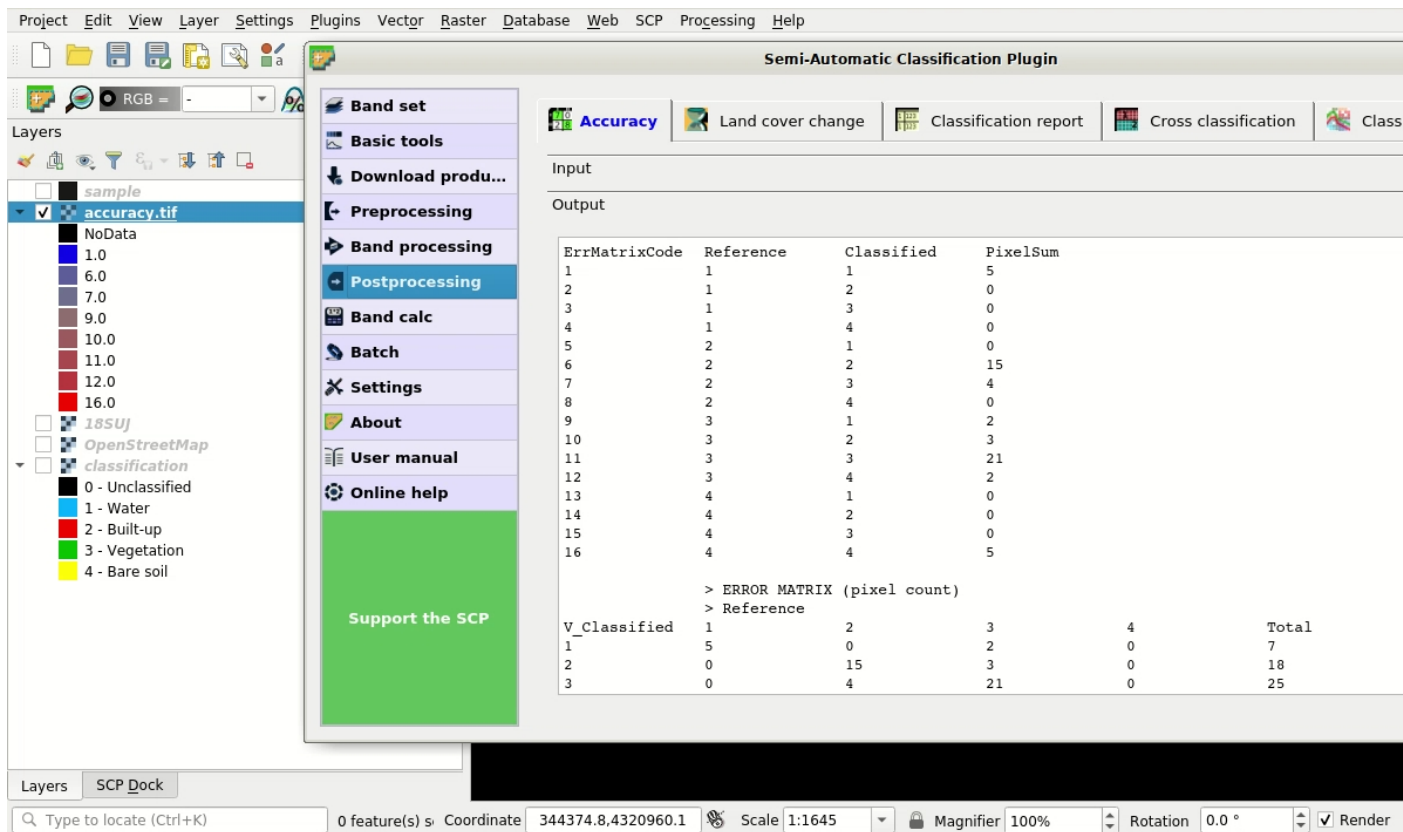


Fig. 9: Output



of area estimates and the confidence intervals. Of course the standard errors are influenced by the low number of samples that we have collected in this tutorial.

#### *Area based error matrix*

|            |   | Reference |        |        |        |
|------------|---|-----------|--------|--------|--------|
|            |   | 1         | 2      | 3      | 4      |
| Classified | 1 | 0.0023    | 0      | 0.0009 | 0      |
|            | 2 | 0         | 0.3094 | 0.0619 | 0      |
|            | 3 | 0         | 0.0998 | 0.5242 | 0      |
|            | 4 | 0         | 0      | 0.0004 | 0.0010 |
| Total      |   | 0.0023    | 0.4092 | 0.5874 | 0.0010 |

The overall accuracy is 83.7% that is a good result (above 80%). However, this classification was produced for the first basic tutorial, therefore the classification could be improved. Also, note that we used a number of samples lower than designed sample.

The user's and producer's accuracy are provided for each class.

#### *Producer's and user's accuracy*

|                     | 1     | 2    | 3    | 4     |
|---------------------|-------|------|------|-------|
| Producer's accuracy | 100.0 | 75.6 | 89.2 | 100.0 |
| User's accuracy     | 71.4  | 83.3 | 84.0 | 71.4  |

We can see that classes 1 and 4 (bare soil and water respectively) have low user's accuracy, while class 2 (built-up) has low producer's accuracy. We also get the unbiased area estimates (in  $m^2$ ) and the confidence intervals.

#### *Unbiased area estimates*

|                              | 1       | 2           | 3           | 4       |
|------------------------------|---------|-------------|-------------|---------|
| Area                         | 697,500 | 122,645,412 | 176,044,017 | 313,071 |
| 95% Confidence interval Area | 352,984 | 33,778,661  | 33,780,877  | 158,436 |

These estimates are quite different from the ones directly derived from the classification raster (in the classification report), but are based on reference data. For instance, the class 2 (built-up) has an estimated area of 122,645,412  $m^2$ , while it resulted 111,267,000  $m^2$  from the classification raster. Also, the confidence intervals provide information about the uncertainty of these estimates.

## 6.2 Tutorial 4

The following is a tutorial about the functions of the Semi-Automatic Classification Plugin (SCP). It is assumed that you have a basic knowledge of QGIS.

- *Tutorial 4: Postprocessing tools for assessing land cover change* (page 203)
  - *Refine the classifications with direct editing* (page 203)
  - *Classification report* (page 206)
  - *Reclassification* (page 206)
  - *Remove isolated pixels* (page 209)
  - *Assess land cover change* (page 210)
  - *Analyze the context of land cover changes* (page 212)

- *Assess the spectral signature of changes* (page 214)
- *Export the changes to vector format* (page 217)

### 6.2.1 Tutorial 4: Postprocessing tools for assessing land cover change

This tutorial aims to analyze land cover change using SCP Postprocessing tools. Basically, we are going to assess land cover change from two raster classifications, and relate the changes to a land use vector file. An overview of several postprocessing tools is also provided.

The following is the video tutorial, and the following text illustrates the phases in detail.

<http://www.youtube.com/watch?v=0IUosyr4pRw>

The tools can be applied to any land cover classification, but we are going to use [Copernicus data](#), which are freely available (as established by the EU Regulation No 1159/2013 of 12 July 2013) and cover the European countries. Of course, this tutorial is designed for demonstration purposes and it is not endorsed by the European Union. The original Copernicus data (produced with funding by the European Union) are downloaded from <https://land.copernicus.eu/> and remain the sole property of the European Union.

Following, a brief description of the data we are going to use.

The [Copernicus High Resolution Layers](#) are raster classifications with 20m spatial resolution. Several land cover classes are available, but in this tutorial we are going to use the Imperviousness Density for 2012 and 2015. These data classify the degree of imperviousness (0-100% of impermeable cover of soil), which is the artificially sealed area. The Imperviousness Density was produced using automatic derivation based on calibrated Normalized Difference Vegetation Index. You can find the detailed product specifications [here](#).

The [Copernicus Corine Land Cover](#) is a land use/land cover vector produced by standard methodology of photo-interpretation of satellite images. The vector is classified in 44 classes divided in 3 hierarchical levels with minimum mapping unit of 25 hectares. In this tutorial we are considering only the first level of Corine Land Cover 2012, divided in these classes:

1. artificial surfaces
2. agricultural areas
3. forests and semi-natural areas
4. wetlands
5. water bodies

#### Refine the classifications with direct editing

You can download the data for this tutorial from [this archive](#), or use your own data (two classification rasters and a land use vector).




For this tutorial, the original Copernicus data were modified by clipping the rasters to a small area over Florence (Italy).

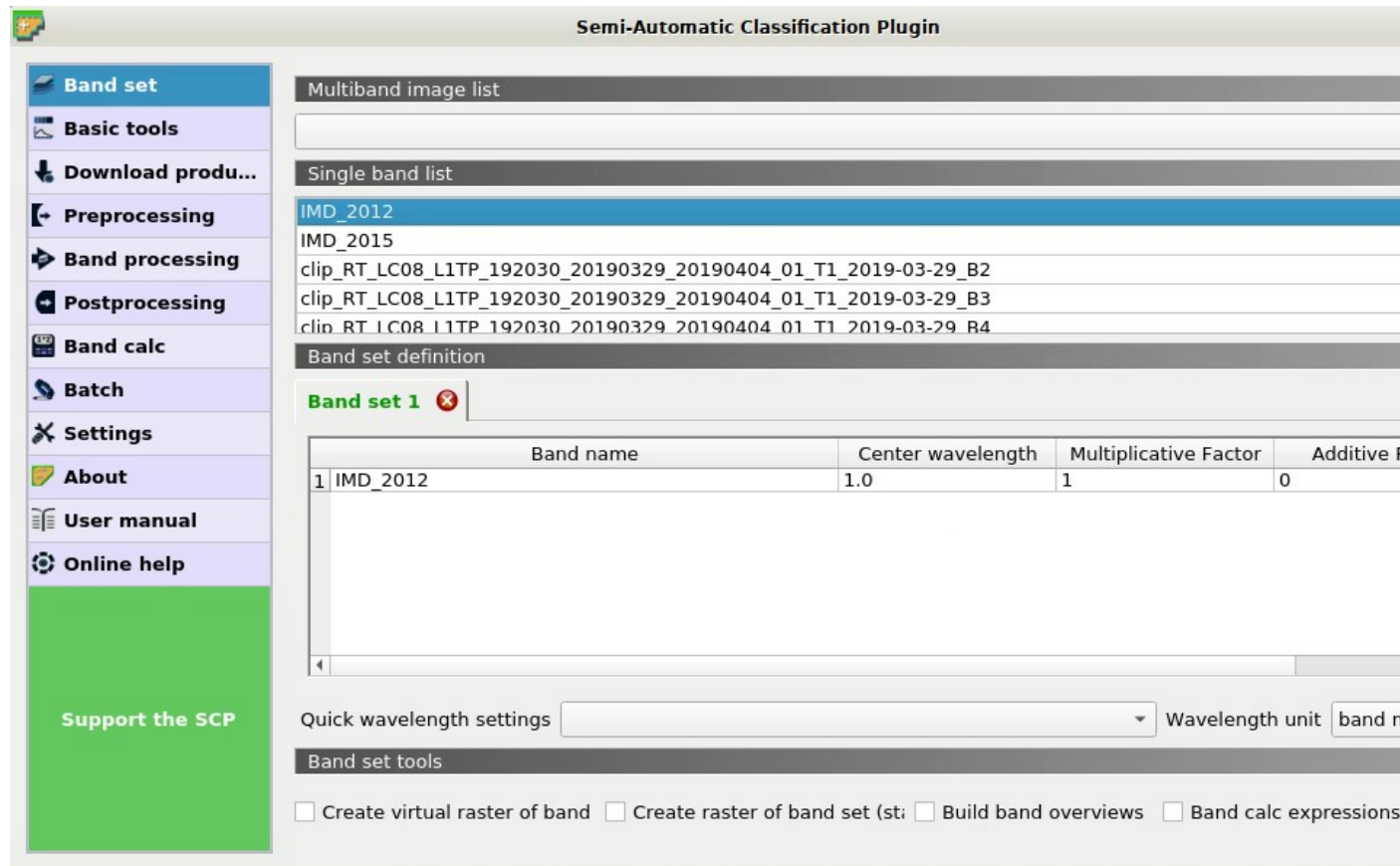
Start QGIS and load the two rasters `IMD_2012.tif` and `IMD_2015.tif` that are Copernicus Imperviousness Density for 2012 and 2015 respectively. As you can see, the rasters have values from 0 to 100, representing the degree of imperviousness.

It is useful to refine the classification by photo-interpretation, especially for data produced by semi-automatic processing.

We can use high resolution images or other services such as [OpenStreetMap](#). For example you can follow this tutorial [Download the Data](#) (page 140) to download satellite images, or you can download a subset of a Landsat 8 image, already converted to reflectance, from [this link](#) (about 27 MB, data available from the U.S. Geological Survey), unzip the downloaded file, and load the bands in QGIS.


First, we need to define a *Band set* containing a classification raster (this is required for drawing ROIs).



Open the tab *Band set* (page 37) clicking the button  in the *SCP menu* (page 21) or the *SCP dock* (page 23). Click the button  to refresh the layer list, and select the `IMD_2012` raster (just this raster is sufficient); then click  to add selected raster to the *Band set 1*.

Fig. 10: *Band set definition*

Optionally, we can create a band set for the satellite image to display a color composite; open the tab *Band set* (page 37) and select all the Landsat bands in the list; click  to add a new band set, then click  to add selected rasters to the *Band set 2*.

In QGIS zoom to an area where we want to correct the classification. In this case we are going to manually remove a few pixels pretending they are classification errors.

We need to manually create a ROI, but first check that the *Band set 1* is active. Now click the button  in the *Working toolbar* (page 34). Left click on the map to define the ROI vertices and right click to define the last vertex closing the polygon. An orange semi-transparent polygon is displayed over the image, which is a temporary polygon (in this case we don't need to define the *Training input*).

Now open the tool  *Edit raster* (page 82) opening the *SCP menu* (page 21) and the submenu *Postprocessing*. Select the *Input raster*, for instance `IMD_2012`. According to the legend of Imperviousness Density, in  *Use constant value* enter 100 (we want to correct impervious pixels; in case we would like to correct not impervious pixels we would enter the value 0). The other options are fine. Therefore, click *RUN*



to edit the raster.

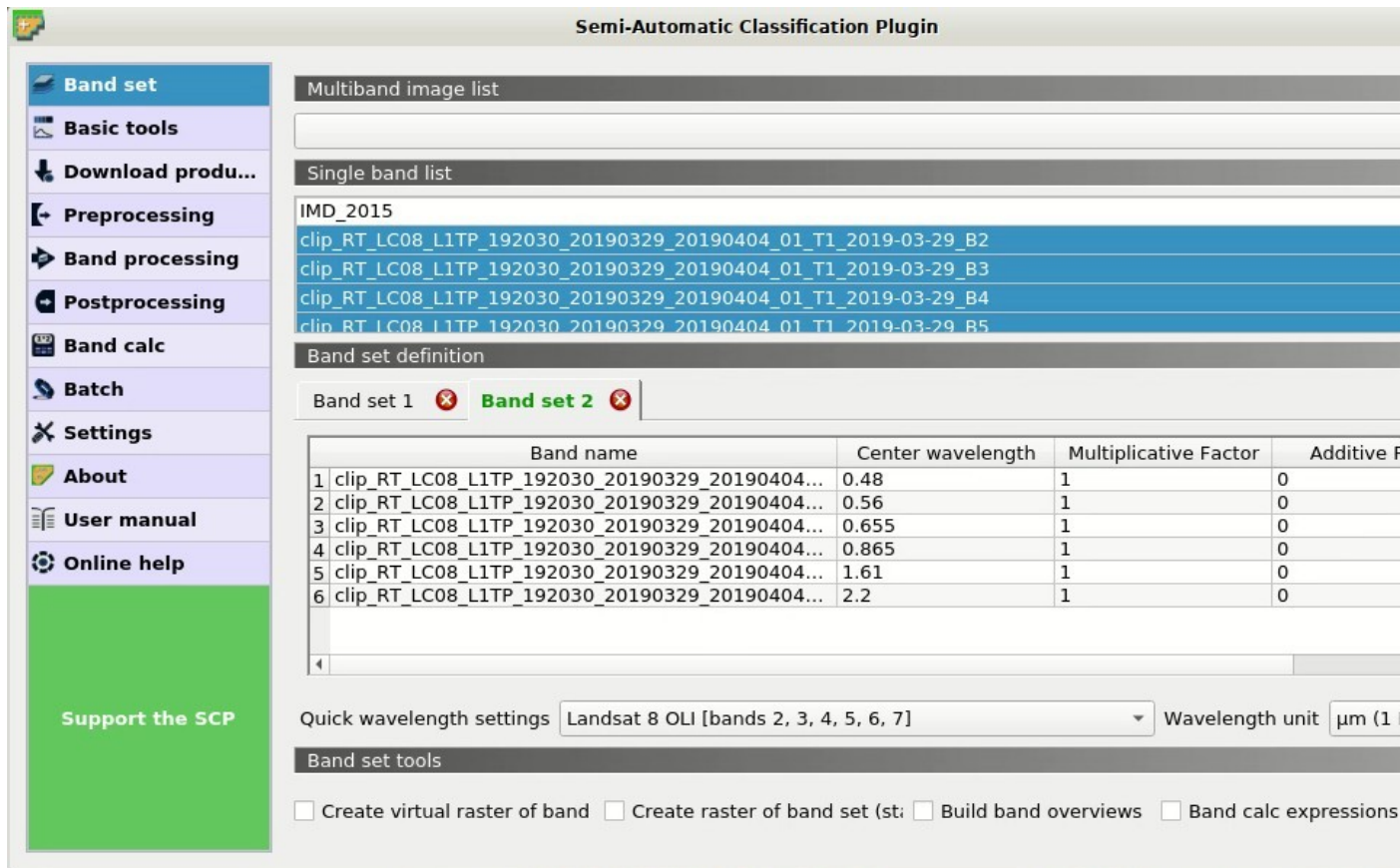


Fig. 11: Band set of the Landsat image

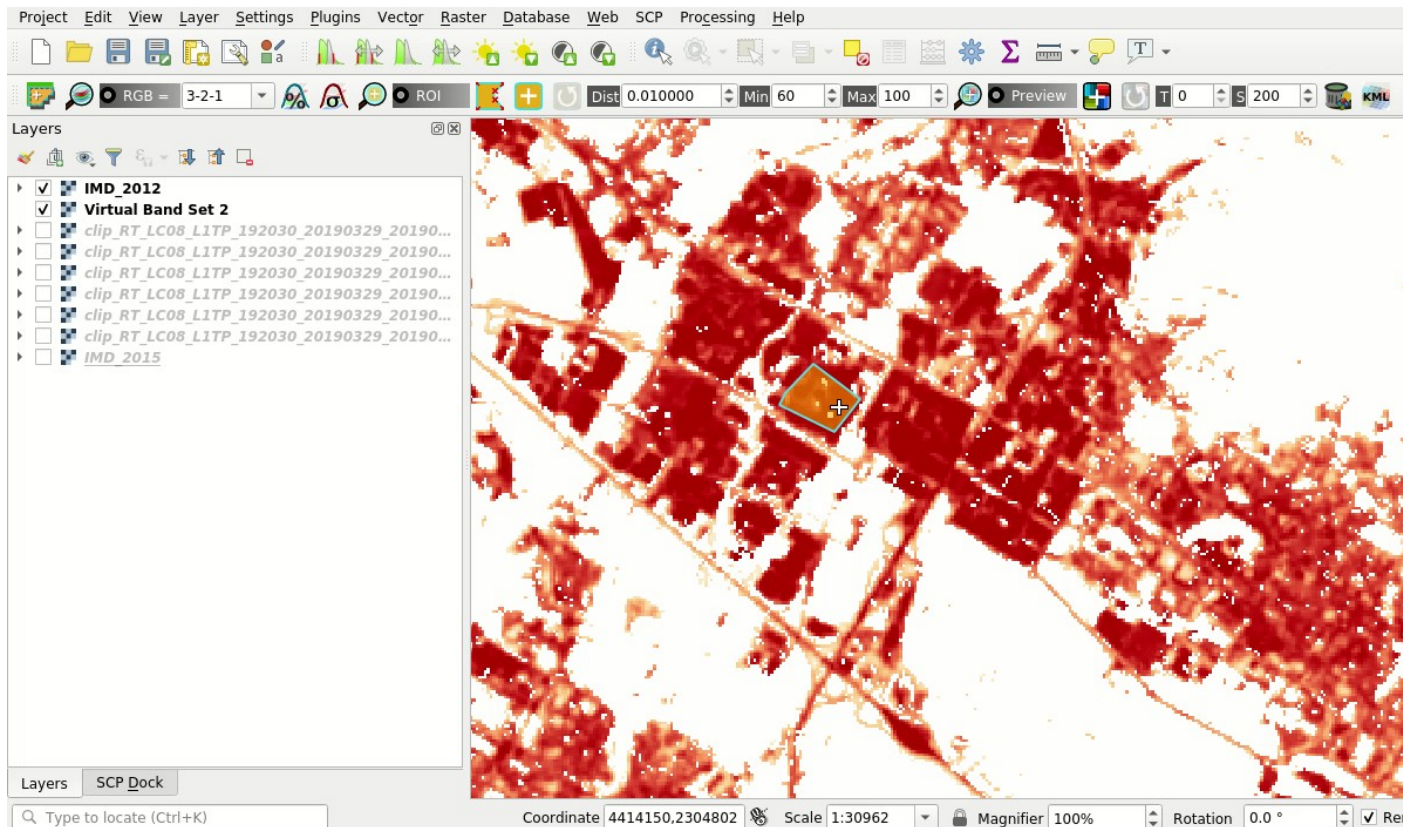


Fig. 12: Manual ROI polygon



**Attention:** the input raster is directly edited; it is recommended to create a **backup copy** of the input raster before using this tool in order to prevent data loss.

