Semi-Automatic Classification Plugin Documentation

Release 7.8.0.1

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Mar 06, 2021

Contents

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 216)). All the main tools are designed for parallel processing.

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.

This **user manual** provides information about the *Plugin Installation* (page 3) of SPC and the *The Interface of SCP* (page 19), with detailed information about all the functions. In addition, the *Brief Introduction to Remote Sensing* (page 125) illustrates the basic concepts and definitions which are required for using the *SCP*.

Basic Tutorials (page 157) are available for learning the main functions of *SCP*.

You are kindly invited to **contribute to SCP** (see *How to contribute to SCP* (page 217)) and join the Facebook group . Also, please read the *Frequently Asked Questions* (page 207).

For more information and tutorials visit the official site

From GIS to Remote Sensing

How to cite:

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Brief history:

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 was developed in the frame of Luca Congedo's PhD in Landscape and Environment at Sapienza University of Rome. *SCP* version 7 as personal commitment to the remote sensing field and open source philosophy.

License:

```
Semi-Automatic Classification Plugin is free software:  you can
redistribute it and/or modify it under the terms of the GNU General
Public License as published by the Free Software Foundation, version 3 of
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
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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.
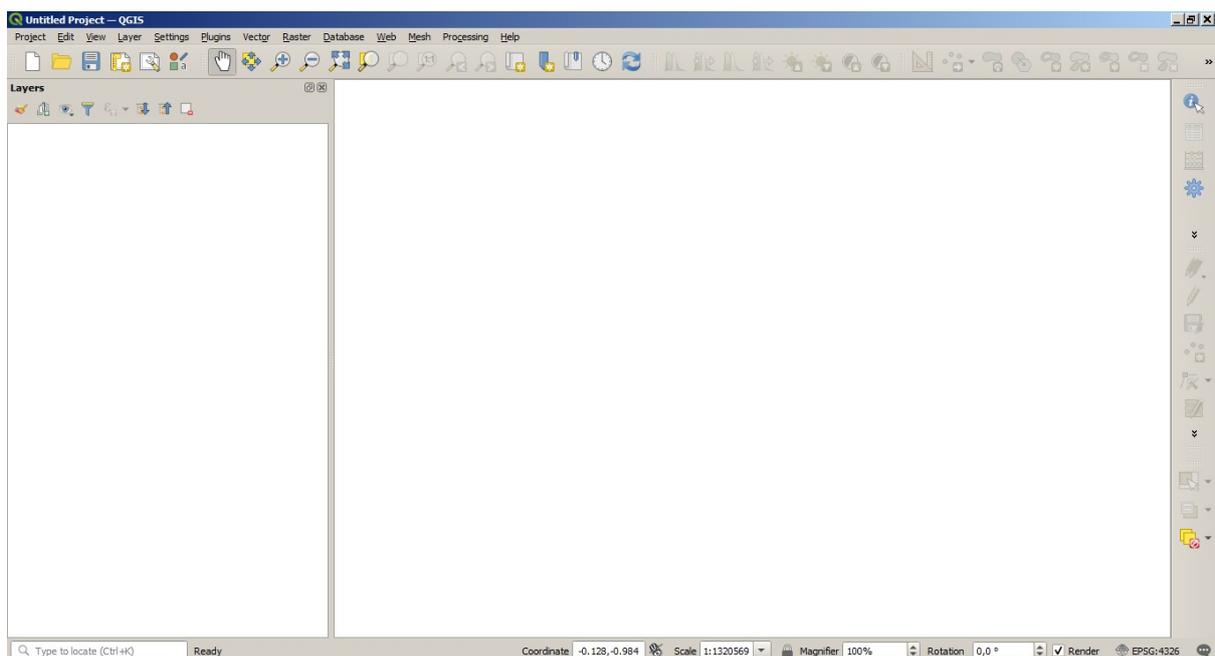
2.1.2 Semi-Automatic Classification Plugin installation

- 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 208) and *How to install the plugin from the official SCP repository?* (page 208).

- 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);
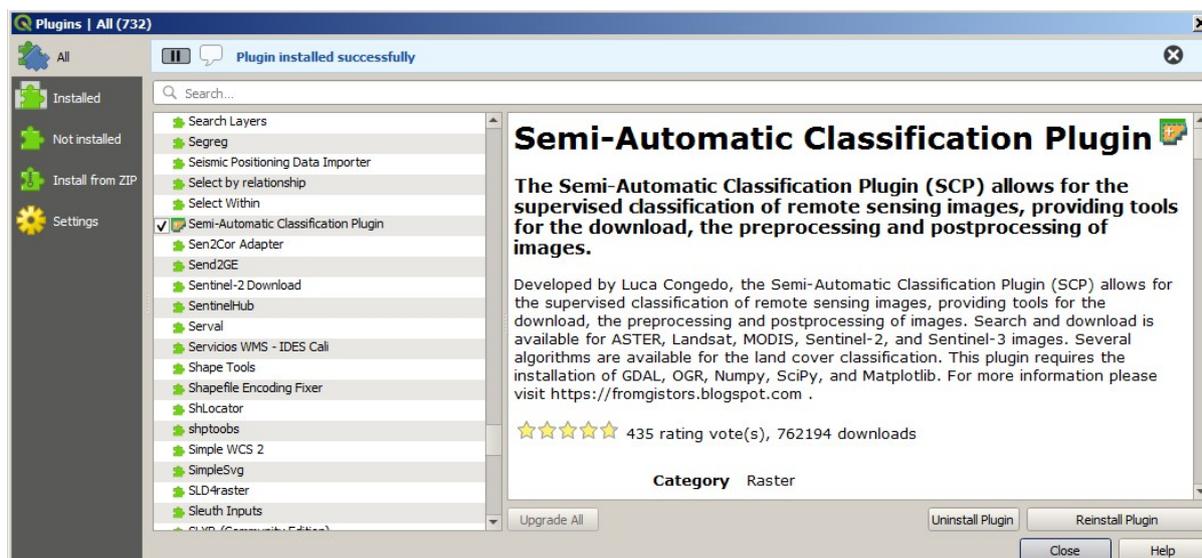
2.1.3 Configuration of the plugin

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.
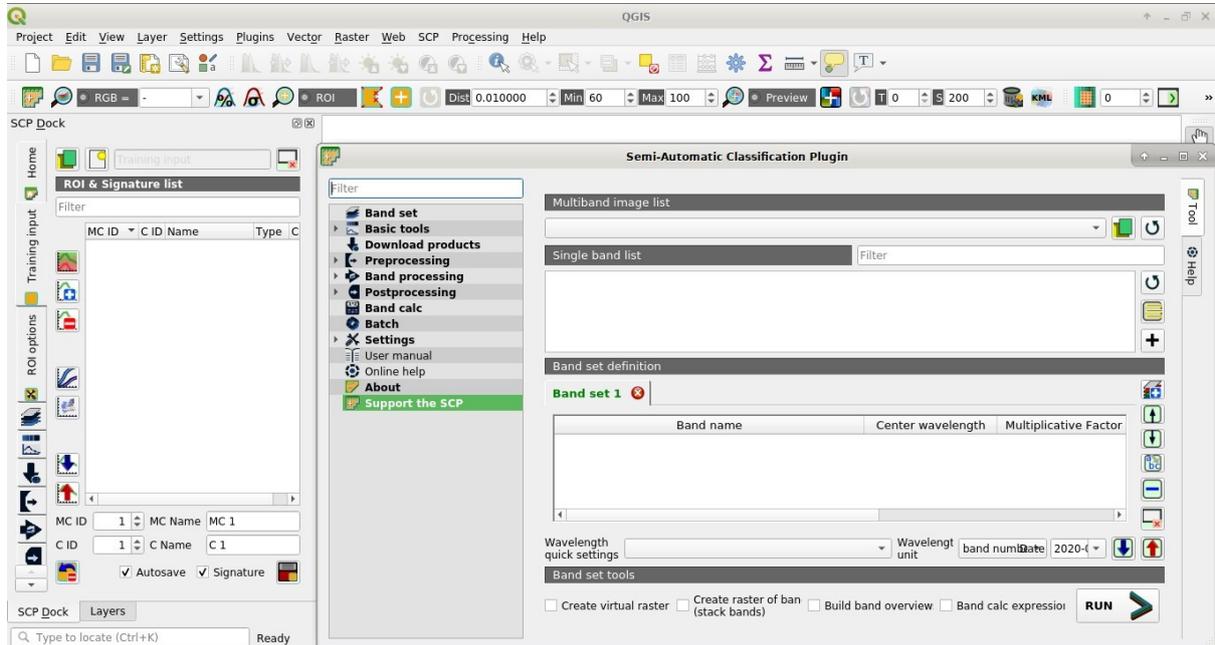
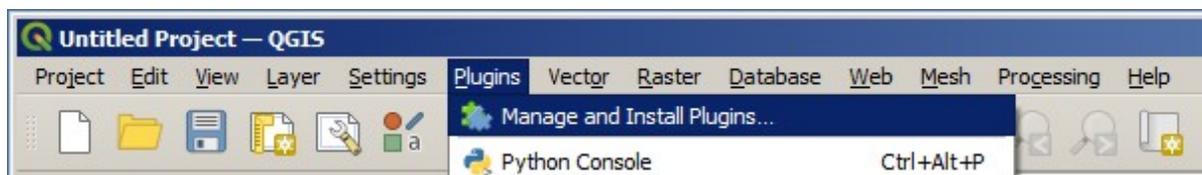## 2.2 Installation in Windows 64 bit

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.