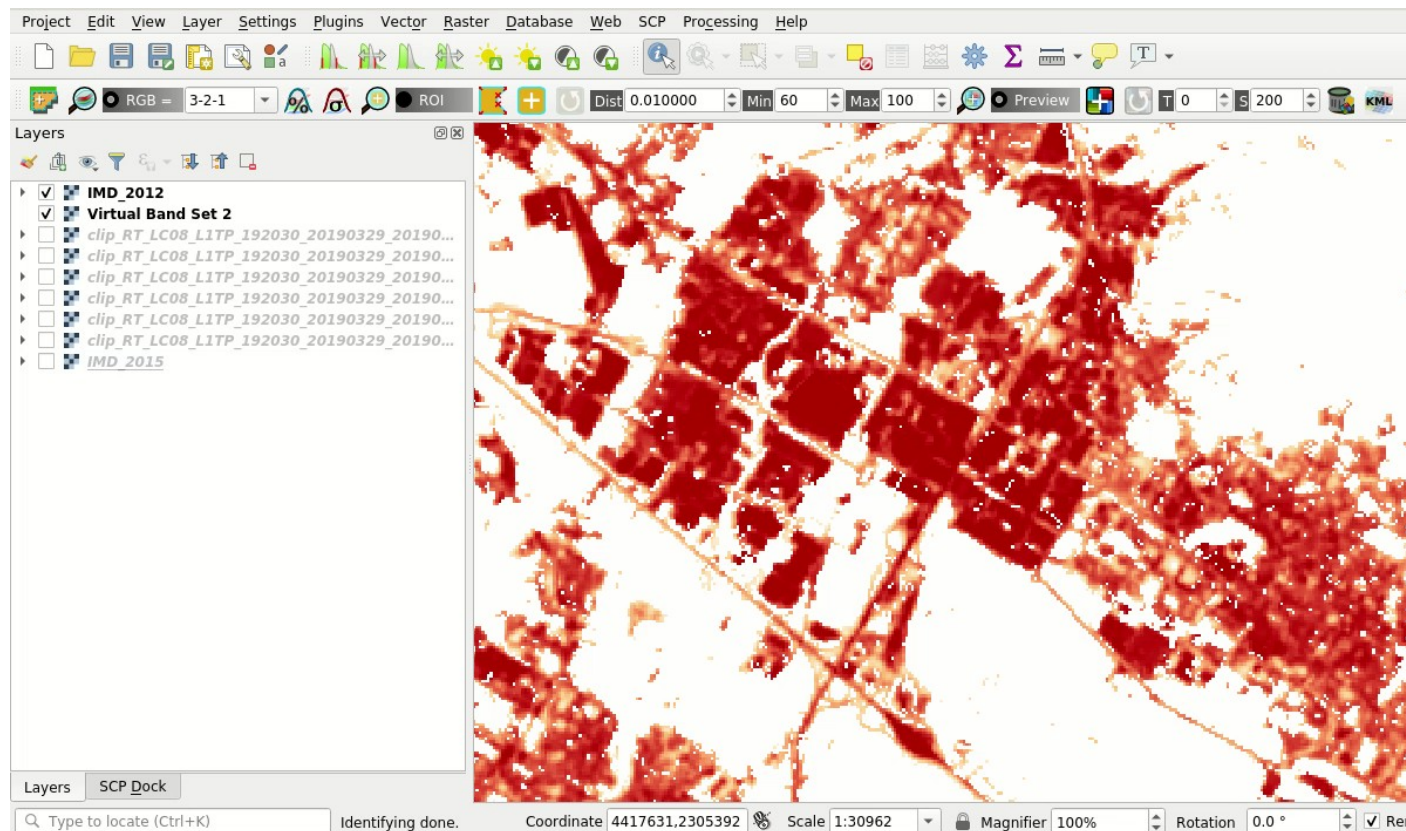







Fig. 13: *The raster modified*

Of course we could repeat these steps to edit any area of the raster.

**TIP :** Sometimes changes are not immediately visible because the raster is not refreshed; try to zoom out and zoom in to refresh the view.

## Classification report

It could be interesting to know the area of each land cover class. In order to get the area statistics, open the *SCP menu* (page 21) and click the tab  *Classification report* (page 77) under the submenu .

Click the button  to refresh the layer list, and select the `IMD_2012` raster in *Select the classification* ; next click *RUN*  to start the calculation; the output report is saved in a text file and displayed in the tab *Output*.

We can repeat the same steps for the `IMD_2015` raster. Over the 86% of the area is not impervious.

## Reclassification

Before calculating land cover change it is convenient to reclassify the imperviousness degree into two classes: built-up and not built-up. A possible threshold for the distinction between built-up and not built-up is 30% (for further information read [this document](#) ). We can reclassify the raster using the SCP tool, obtaining the simple classification 1 = built-up and 0 = not built-up.

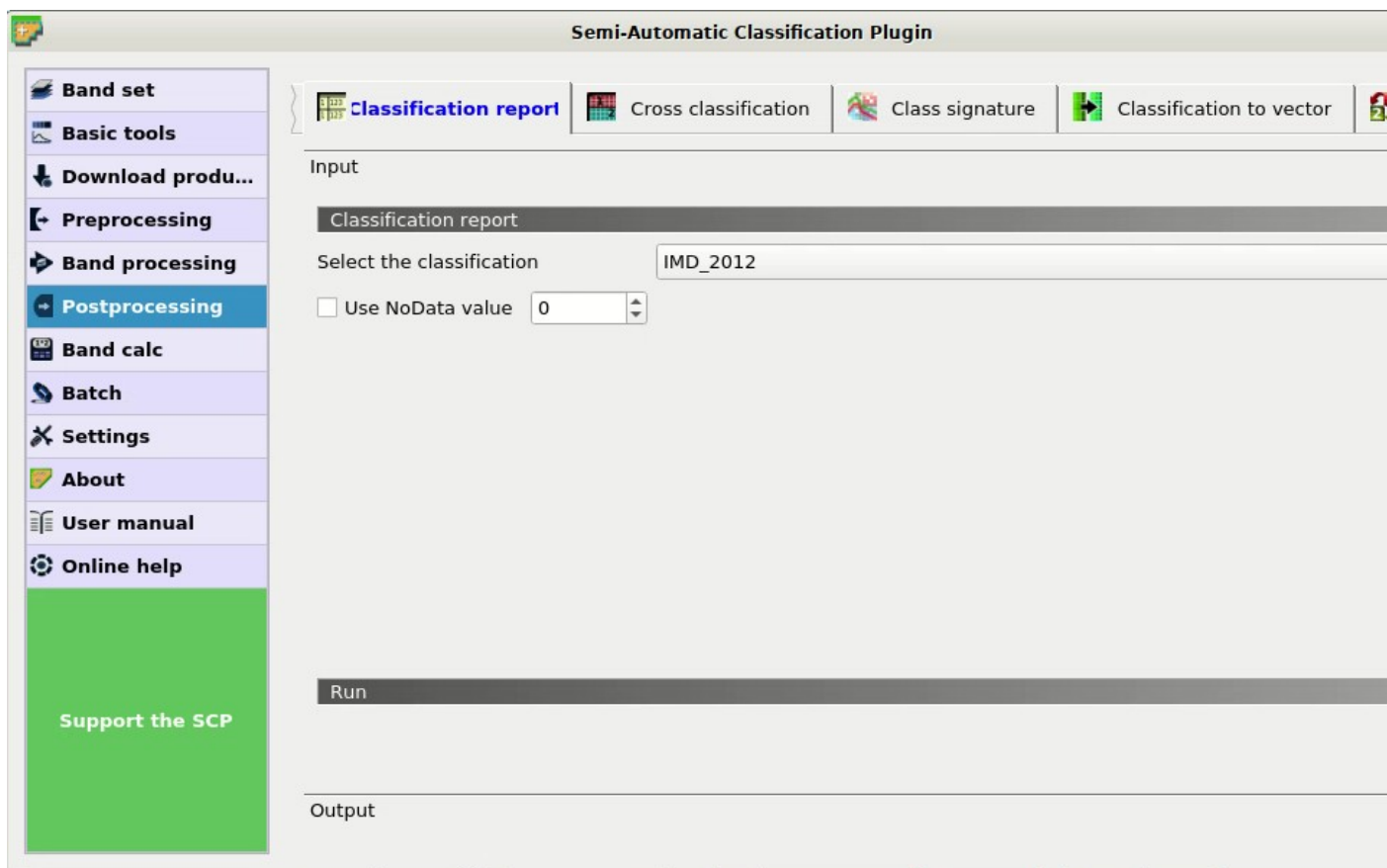


Fig. 14: Report tool



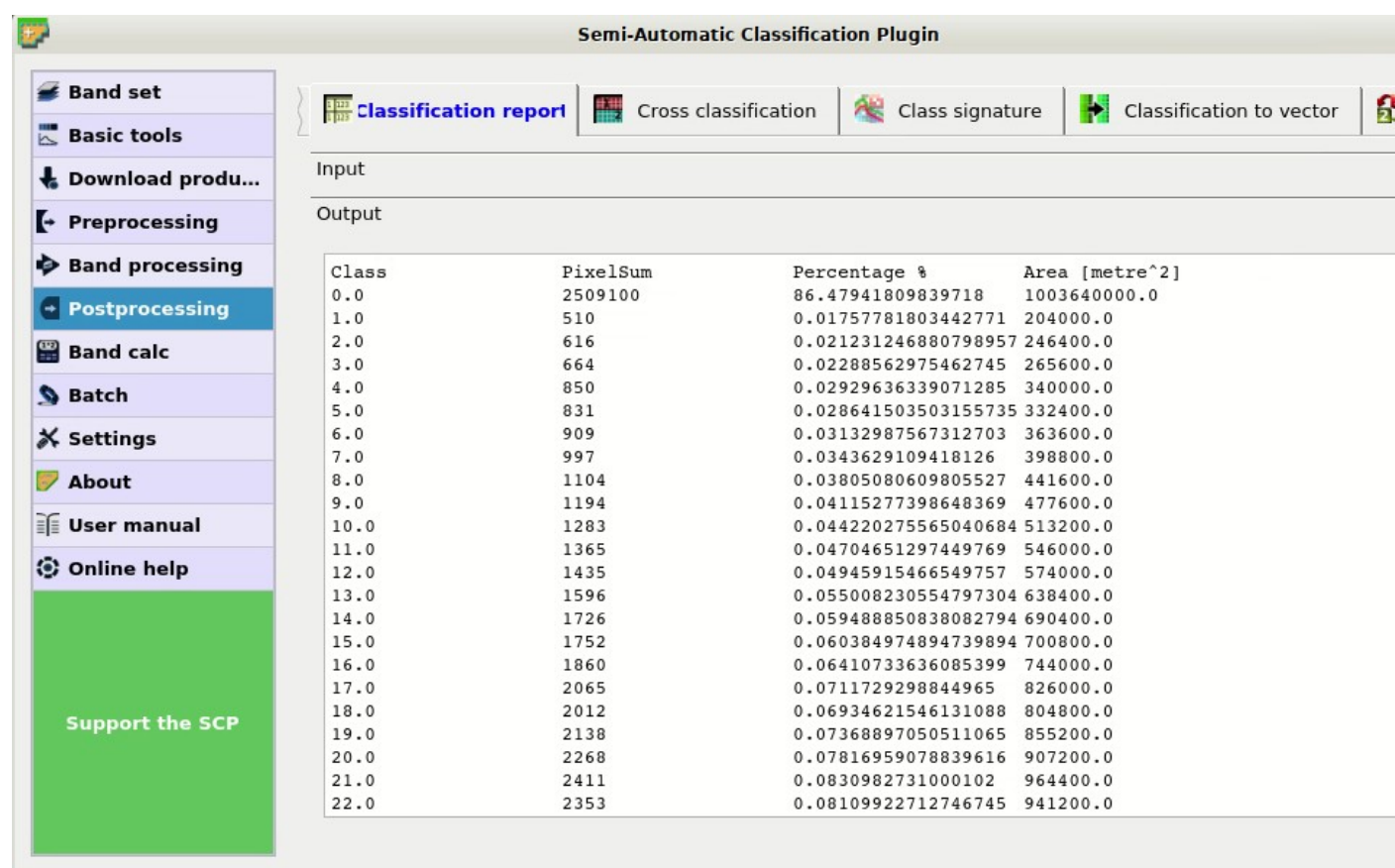






Fig. 15: The classification report

Open the tool  *Reclassification* (page 81). In *Select the classification* select the raster IMD\_2012. Click the button  twice to add two rows to the table. We need to enter the expressions illustrated in the following table.

*Reclassification table*

| Old value    | New value |
|--------------|-----------|
| raster < 30  | 0         |
| raster >= 30 | 1         |

Uncheck the options  *Use code from Signature list* and click *RUN*  to start the reclassification. A new raster will be created (e.g. BU\_2012).

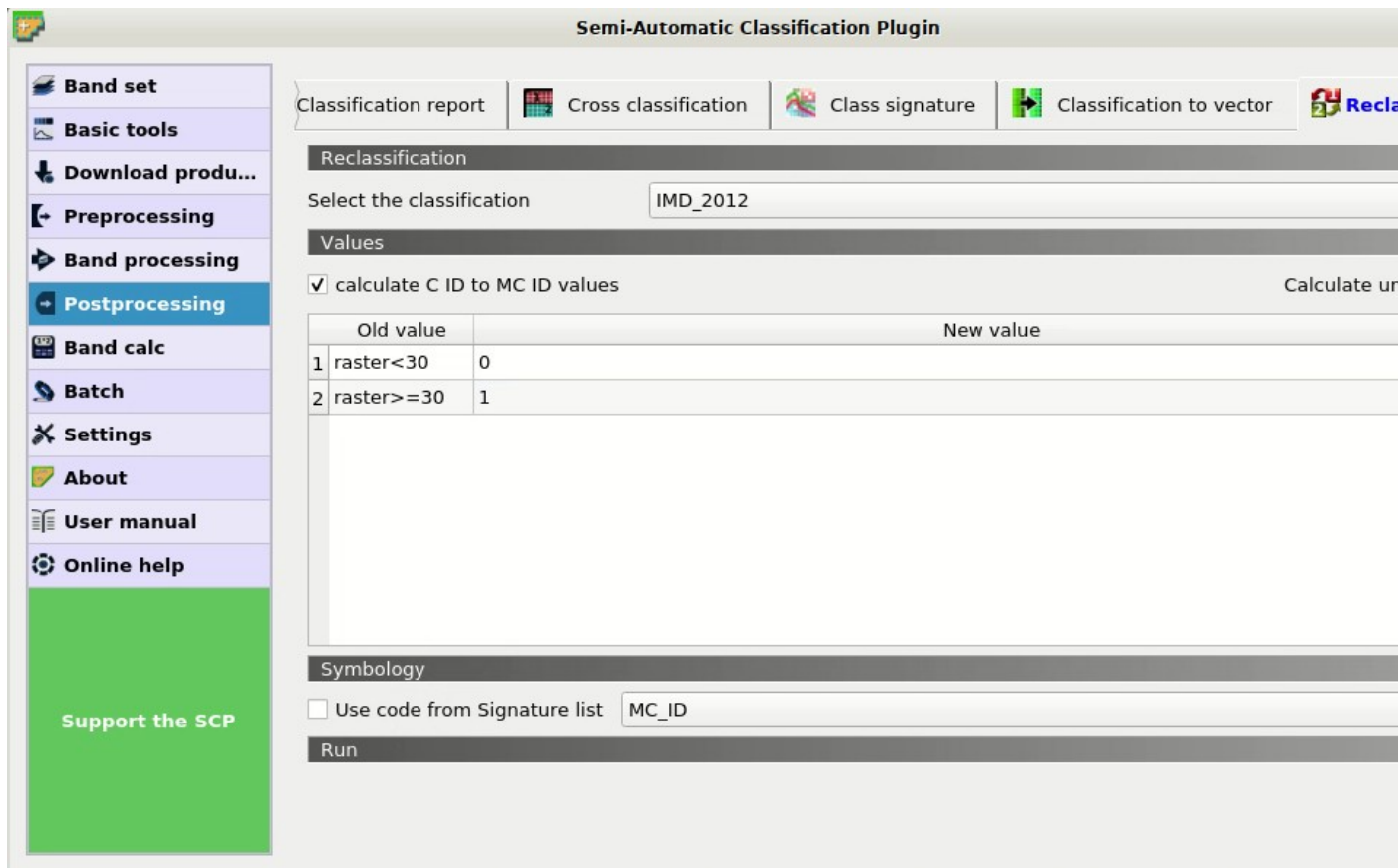



Fig. 16: *Reclassification tool*

Now select the IMD\_2015 (the reclassification table is the same as before) and click *RUN*  to reclassify the 2015 raster (e.g. BU\_2015). Now the two reclassified rasters are loaded in the map and we can assign an appropriate symbology.

## Remove isolated pixels

We are going to compute the land cover change, but first we may want to remove isolated pixels in order to improve the analysis. In fact, single pixels may not represent real changes between the two classifications, because of geometrical shifts or isolated classification errors. Of course, this step is not always required, and it should be avoided if the purpose of the analysis is to find also the smallest changes.

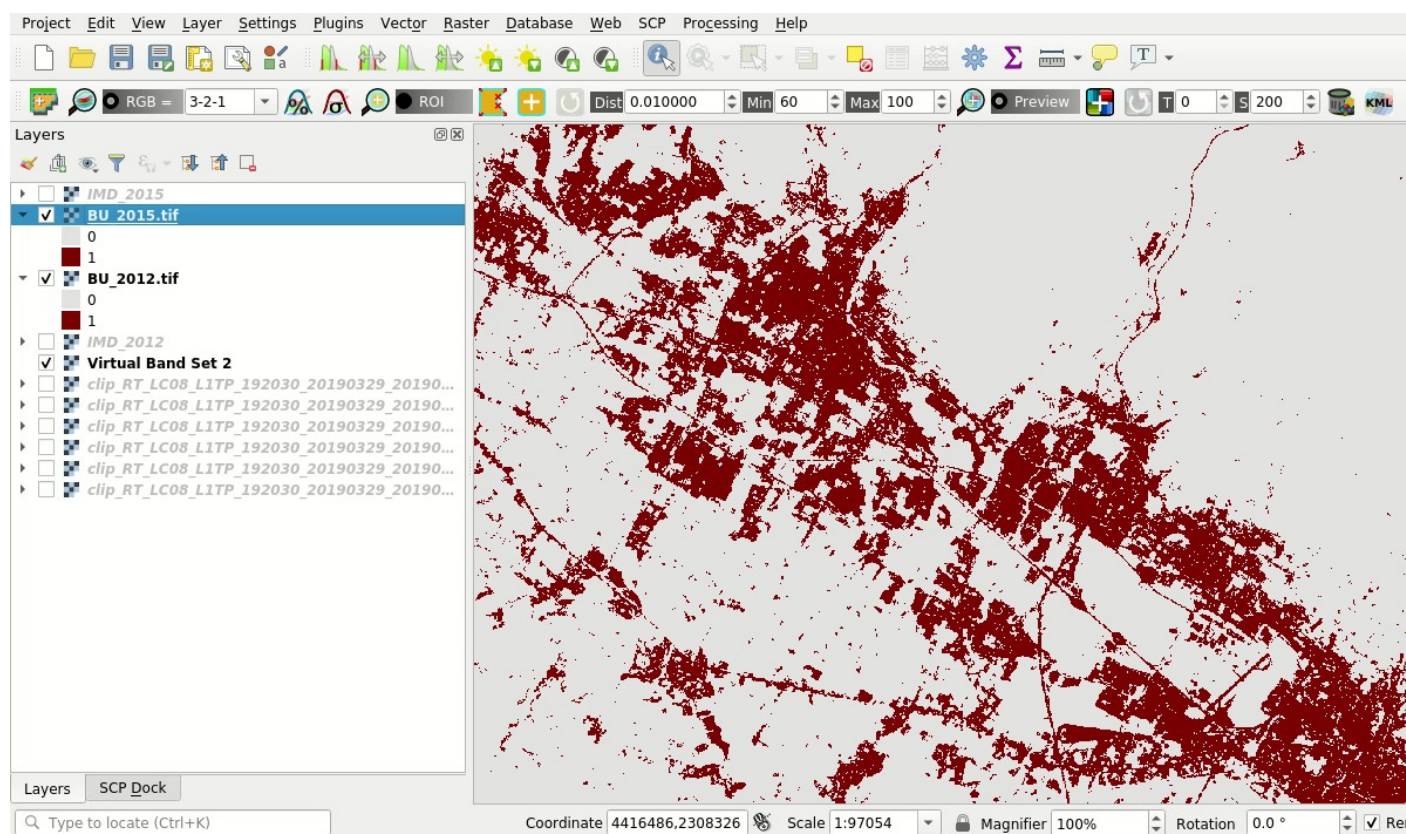




Fig. 17: Reclassified rasters

We are going to use classification sieve for removing single pixels. Open the tool  *Classification sieve* (page 84).


In *Size threshold* leave 2; all patches smaller than the selected number of pixels (i.e. single pixels) will be replaced by the value of the largest neighbour patch. Of course we could increase this value if we want to remove larger patches.


In *Select the classification* select the raster BU\_2012. The option 4 in *Pixel connection* determines how pixels are considered connected, that is in a 3x3 window diagonal pixels are not considered connected. If we select the option 8 also diagonal pixels are considered connected.


Now click *RUN*  to create the new raster BU\_2012\_sieve.

Of course, we should repeat these steps also for raster BU\_2015 to create the new raster BU\_2015\_sieve.

## Assess land cover change

Now we can use the tool to assess land cover change between the two classifications 2012 and 2015. Open the tool  *Land cover change* (page 76).

This tool is quite straightforward. Click the button  to refresh the layer list. In *Select the reference classification* select the BU\_2012\_sieve raster, that is the first classification. In *Select the new classification* select the BU\_2015\_sieve raster, that is the latest classification.

Uncheck the option  *Report unchanged pixels*, because we want to report only the pixels where the classifi-

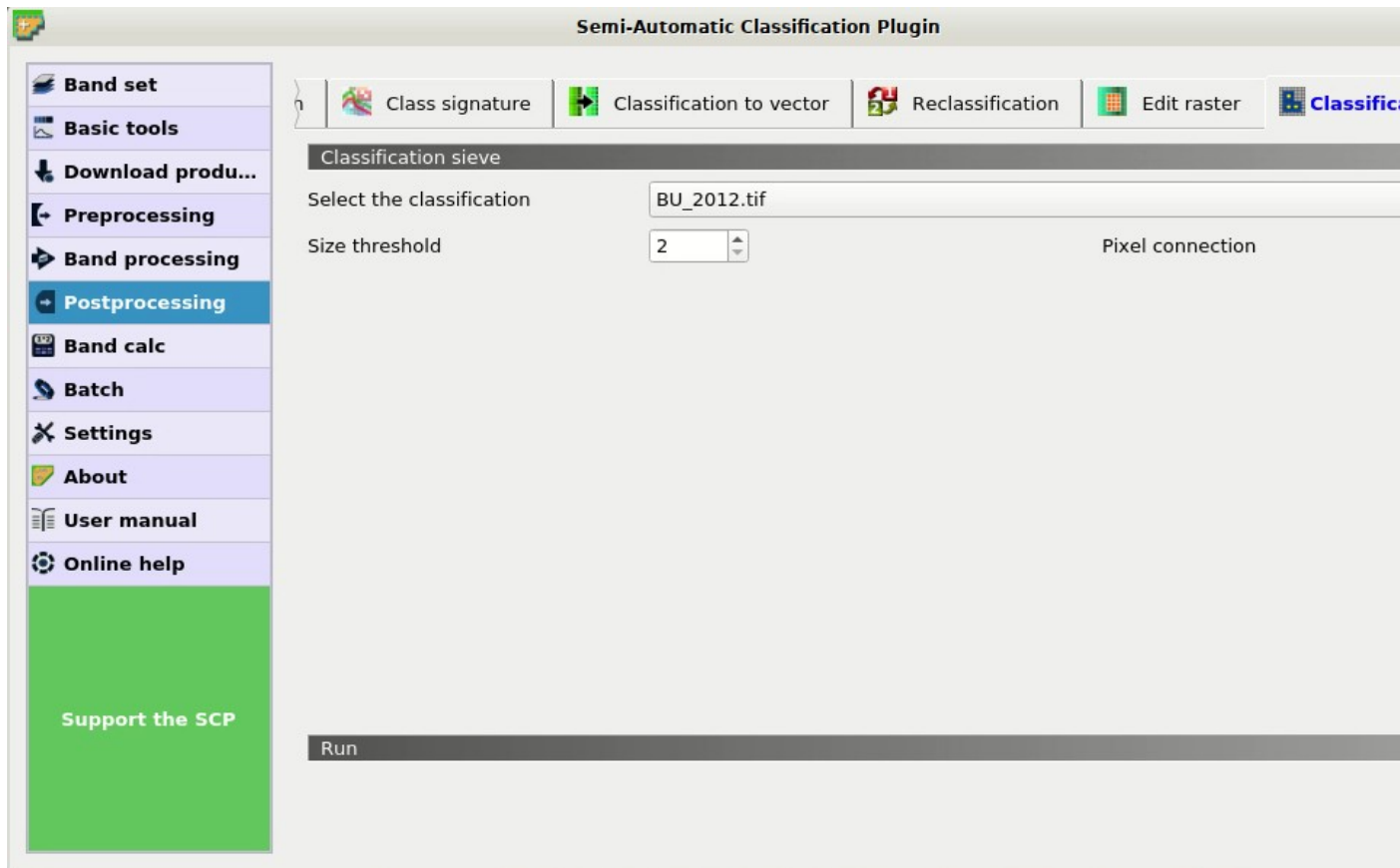


Fig. 18: Tool classification sieve

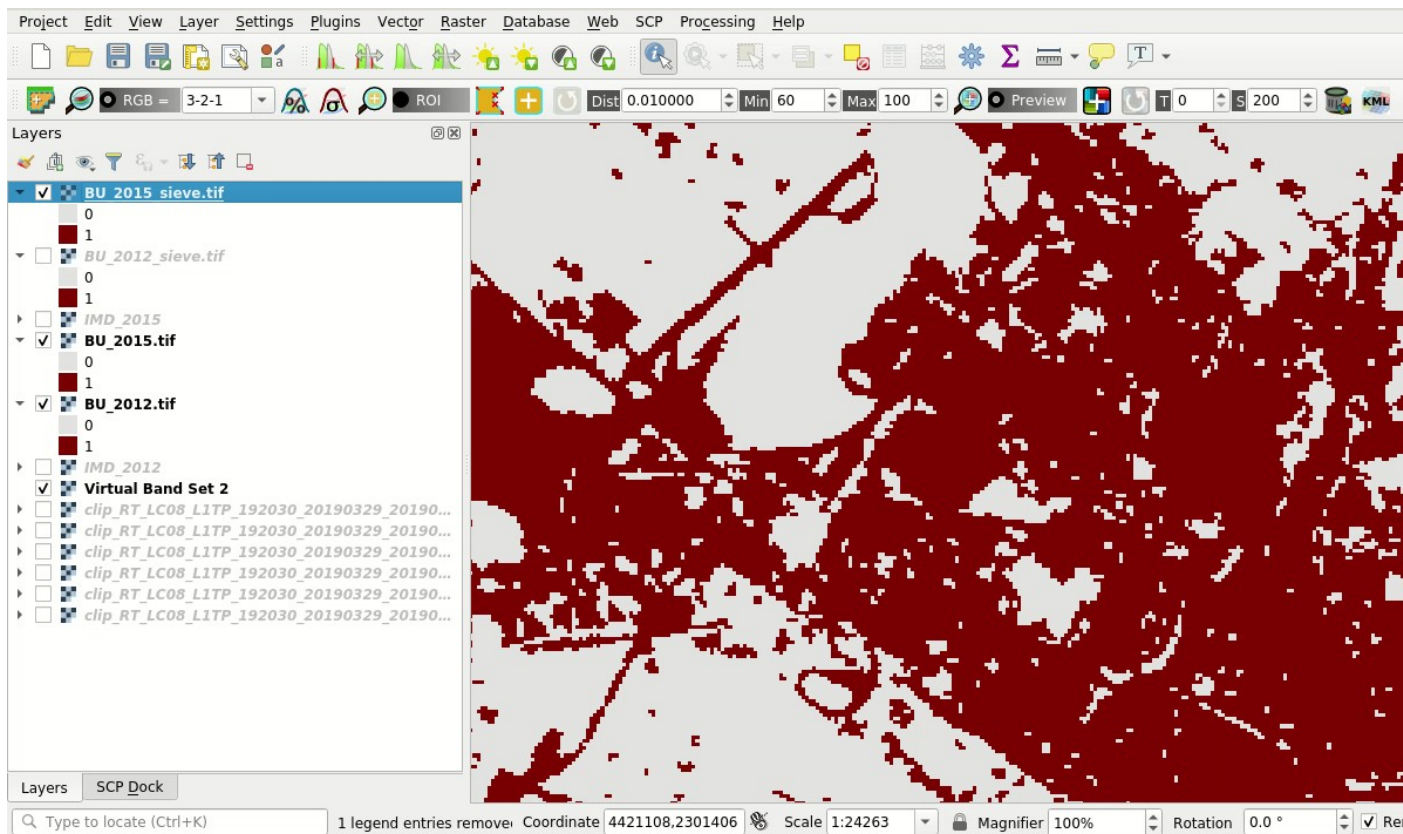


Fig. 19: The rasters after removing isolated pixels



cation changed between 2012 and 2015. Now click *RUN*  to create the new land cover change raster (e.g. change). Also, a text file is created (i.e. a file .csv separated by tab) containing the land cover change statistics.

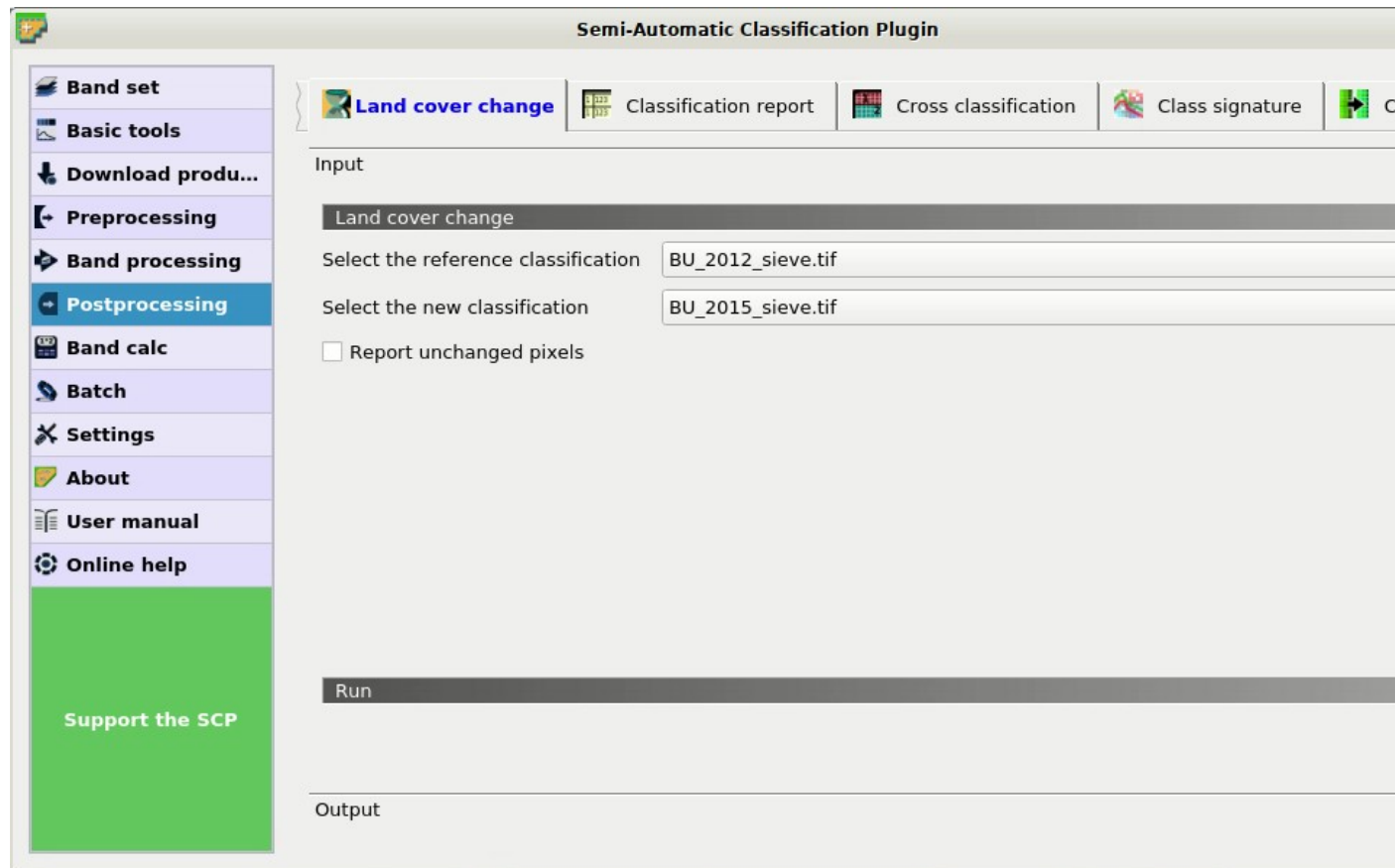


Fig. 20: *Land cover change tool*

The values of the land cover change raster represent a combination between reference and new classification, as described in the text file. In this case, only the value 1 is present that is the condition where  $BU_{2012\_sieve} = 0$  and  $BU_{2015\_sieve} = 1$ .

From the report we can read that 520 pixels changed from 0 to 1, while no pixel changed from 1 to 0 between years 2012 and 2015.

### Analyze the context of land cover changes

Now, it could be interesting to compare land cover change to other data such as land use, in order to analyze the context of new built-up areas. We are going to cross the land cover changes to the vector of Corine Land Cover; this way we can differentiate the new built-up areas according to Corine Land Cover classification system.

The original Corine Land Cover data were modified by clipping to a small area over Florence (Italy) and adding a field `Class_1` filled with the first level of classification.

Load in QGIS the Copernicus Corine Land Cover shapefile `CLC_2012.shp` previously downloaded. You can see the symbology of the first level Corine Land Cover classes that are:

1. artificial surfaces
2. agricultural areas
3. forests and semi-natural areas
4. wetlands

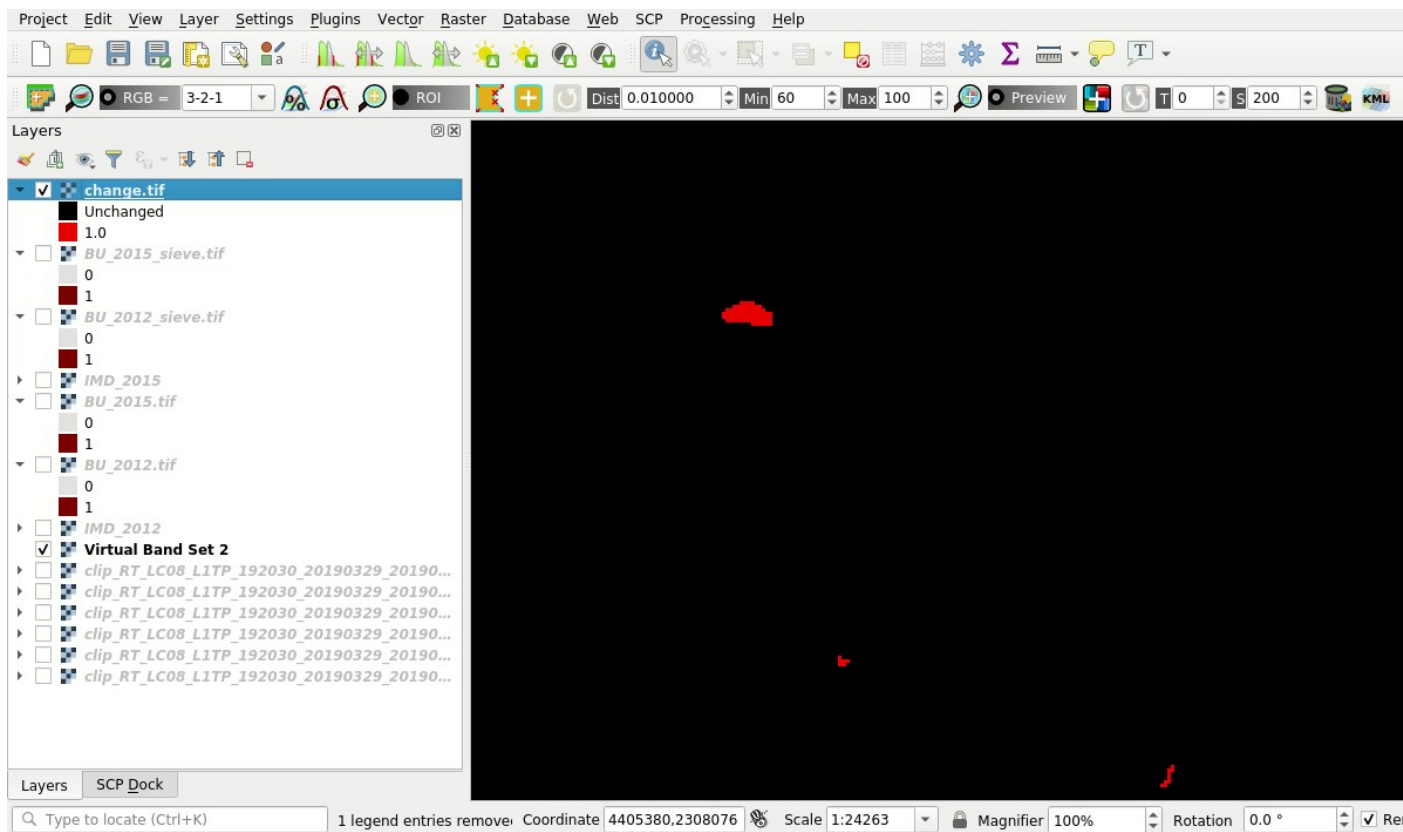


Fig. 21: Land cover change raster

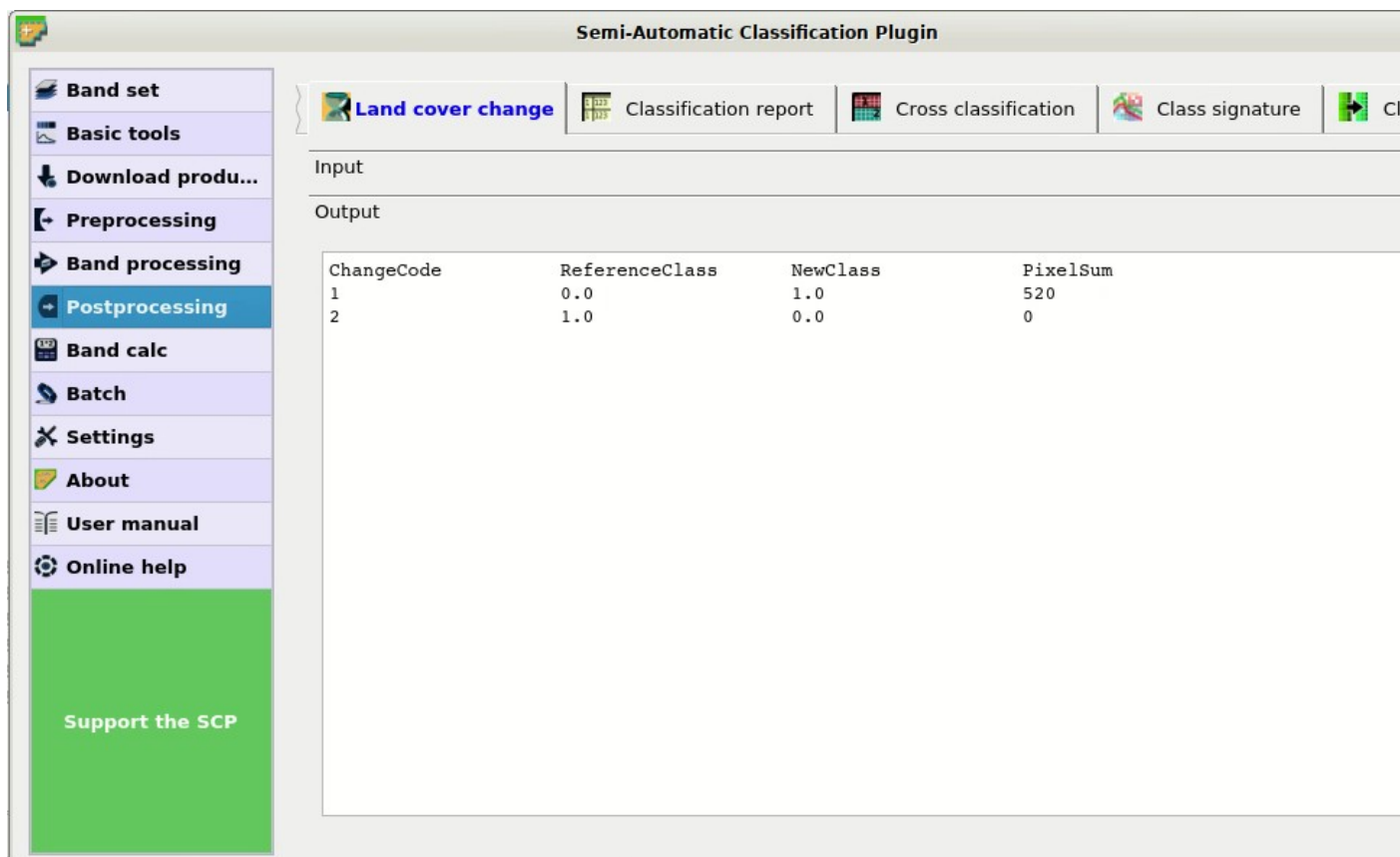


Fig. 22: Land cover change report



## 5. water bodies

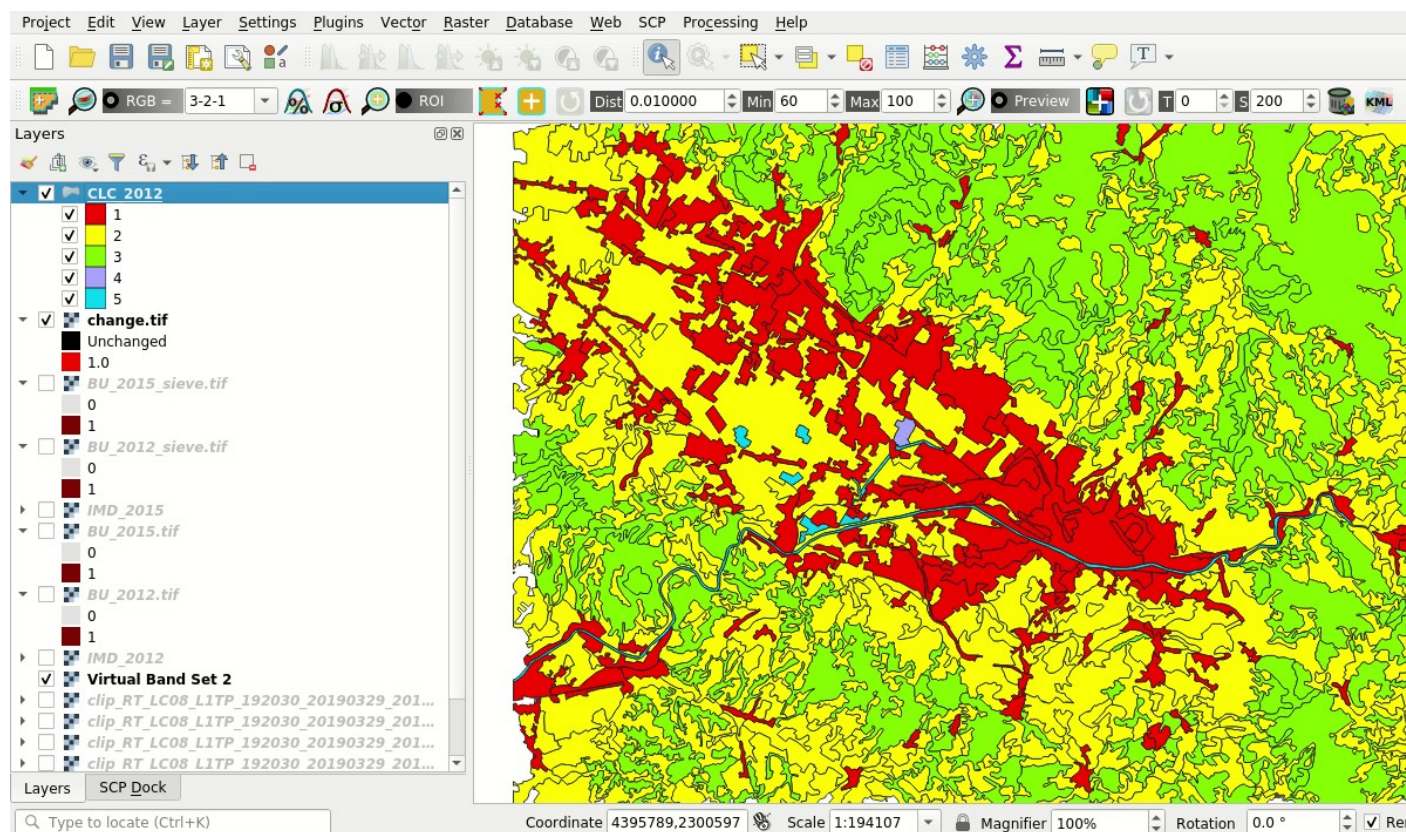





Fig. 23: A subset of Corine Land Cover

Open the tool  *Cross classification* (page 78). Click the button  to refresh the layer list. In *Select the classification* select the *change* raster, that is our land cover change. Check  *Use NoData value* and set the value 0, in order to exclude unchanged pixels (having value 0 in the change raster) from the analysis.

In *Select the reference vector or raster* select the vector *CLC\_2012* and in *Vector field* select the field *Class\_1*, containing the code of first level classes.

Now click *RUN*  to create a new raster of comparison (e.g. *change\_CLC*). The output will report the area of each combination between change code and *CLC\_2012* code.

From the cross matrix we can evaluate the area in  $m^2$  of built-up changes occurred in the 5 classes of Corine Land Cover classification.

*Cross matrix*

|        |   | CLC_2012 |       |      |   |   |
|--------|---|----------|-------|------|---|---|
|        |   | 1        | 2     | 3    | 4 | 5 |
| Change | 1 | 157600   | 48400 | 2000 | 0 | 0 |

The tool *Cross classification* (page 78) can be very useful also for other analyses that involve the comparison with other data, such as population or flood risk, but this could be the subject of other tutorials.

## Assess the spectral signature of changes

An optional step could be the assessment of the spectral signature of changes. We can download satellite images (see *Tutorial 1: Your First Land Cover Classification* (page 139) for the details) and calculate spectral signatures

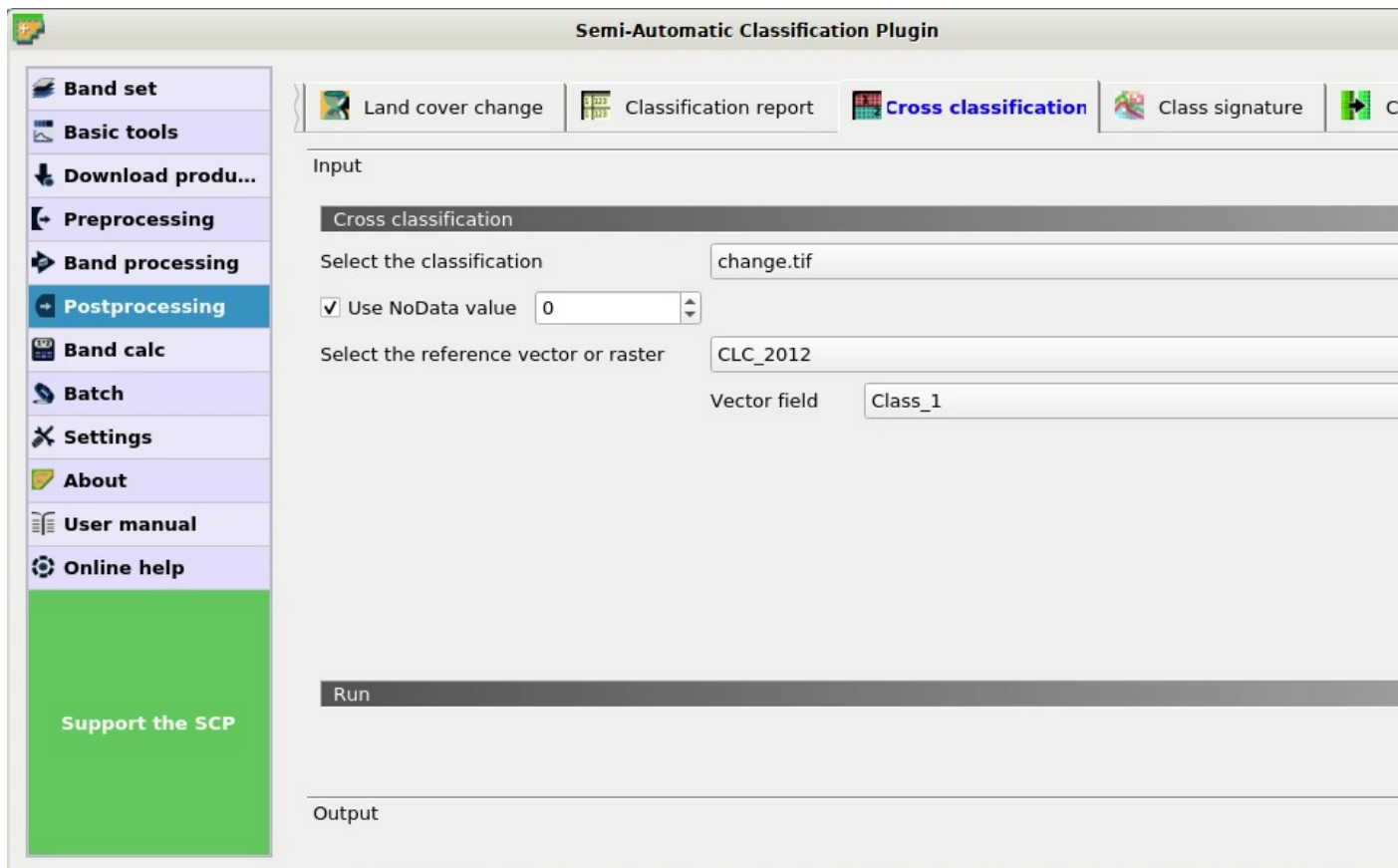





Fig. 24: Cross classification tool

for monitoring the changes through time.

We are going to use the Landsat 8 image downloaded at the beginning of this tutorial for calculating the spectral signature of changes. First, we need to create a *Training input* to store the spectral signatures calculated from the

classes. In the *SCP dock* (page 23) select the tab *Training input* (page 24) and click the button  to create the *Training input* (define a name such as `signatures.scp`). The path of the file is displayed and a vector is added to QGIS layers with the same name as the *Training input* (in order to prevent data loss, you should not edit this layer using QGIS functions).

Now open the tool  *Class signature* (page 79) opening the *SCP menu* (page 21) and the submenu  *Postprocessing*. In *Select the classification* select the raster `change_CLC`, thus we can distinguish the spectral signatures of changes. In *Select input band set* enter the number of the band set containing the Landsat 8

bands (i.e. 2). Now click *RUN*  to start the calculation.

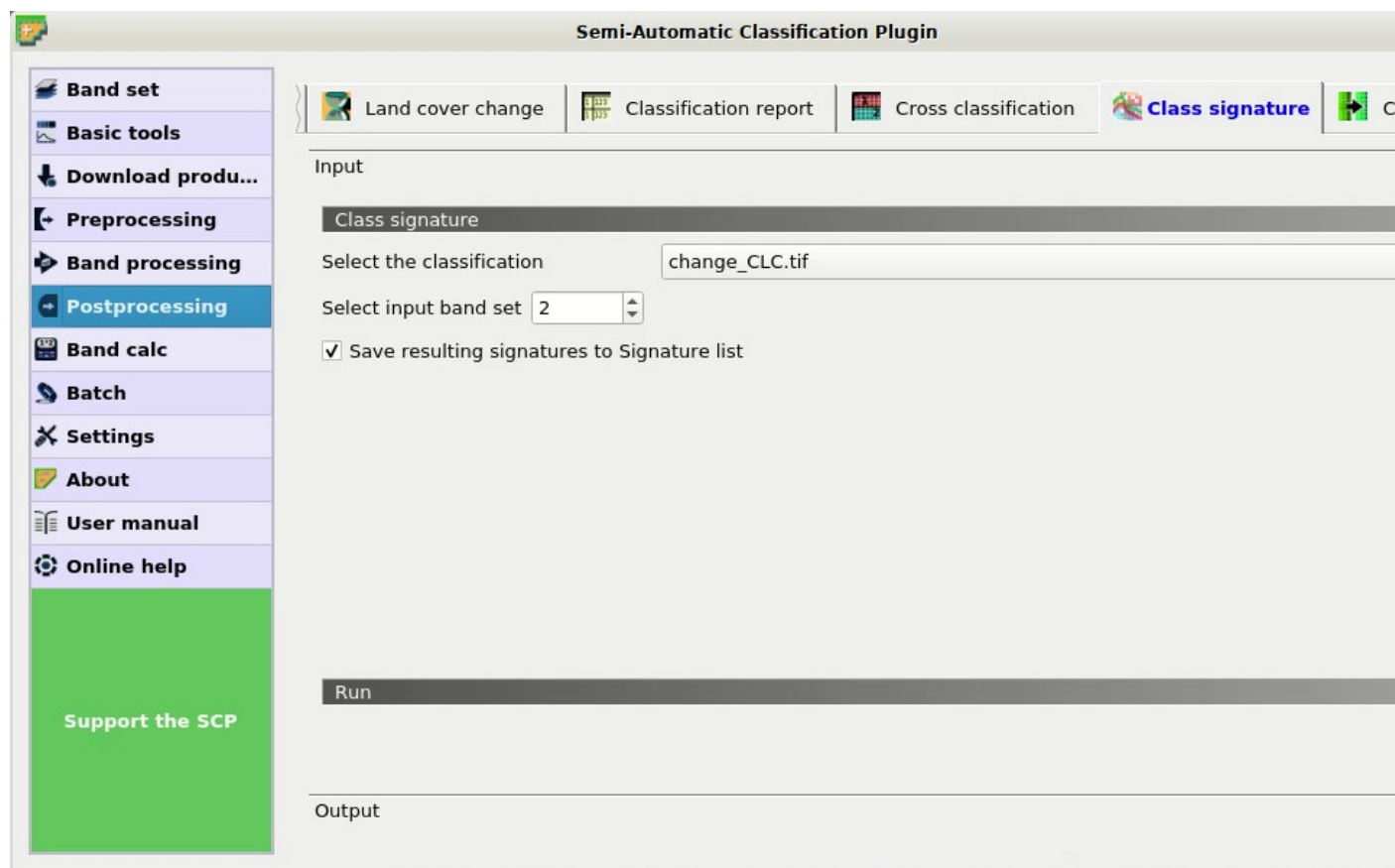


Fig. 25: The tool for extracting spectral signatures from classes

After a while the spectral signatures are loaded in the *Training input*.

If the changes involved vegetation, we could calculate spectral signatures for images acquired in different seasons and assess the phenological variations of vegetation through spectral signatures. Also, these spectral signatures could be used as training input for further land cover classifications.

In order to display the signature plot, in the *ROI Signature list* (page 27) highlight two or more spectral signatures (with click in the table), then click the button . The *Spectral Signature Plot* (page 98) is displayed in a new window.

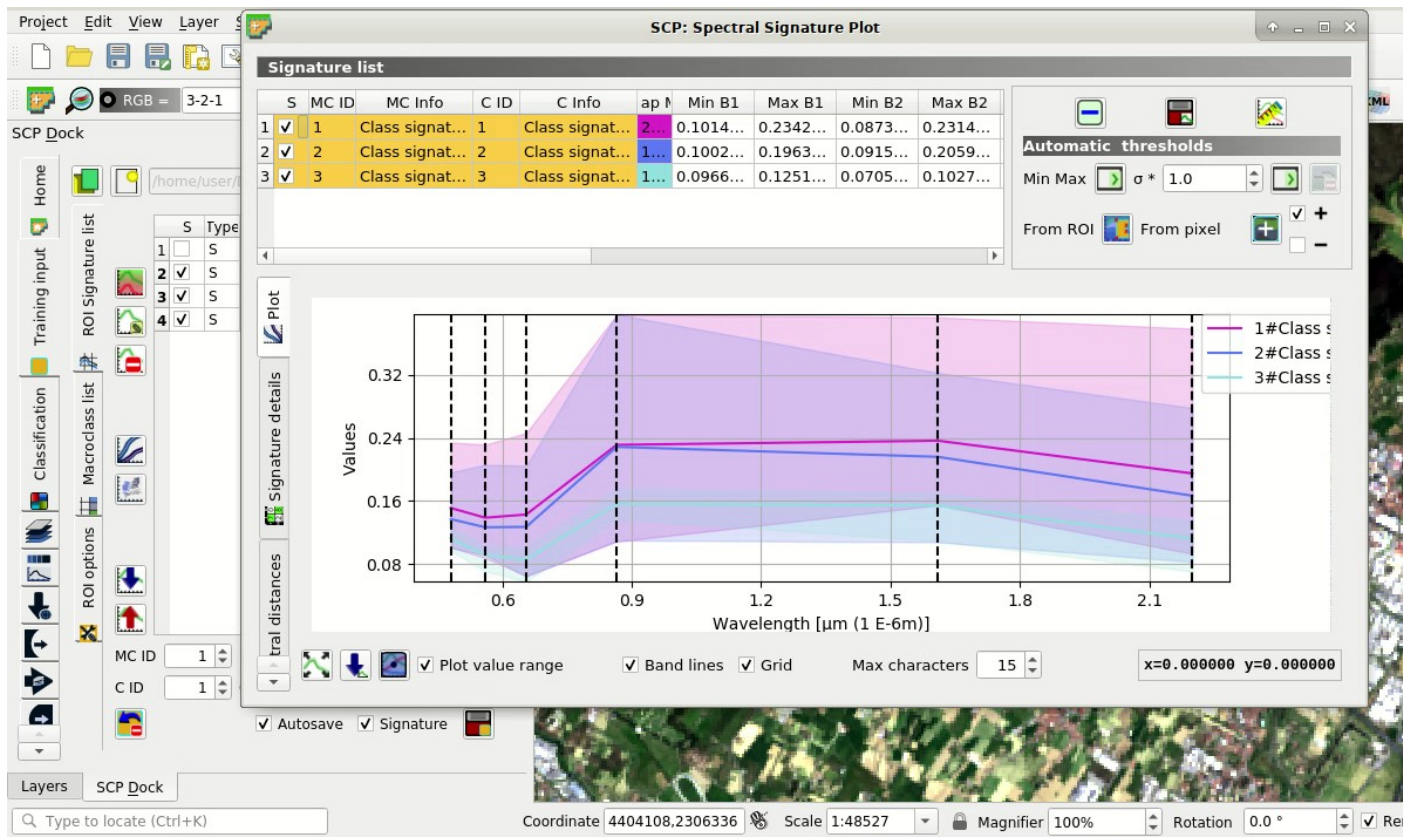





Fig. 26: The calculated spectral signatures

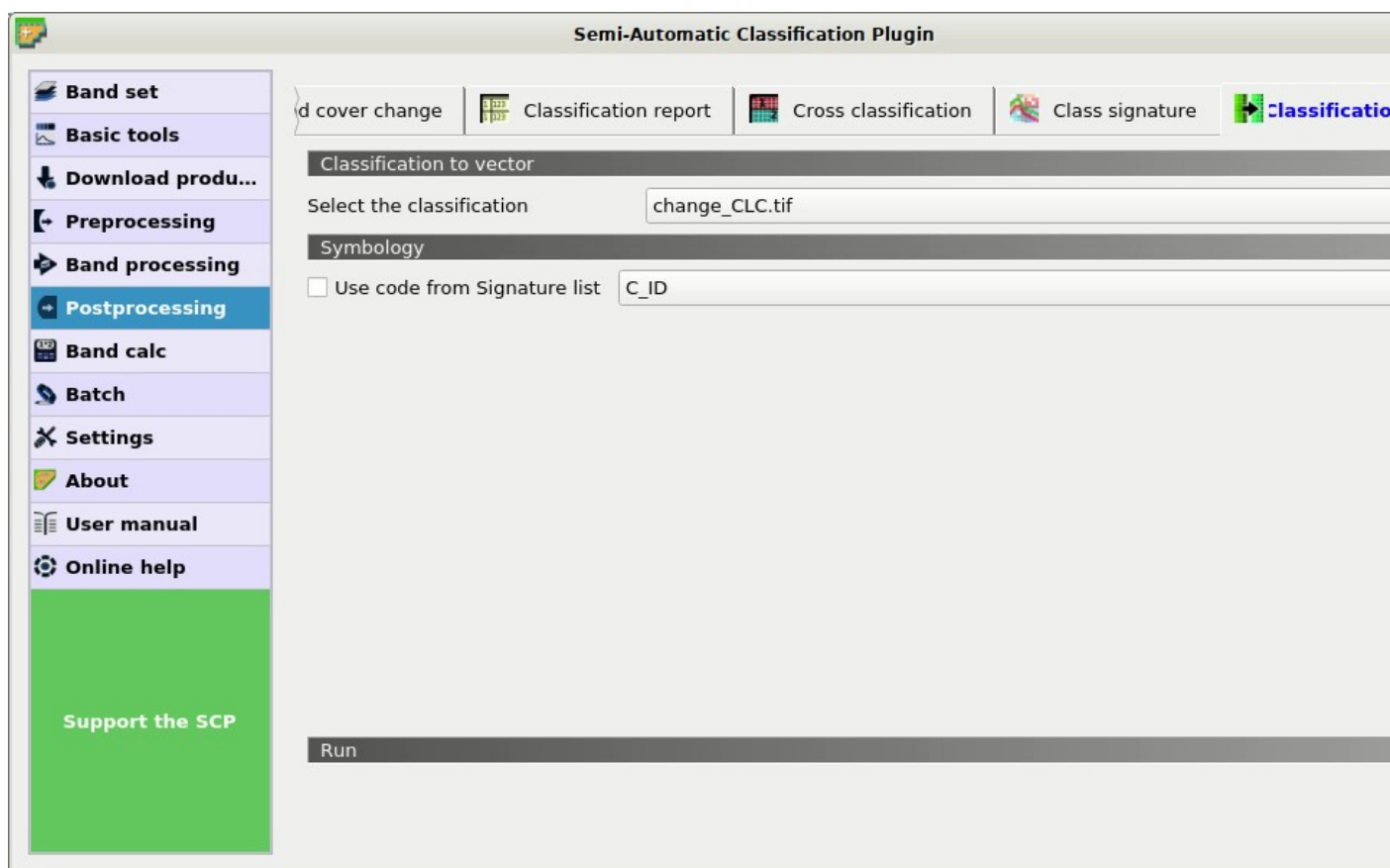
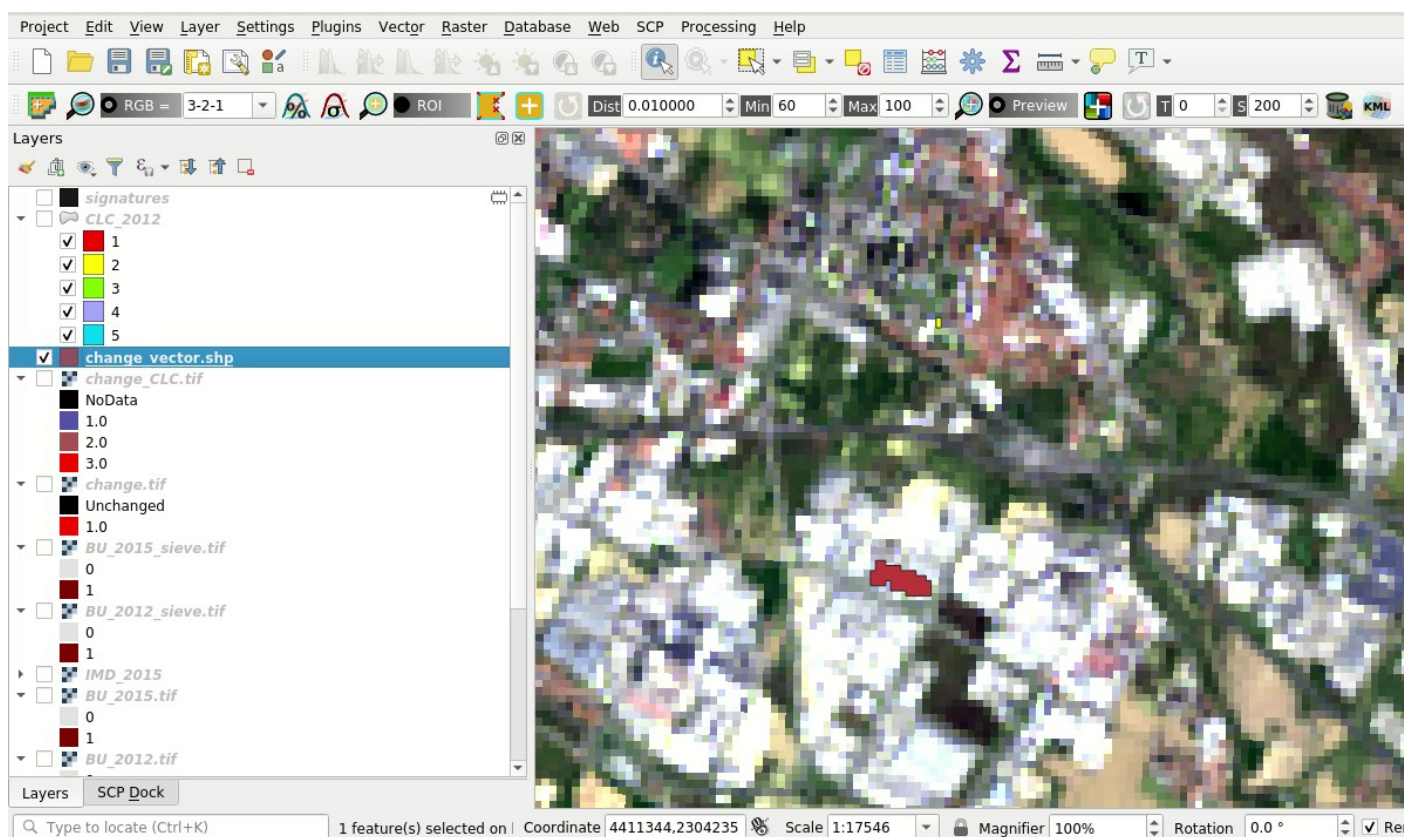
## Export the changes to vector format

This is an optional step that may be useful for further analyses and integration with other data. We are going to convert the change raster to vector.

Open the tool  *Classification to vector* (page 80). In *Select the classification* select the `change_CLC` raster and uncheck the  *Use code from Signature list*. Now click *RUN*  to create a new vector (e.g. `change_vector`).

In the attribute table of this `change_vector` you can see the field `C_ID` that represents the code of the change raster as described in *Assess land cover change* (page 210). Of course we could delete the polygons with code 0 (unchanged area), displaying only changes with code 1.



Fig. 27: *Raster to vector tool*Fig. 28: *The vector of changes over the Landsat image*

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### Semi-Automatic OS

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To be updated.

The Semi-Automatic OS is a lightweight virtual machine for the land cover classification of remote sensing images. It includes the Semi-Automatic Classification Plugin (SCP) for QGIS, already configured along with all the required dependencies.

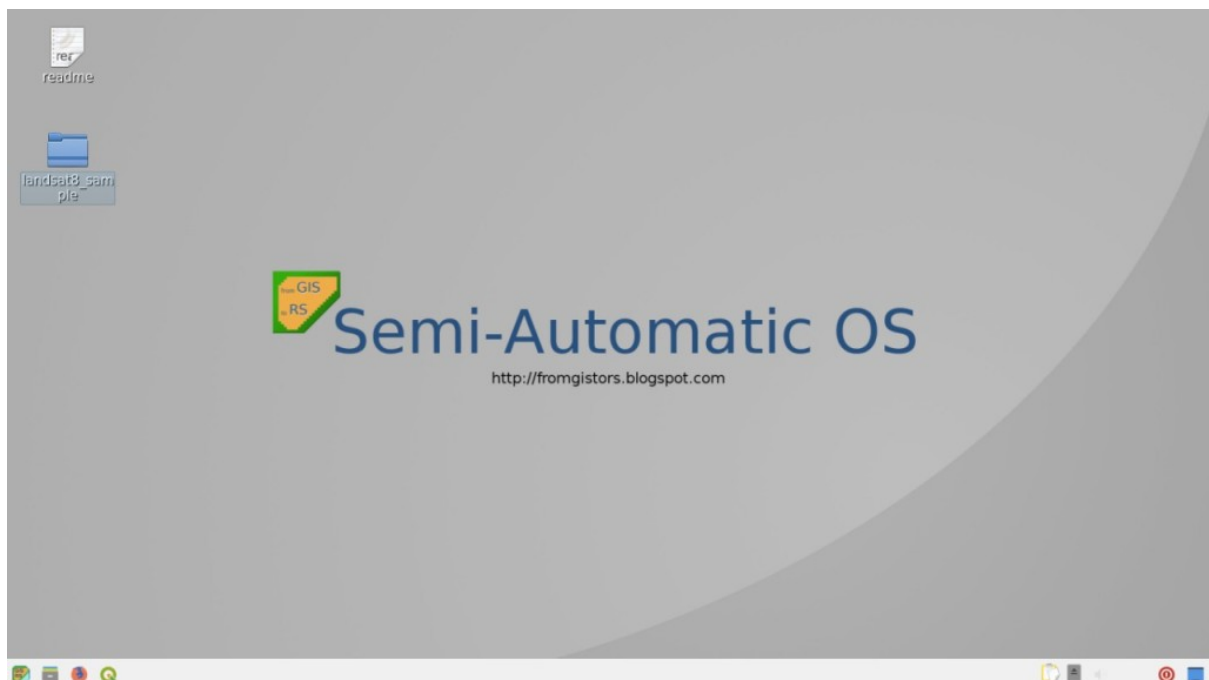


Fig. 1: *Semi-Automatic OS desktop*

The Semi-Automatic OS is based on [Debian](#) , and it is designed to require very little hardware resources. It uses [LXQT](#) as main desktop environment. This virtual machine can be useful for testing the Semi-Automatic Classification Plugin, or when the installation of the required programs in the host system is problematic.

The Semi-Automatic OS is available as 64 bit virtual machine that can be run in the open source VirtualBox, or any other virtualization program. The following is a guide for the installation of the Semi-Automatic OS in the open source program of virtualization VirtualBox.

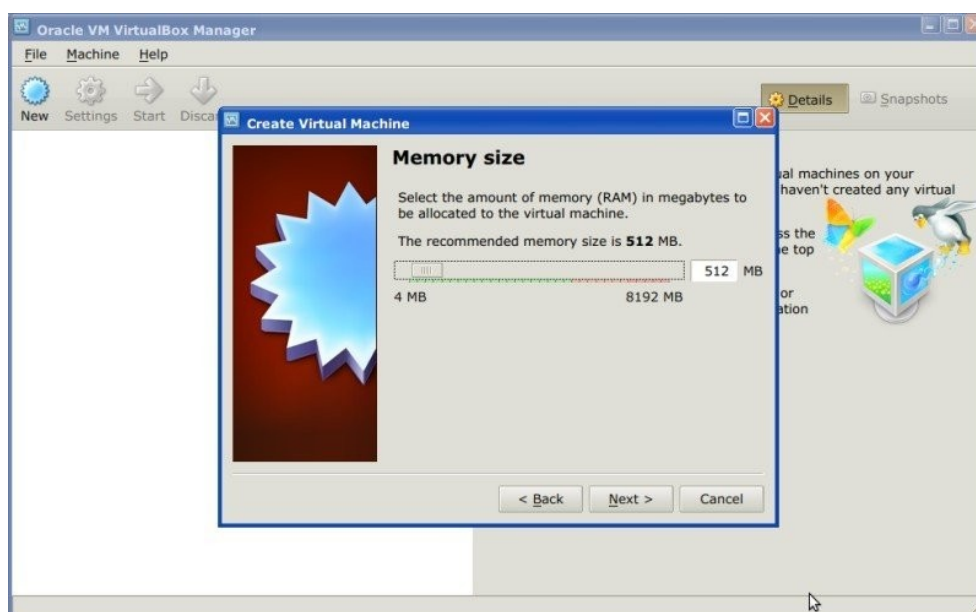


## 7.1 Installation in VirtualBox

1. Download [VirtualBox](#) open source software (select a proper version depending on your OS) and install it; at the end of the installation restart the system;
2. Download the Semi-Automatic OS virtual machine from [here](#) ;
3. Extract the virtual machine content in a directory; the file is compressed in 7z format (if needed, download the open source extraction software from <http://www.7-zip.org/>);
4. Run VirtualBox and create a new Debian virtual machine;
  1. Click the New button;
  2. Type a name for the virtual machine (for instance Semi-Automatic OS); select Linux and Debian (32 or 64 bit) as Type and Version respectively; click Next;



3. Set the memory size; the more is the better, but this parameter should not exceed a half of the host system RAM (for instance if the host system has 1 GB of RAM, type 512 MB); click Next;

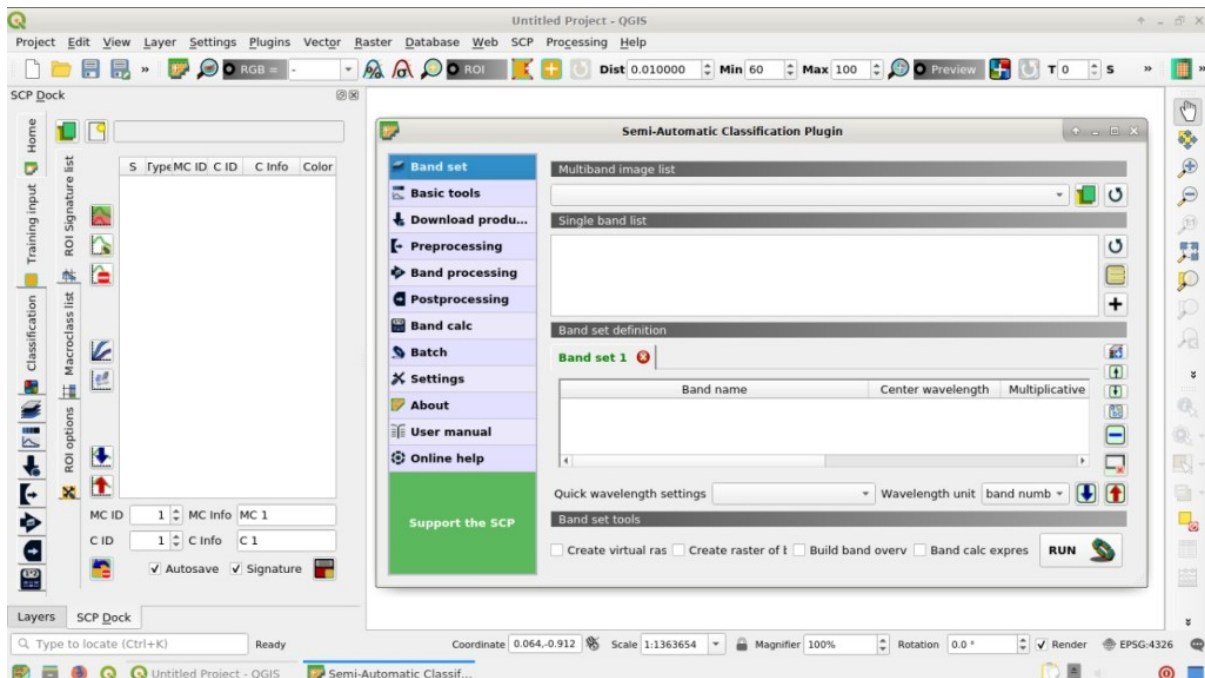


4. In the Hard drive settings select Use an existing virtual hard drive file and select the downloaded file SemiAutomaticOS.vmdk; click Create;



5. Start the Semi-Automatic OS by clicking the Start button;
6. It is recommended to install the virtualbox-guest-utils in the virtual machine, from the Menu > Preferences > Synaptic Package Manager; it allows for a better integration of the Semi-Automatic OS in the host system, such as: the resize of the system window, or the folder sharing.

The Semi-Automatic OS includes a sample dataset of a Landsat image (available from the U.S. Geological Survey) that is the input for the first basic tutorial of the user manual.



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See <http://www.gnu.org/licenses/>.

## Frequently Asked Questions

If you have comments or questions please join the [Facebook group](#) .

Before asking, please check the official site [From GIS to Remote Sensing](#) and the following Frequently Asked Questions.

- *Plugin installation* (page 224)
  - *How to install the plugin manually?* (page 224)
  - *How to install the plugin from the official SCP repository?* (page 224)
- *Pre processing* (page 226)
  - *Which image bands should I use for a semi-automatic classification?* (page 226)
  - *Which Landsat bands can be converted to reflectance by the SCP?* (page 226)
  - *Can I apply the conversion to Sentinel-2 images download from the web?* (page 227)
  - *How are converted Sentinel-2 images that have different resolutions?* (page 227)
  - *Can I apply the Landsat conversion and DOS correction to clipped bands?* (page 227)
  - *Can I apply the DOS correction to bands with black border (i.e. with NoData value)?* (page 227)
  - *How to remove cloud cover from images?* (page 227)
  - *After pan-sharpening of Landsat 8 images, why NIR bands still have 30m resolution?* (page 227)
- *Processing* (page 227)
  - *I get classification errors. How can I improve the accuracy?* (page 227)
  - *Is it possible to use the same training input for multiple images?* (page 228)
  - *What is the difference between classes and macroclasses?* (page 228)
  - *Can I use SCP with images from drones or aerial photographs?* (page 228)
  - *Why using only Landsat 8 band 10 in the estimation of surface temperature?* (page 228)
- *Warnings* (page 228)

- *Warning [12]: The following signature will be excluded if using Maximum Likelihood. Why?* (page 228)
- *Errors* (page 228)
  - *How can I report an error?* (page 228)
  - *Virtual raster creation issues. Why?* (page 229)
  - *Error ‘Plugin is damaged. Python said: ascii’. Why?* (page 229)
  - *Error [50] ‘Internet error’. Unable to download Sentinel-2 images. Why?* (page 230)
  - *Error installing the plugin, possible missing dependencies. Why?* (page 230)
- *Various* (page 230)
  - *What can I do with the SCP?* (page 230)
  - *How to contribute to SCP* (page 231)
  - *Free and valuable resources about remote sensing and GIS* (page 231)
  - *Other tutorials about SCP, also in languages other than English* (page 232)
  - *How can I translate this user manual to another language?* (page 232)
  - *Where is the source code of SCP?* (page 233)
  - *How to install QGIS using OSGeo4W?* (page 233)

## 8.1 Plugin installation

### 8.1.1 How to install the plugin manually?

The SCP can be installed manually (this can be useful when an internet connection is not available, or the installation is required on multiple computers), following a few steps:

1. download the SCP zip archive from <https://github.com/semiautomaticgit/SemiAutomaticClassificationPlugin/archive/master.zip> ;
2. extract the content of the archive (several files such as `COPYING.txt` and folders such as `ui`) in a new folder named `SemiAutomaticClassificationPlugin` (without `-master`);
3. open the QGIS plugins directory (in Windows usually `C:\Users\username\AppData\Roaming\QGIS\QGIS3\profiles/default/python/plugins`) and delete the folder `SemiAutomaticClassificationPlugin` if present;
4. copy the folder `SemiAutomaticClassificationPlugin` inside the QGIS plugins directory;
5. the plugin should be installed; start QGIS, open the Plugin Manager and be sure that Semi-Automatic Classification Plugin is checked.

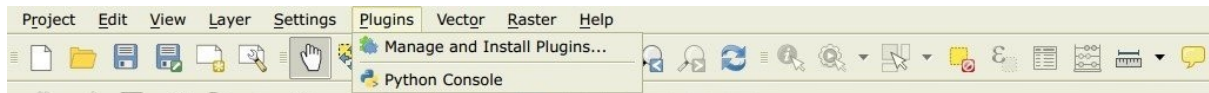
### 8.1.2 How to install the plugin from the official SCP repository?

It is possible to install the SCP using the official repository. This repository allows for the installation of the latest version of SCP (`master`), in some cases also before the availability thereof in the QGIS repository. Therefore, this can be useful if you need a fix or a new function that is still not available in the QGIS repository. Moreover, the `master` version in the SCP repository can be installed along with the version available in the QGIS repository.

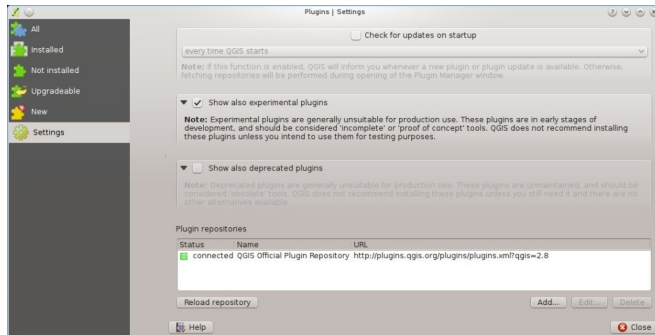
In order to install the SCP repository follow these steps:

- Run QGIS;

- From the main menu, select **Plugins > Manage and Install Plugins**;



- Click **Settings** then click the button **Add**;



- Inside the **Repository** details enter:

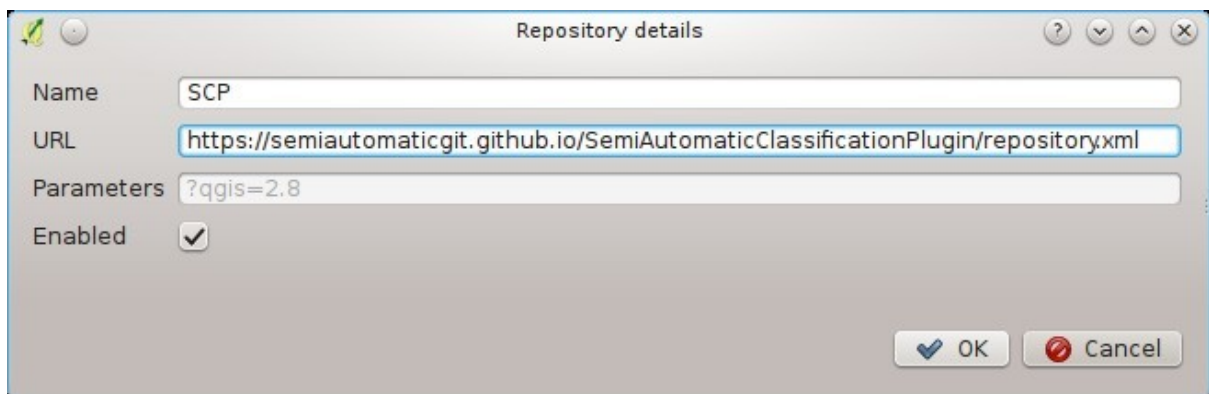
Name:

SCP

URL:

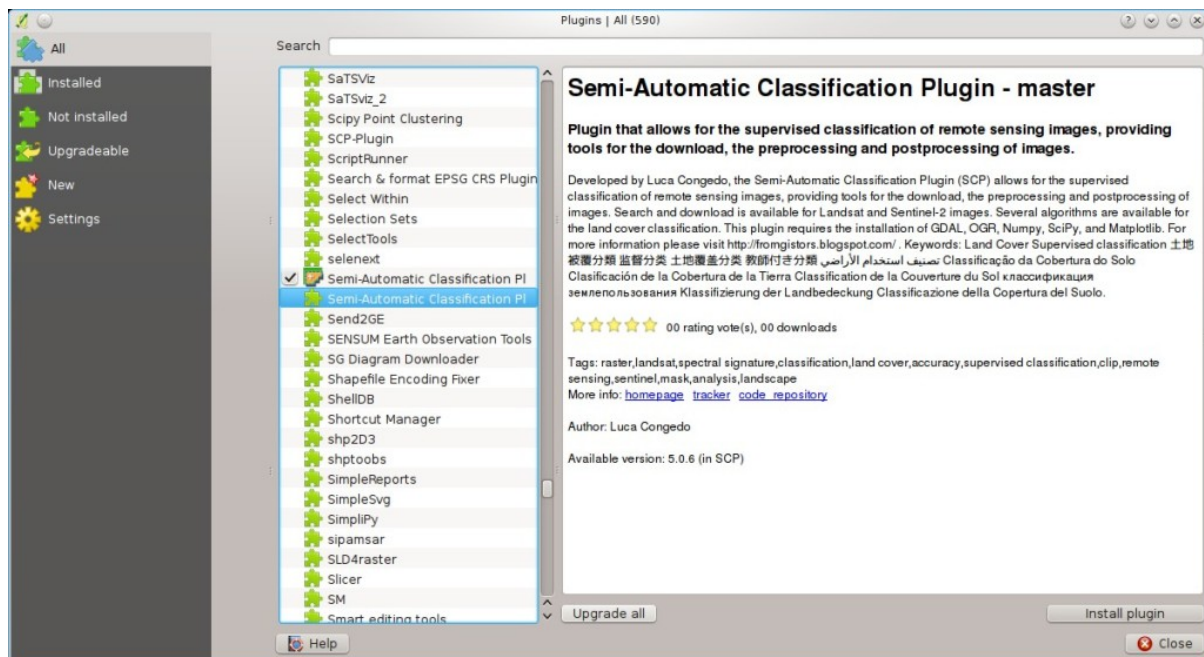
<https://semiautomaticgit.github.io/SemiAutomaticClassificationPlugin/repository.xml>

and click **OK**;

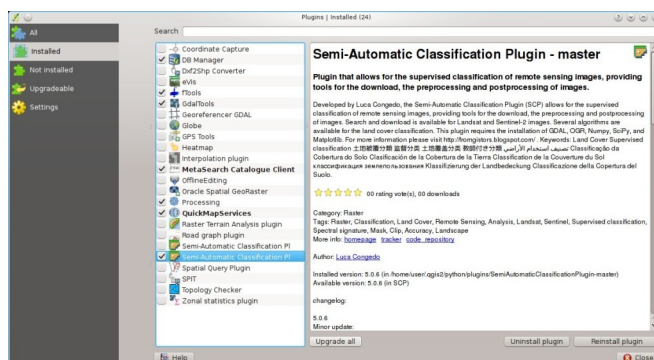


- After the repository update, the item **Semi-Automatic Classification Plugin - master** should be listed with the other plugins;





- From the menu All, select the Semi-Automatic Classification Plugin – master and click the button Install plugin; the latest version of SCP should be automatically activated (ignore errors, the restart of QGIS could be necessary to complete the SCP installation); it is possible to deactivate the other SCP installed in the QGIS repository;



## 8.2 Pre processing

### 8.2.1 Which image bands should I use for a semi-automatic classification?

In general, it is preferable to avoid thermal infrared bands. If you are using Landsat 4, 5 or 7 you should select bands: 1, 2, 3, 4, 5, 7 avoiding band 6 that is thermal infrared; for Landsat 8 you should select bands: 2, 3, 4, 5, 6, 7. Landsat 8 band 1 is generally avoided because it is very similar to the blue band and it is mainly used for coastal aerosol study. Landsat thermal infrared band is excluded from classifications because values are mainly related to object temperature.

For Sentinel-2 images you can use bands: 2, 3, 4, 5, 6, 7, 8, 8A, 11, 12.

### 8.2.2 Which Landsat bands can be converted to reflectance by the SCP?

All Landsat 1,2, and 3 MSS and Landsat 4, 5, 7, and 8 images downloaded from <http://earthexplorer.usgs.gov/> and processed with the Level 1 Product Generation System (LPGS) can be converted to reflectance automatically by the SCP; products generated by the LPGS have a MTL file included that is required for the conversion.

### 8.2.3 Can I apply the conversion to Sentinel-2 images download from the web?

Yes, you can convert also images downloaded from the web (actually the conversion is recommended). You should move all the bands (.jp2 files) and if available the .xml file whose name contains MDT\_SAFL1C in the same directory. Then select this directory in *Sentinel-2 conversion* (page 58). Images are converted to reflectance.

### 8.2.4 How are converted Sentinel-2 images that have different resolutions?

During the conversion to reflectance, pixels of 20m bands are split in 4 pixels of 10m whose values are the same as the original 20m pixel. The purpose of this operation is to allow for the calculation between all the bands, without changing original values.

### 8.2.5 Can I apply the Landsat conversion and DOS correction to clipped bands?

Yes, you can clip the images before the conversion to reflectance and then copy the MTL file (contained in the Landsat dataset) inside the directory with the clipped bands. If you want to apply the DOS correction (which is an image based technique) you should convert the original Landsat bands (the entire image) and then clip the conversion output (i.e. bands converted to reflectance).

### 8.2.6 Can I apply the DOS correction to bands with black border (i.e. with NoData value)?

If you want to apply the DOS correction to an entire band which has NoData values (the black border with value = 0) then you have to check the checkbox `Use NoData value` and set the value to 0. This is because DOS is an image based technique, and NoData values must be excluded from the calculation.

### 8.2.7 How to remove cloud cover from images?

DOS1 correction does not remove clouds from the image. However, Landsat 8 images include Band 9 that identifies clouds (see this [NASA site](#)). You can use this band for the creation of a mask.

For other Landsat satellites, clouds can be masked using the approach described [this paper](#).

Also, see the following [video-tutorial](#).

### 8.2.8 After pan-sharpening of Landsat 8 images, why NIR bands still have 30m resolution?

Landsat 8 panchromatic band doesn't acquire in the Near Infrared (NIR) region (see *Landsat Satellites* (page 113)). Therefore, the pan-sharpening process can't improve the resolution of NIR and SWIR bands (see *Pan-sharpening* (page 128)), which appear to have 30m resolution. However, all pan-sharpened rasters have 15m resolution to allow raster calculation.

## 8.3 Processing

### 8.3.1 I get classification errors. How can I improve the accuracy?

Several materials have similar spectral signatures (e.g. soil and built-up, or forest and other types of dense low vegetation), which can cause classification errors if ROIs, and spectral signatures thereof, are not acquired correctly. In order to improve the results, you can try to collect more ROIs over these areas, in order to train the algorithm for these very similar areas, also, display the spectral signatures of these areas in *Spectral Signature Plot* (page 98) to assess their similarity. You can also use a *Signature threshold* (page 48) for these signatures in

order to reduce the variability thereof (only pixels very similar to the input signatures will be classified). The [Land Cover Signature Classification](#) (page 122) is also useful for classifying specific materials that can be spectrally similar to other ones.

### 8.3.2 Is it possible to use the same training input for multiple images?

Yes, it is possible if all the images have the same number of bands. However, if images are acquired in different months, land cover changes (especially of vegetation state) will affect the spectral signature (i.e. the same pixel has different spectral signature in different periods). Atmospheric effects could also affect the images differently. That could reduce classification accuracy. Therefore, it is suggested to collect always the ROIs and spectral signatures for every image.

### 8.3.3 What is the difference between classes and macroclasses?

Please see [Classes and Macroclasses](#) (page 118).

### 8.3.4 Can I use SCP with images from drones or aerial photographs?

Yes, you can use them if they have at least 4 bands. With less than 4 bands, semi-automatic classification algorithms are unable to classify the land cover correctly. Alternative classification methods exist, such as object oriented classification, which is not implemented in SCP.

### 8.3.5 Why using only Landsat 8 band 10 in the estimation of surface temperature?

Several methods were developed for estimating surface temperature. The method described in the tutorial for temperature estimation requires only one band. Moreover, USGS recommends that users refrain from relying on Landsat 8 Band 11 data in quantitative analysis of the Thermal Infrared Sensor data (see [Changes to Thermal Infrared Sensor \(TIRS\) data](#) by USGS).

## 8.4 Warnings


### 8.4.1 Warning [12]: The following signature will be excluded if using Maximum Likelihood. Why?

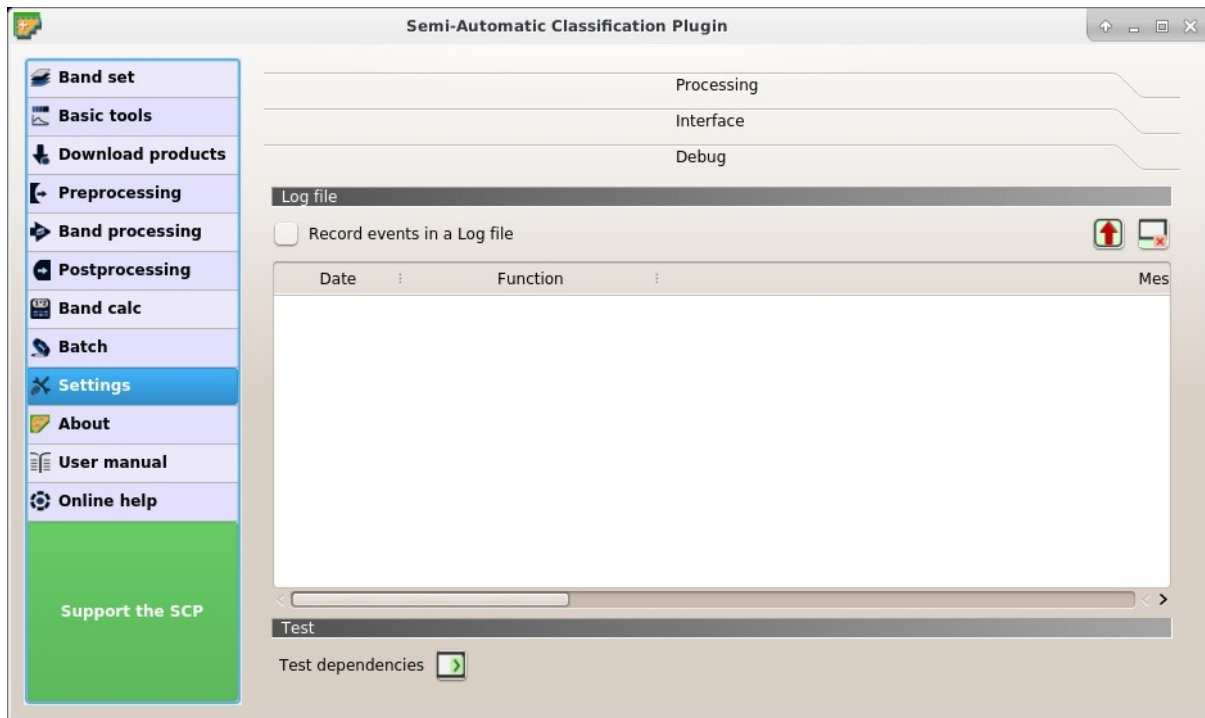
The ROI is too small (or too homogeneous) for the [Maximum Likelihood](#) (page 120) algorithm because that ROI has a singular covariance matrix. You should create larger ROIs or don't use the Maximum Likelihood algorithm in the classification process.




## 8.5 Errors

### 8.5.1 How can I report an error?

If you found an error of the Semi-Automatic Classification Plugin please follow these steps in order to collect the required information (log file):

1. close QGIS if already open;
2. open QGIS, open the Plugin tab [Debug](#) (page 97) and check the checkbox  *Records events in a log file* ;

Fig. 1: *Debug*

3. click the button *Test dependencies*  in the tab *Debug* (page 97) ;
4. **load the data in QGIS (or open a previously saved QGIS project) and repeat all the steps that cause the error in the PL**
  - if the issue could be related to the image data, please use [this sample dataset](#) ;
5. if an error message appears (like the one in the following image), copy the whole content of the message in a text file;
6. open the tab *Debug* (page 97) and uncheck the checkbox  *Records events in a log file*, then click the button  and save the **log file** (which is a text file containing information about the Plugin processes);
7. open the **log file** and copy the whole content of the file;
8. join the Facebook [group](#) , create a new post and copy the error message and the **log file** (or attach them).

### 8.5.2 Virtual raster creation issues. Why?

The automatic creation of the virtual raster after Landsat conversion to reflectance is not required for the classification. Errors could happen if the output destination path contains special characters (such as accented letters) or spaces; try to rename directories (e.g. `rename new_directory to new_directory`). If you still get the same error you can create a virtual raster manually.

### 8.5.3 Error 'Plugin is damaged. Python said: ascii'. Why?

It could be related to a wrong installation. Please, uninstall QGIS and install it again with administrative rights. Then run QGIS and try to install the plugin following the [Plugin Installation](#) (page 3) guide.

Also, it could be related to the user name containing special characters. Please try the installation creating a new user without special characters (e.g. `user`).

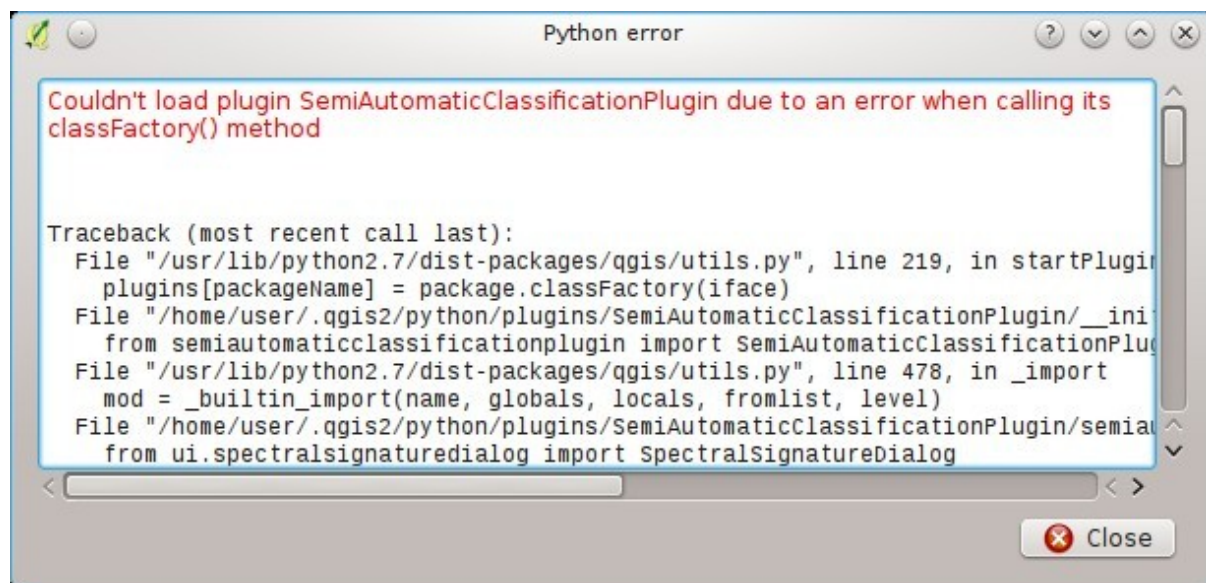


Fig. 2: Error message

### 8.5.4 Error [50] ‘Internet error’. Unable to download Sentinel-2 images. Why?

The error message usually includes some information about the issue. First, check the user name and password. If the account registration was recent, it could take a few days to complete the process for allowing the download from SCP.

Also, there could be an interruption of the service. For Sentinel-2 images please check this website <https://scihub.copernicus.eu/news/> for messages about the state of the service.

In case you still get the same error, please follow these steps [How can I report an error?](#) (page 228).

### 8.5.5 Error installing the plugin, possible missing dependencies. Why?

The plugin requires the installation of GDAL, NumPy, SciPy and Matplotlib, which should be installed along with QGIS. If the plugin installation fails, and you get a message about possible missing dependencies, you should try to install or update QGIS and the required dependencies. Notice that in order to avoid this error, python dependencies should not be installed through Anaconda.

## 8.6 Various

### 8.6.1 What can I do with the SCP?

SCP allows for the **land cover classification** of remote sensing images through *Supervised Classification* (page 116). You can produce a land cover raster using one of the *Classification Algorithms* (page 118) available in SCP. These algorithms require spectral signatures or ROIs as input (for definitions please read *Brief Introduction to Remote Sensing* (page 109)) that define the land cover classes to be identified in the image.

SCP can work with **multispectral images** acquired by satellites, airplanes, or drones. Also, SCP allows for the direct search and download of free images (see *Download products* (page 51)). You cannot use orthophotos with less than 4 bands, SAR data, and LIDAR data with SCP.

**Input image** in SCP is called *Band set* (page 37), which is used as input for the classification. SCP provides several tools for the *Preprocessing* (page 56) of downloaded images, such as the conversion to reflectance and manipulation of bands.



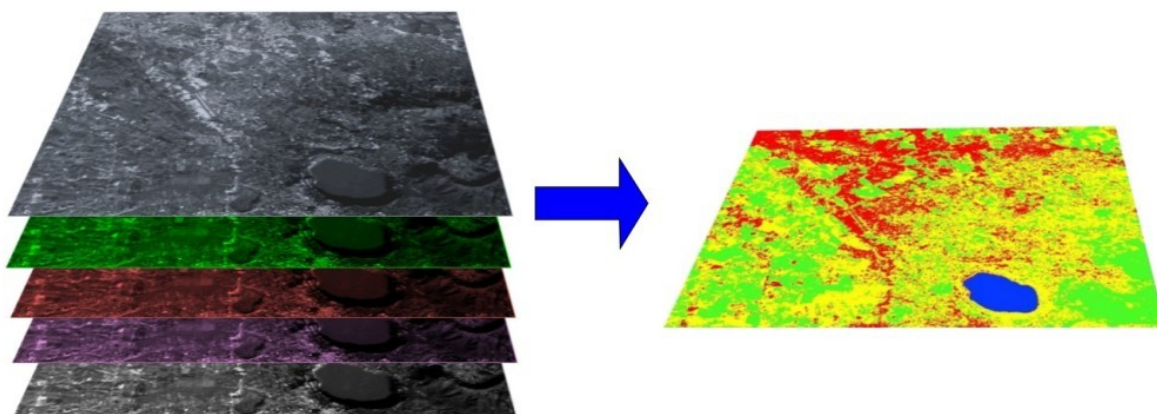


Fig. 3: A multispectral image processed to produce a land cover classification  
(Landsat image provided by USGS)

**Classification results** can be assessed with the tools *Accuracy* (page 75) and *Classification report* (page 77). Also, rasters can be manipulated using *Postprocessing* (page 75) tools such as *Classification to vector* (page 80), *Reclassification* (page 81), *Edit raster* (page 82) directly, *Classification sieve* (page 84), *Classification erosion* (page 85), and *Classification dilation* (page 86).

The *Spectral Signature Plot* (page 98) and *Scatter Plot* (page 104) allow for the **analysis of spectral signatures and ROIs**. Also, several *Basic tools* (page 40) are available for easing the ROI creation and editing spectral signatures.

**Raster calculation** is available through the seamless integration of the tool *Band calc* (page 87) with bands in the *Band set* (page 37), calculating mathematical expressions and spectral indices. Also, an output raster can be calculated based on *Decision rules* (page 89).

The tool *Batch* (page 91) allows for the automatic execution of several *SCP* functions using a scripting interface. See the *Basic Tutorials* (page 139) for more information and examples.

## 8.6.2 How to contribute to SCP

You can contribute to *SCP* by fixing and adding functionalities (see *Where is the source code of SCP?* (page 233)), or translating the user manual (see *How can I translate this user manual to another language?* (page 232)).

Also, you can donate to this project at the following link <https://fromgistors.blogspot.com/p/donations.html>.

## 8.6.3 Free and valuable resources about remote sensing and GIS

The following links are valuable resources:

- The Landsat 8 Data Users Handbook by USGS;
- The Landsat 7 Science Data Users Handbook by NASA;
- Webinar: Fundamentals of Remote Sensing by NASA.
- Webinar: NASA Remote Sensing for Land Management by NASA.
- Webinar: Creating and Using Normalized Difference Vegetation Index (NDVI) from Satellite Imagery by NASA.
- Webinar: Remote Sensing of Forest Cover and Change Assessment for Carbon Monitoring by NASA.
- Webinar: Introduction to Remote Sensing for Conservation Management by NASA.



### 8.6.4 Other tutorials about SCP, also in languages other than English

There are several tutorials about *SCP* on the internet. Following an incomplete list of these resources (please note that these resources could use older versions of SCP):

- English: Webinar by NASA ARSET about Land Cover Classification with Satellite Imagery;
- English: Recommended Practice by UN-SPIDER about Burn Severity Mapping Burn Severity with QGIS;
- English: Using the SCP QGIS plugin to download and process Sentinel 2 imagery;
- French: Télédétection des feux de forêts;
- German: 2015 Jakob Erfassung von Landnutzungsveränderungen mit FOSS Image Processing Tools;
- Indonesian: Koreksi Radiometrik Menggunakan QGIS:Semi Automatic Classification;
- Italian: Classificazione e Mosaico di Varie Immagini Landsat;
- Korean: QGIS Semi-Automatic Classification Plugin;
- Portuguese: Workshop de Detecção Remota e Processamento Digital de Imagem com o QGIS e o Semi-Automatic Classification Plugin;
- Portuguese: Classificacao supervisionada de imagens Sentinel-2 com QGIS e SCP;
- Portuguese: Avaliação do erro de uma imagem de satélite usando o QGIS e o SCP;
- Portuguese: Conversão Sentinel-2 para refletância com QGIS SCP;
- Portuguese: Criar composições coloridas no QGIS com SCP;
- Portuguese: Corte de imagem Sentinel-2 usand QGIS e SCP;
- Portuguese: Detecção Remota Com O QGIS;
- Russian: Sentinel- 2a Semi-Automatic Classification Plugin QGIS;
- Spanish: Descarga de imágenes de satélite desde servidores públicos;
- Swedish: Landsat 8 och fjärranalys med QGIS;
- Ukrainian: Semi-Automatic Classification 5.0;
- Ukrainian: Qgis ;

### 8.6.5 How can I translate this user manual to another language?

It is possible to easily translate the user manual to any language, because it is written in reStructuredText as markup language (using Sphinx). Therefore, your contribution is fundamental for the translation of the manual to your language. The following guide illustrates the main steps for the translation, which can be performed:

- using the free online service Transifex;
- using the gettext .po files.

Before translating, please [read this document](#) from the QGIS translation guide, which helps you understand the reStructuredText.

#### Method 1. Translation using the free online service Transifex

This is probably the easiest way to translate the manual using an online service.

1. Join the Semi-automatic Classification Manual project

Go to the page <https://www.transifex.com/semi-automatic-classification/semi-automatic-classification-plugin-manual> and click the button Help translate. You can sign in using your Google or Facebook account, or with a free registration.

2. Select your language

Select your language and click the button `Join team`. If your language is not listed, click the button `Request language`.

### 3. Translation

There are several files to be translated, which refer to the sections of the SCP documentation. To translate the SCP interface you should select the file `semiautomaticclassificationplugin.ts`.

#### Method 2. Translation using the gettext .po files

In order to use this method, you should be familiar with GitHub. This translation method allows for the translation of the PO files locally.

##### 1. Download the translation files

Go to the GitHub project [https://github.com/semiautomaticgit/SemiAutomaticClassificationManual\\_v4/tree/master/locale](https://github.com/semiautomaticgit/SemiAutomaticClassificationManual_v4/tree/master/locale) and download the .po files of your language (you can add your language, if it is not listed), or you can fork the repository. Every file .po is a text file that refers to a section of the User Manual.

##### 2. Edit the translation files

Now you can edit the .po files. It is convenient to edit those file using one of the following programs: for instance [Poedit](#) for Windows and Mac OS X, or [Gtranslator](#) for Linux or [OmegaT](#) (Java based) for Windows, Linux and Mac OS X. These editors allow for an easy translation of every sentence in the User Manual.

## 8.6.6 Where is the source code of SCP?

You can find the source code of SPC is at the following link <https://github.com/semiautomaticgit/SemiAutomaticClassificationPlugin>

## 8.6.7 How to install QGIS using OSGeo4W?

To install QGIS, first download the [OSGeo4W installer x86](#) or [OSGeo4W installer x64](#) according to your operating system.

Then start the installer and select `Advanced Install`.

## OSGeo4W Net Release Setup Program



This setup program is used for the initial installation of the OSGeo4W environment as well as all subsequent updates. Make sure to remember where you saved it.

The pages that follow will guide you through the installation. Please note that OSGeo4W consists of a large number of packages spanning a wide variety of purposes. We only install a base set of packages by default. You can always run this program at any time in the future to add, remove, or upgrade packages as necessary.

- ☐ Express Desktop Install
- ☐ Express Web-GIS Install
- ☒ Advanced Install

Check `Install from Internet` and click `Next`.

### Choose A Download Source

Choose whether to install or download from the internet, or install from files in a local directory.

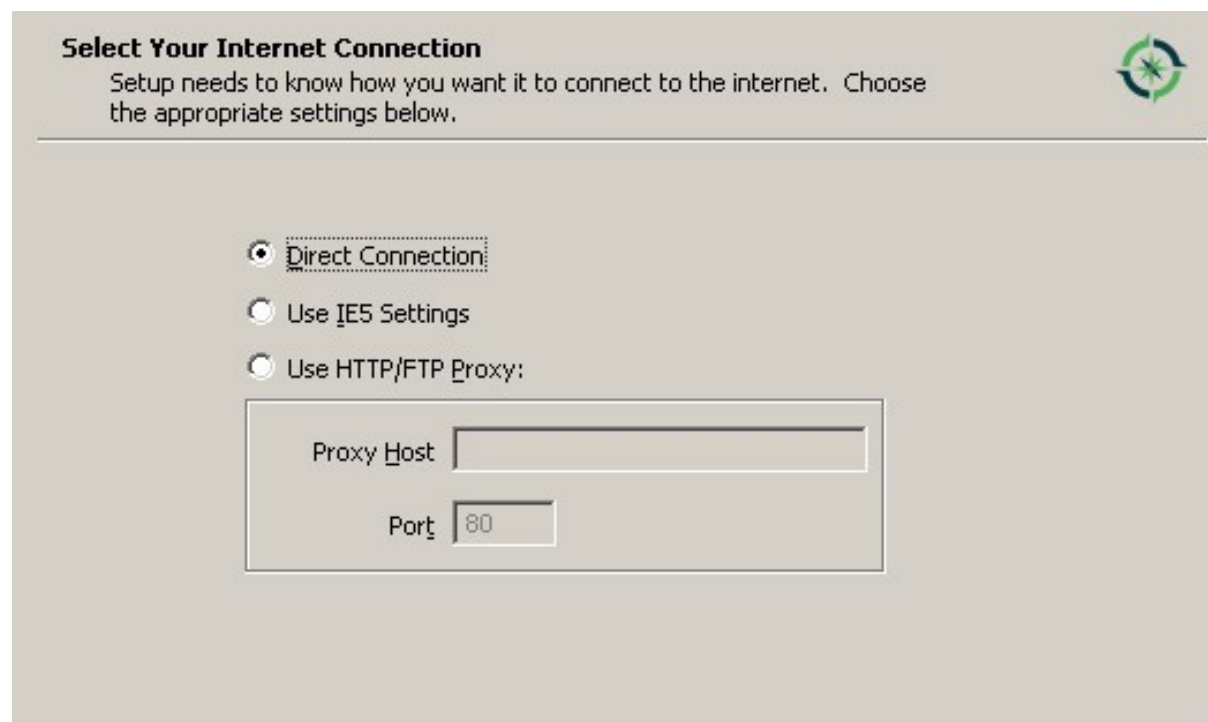


- ☒ Install from Internet  
(downloaded files will be kept for future re-use)
- ☐ Download Without Installing
- ☐ Install from Local Directory

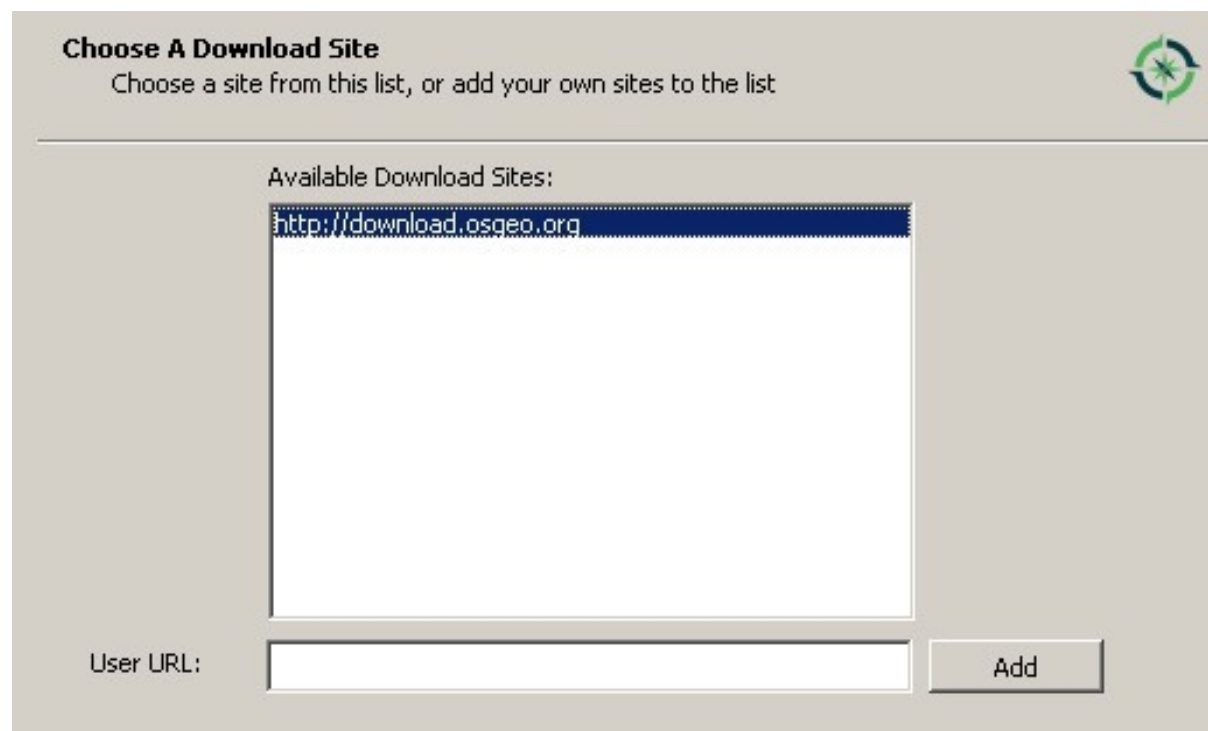
Select the installation directory and click `Next`.

Select the local package directory and click **Next**.

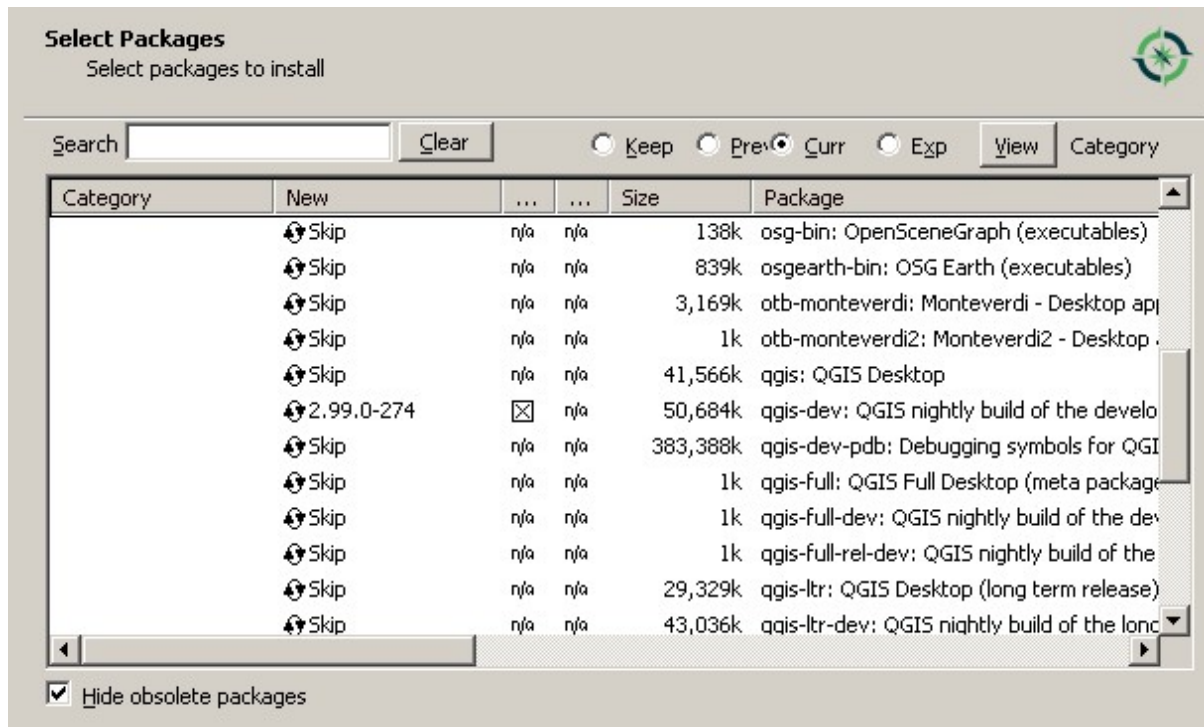
Select **Direct** connection (or select an internet connection option) and click **Next**.



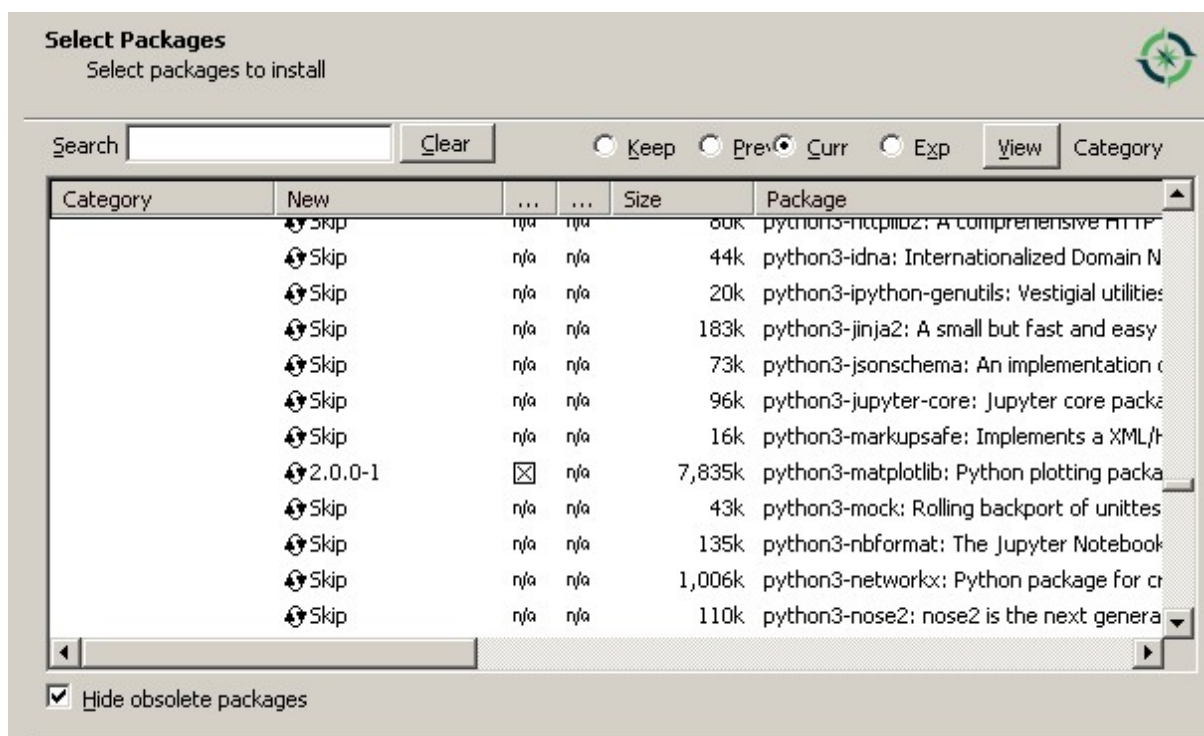
Select the first download site and click Next.



In the package list select `qgis-dev` (in category Desktop) until QGIS3 is released.

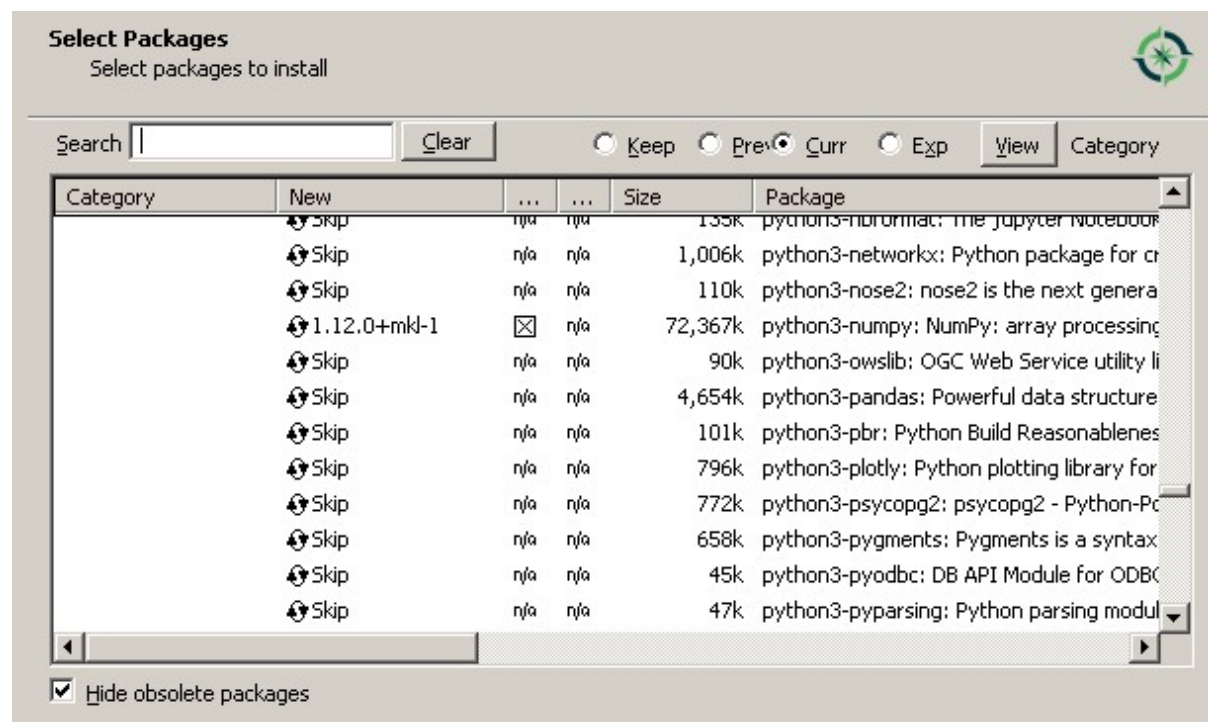


In the package list select `python3-matplotlib` (in category Libs).

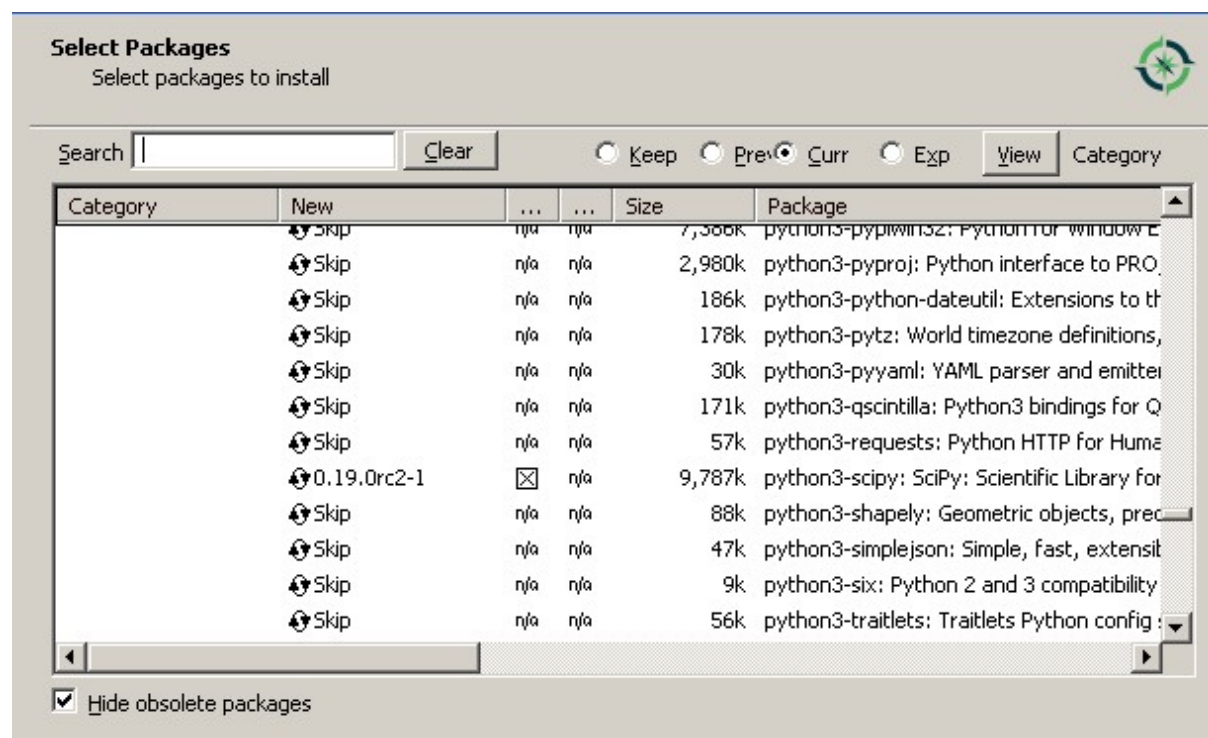


In the package list select `python3-numpy` (in category Libs).

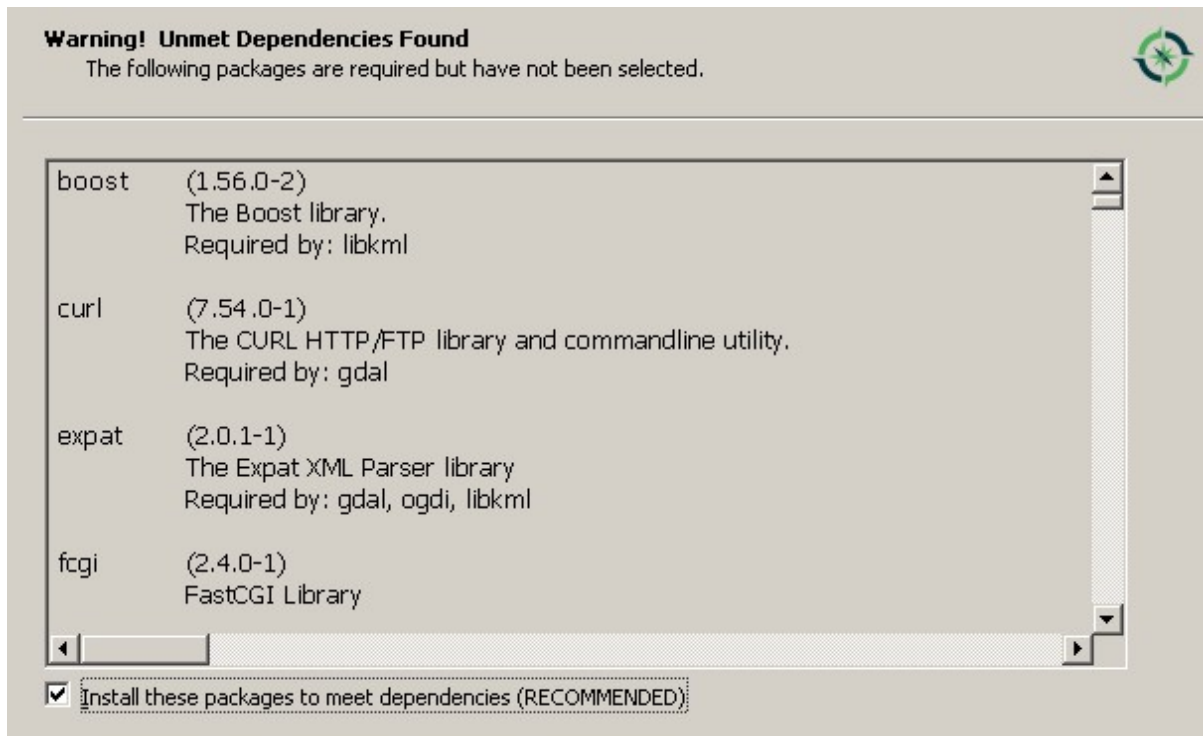




In the package list select `python3-scipy` (in category `Libs`) and click `Next`.



Click `Next` to install also other dependencies.



After the download, QGIS should be installed with all the required dependencies for SCP.