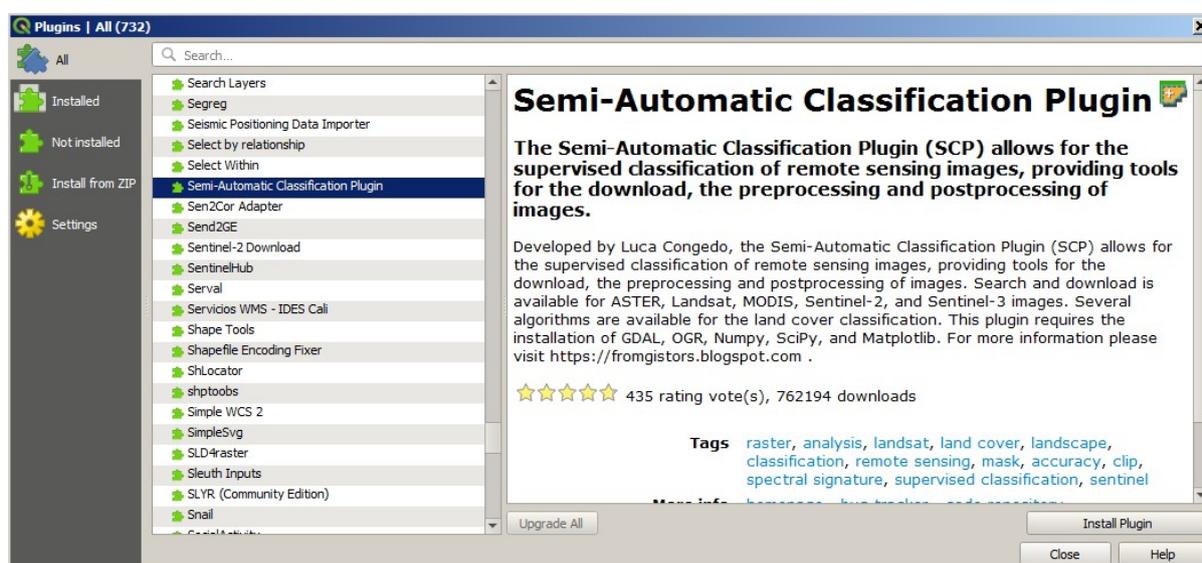
Now, QGIS is installed.
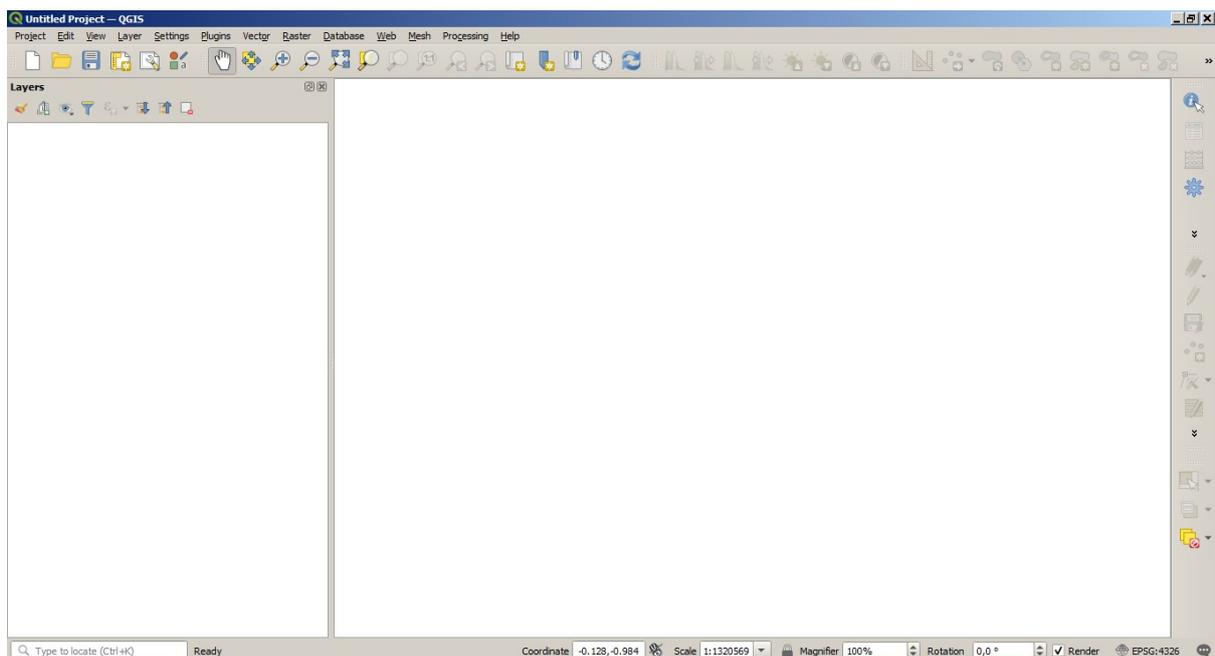
2.2.2 Semi-Automatic Classification Plugin installation

- 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 208) and *How to install the plugin from the official SCP repository?* (page 208).


- 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);
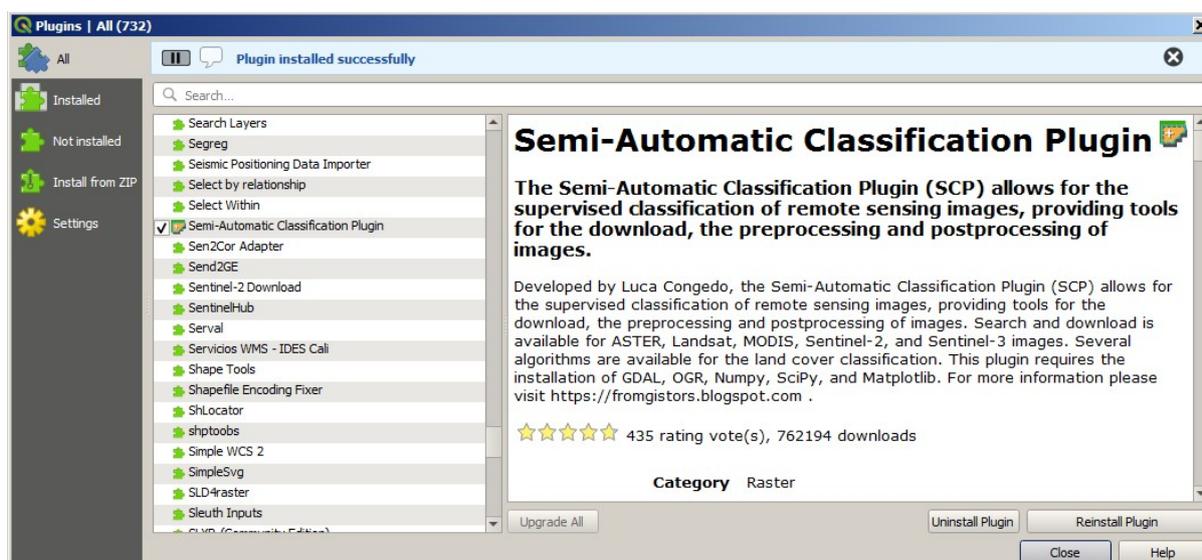
2.2.3 Configuration of the plugin

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.
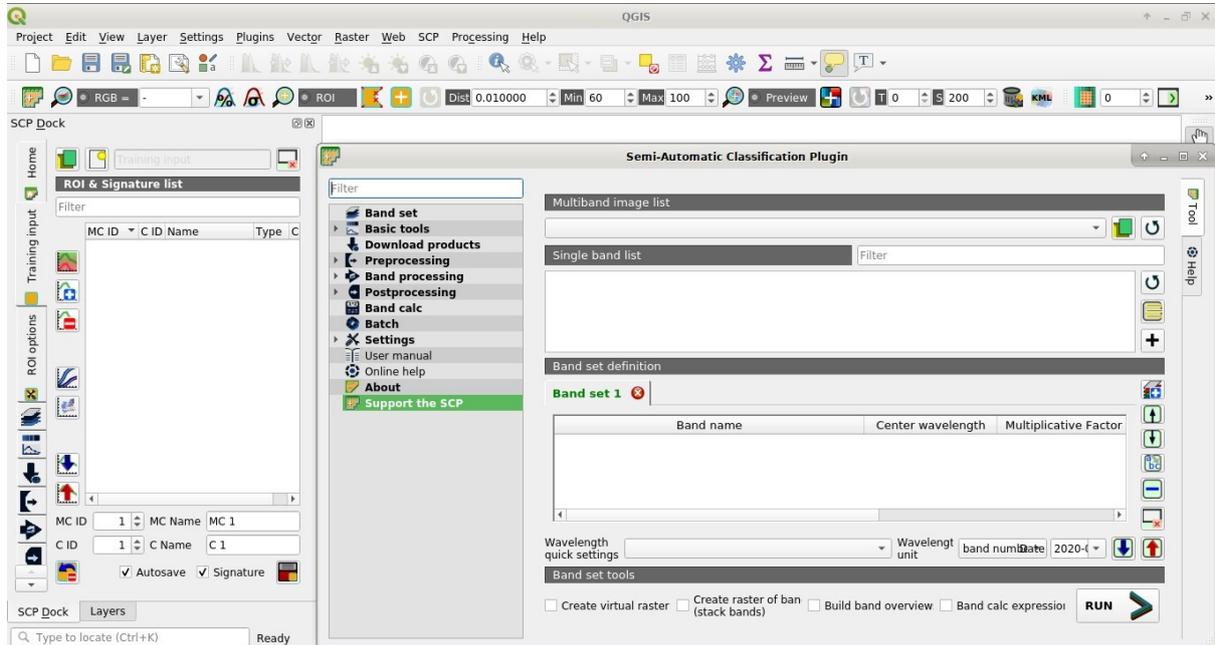
The configuration of available RAM is recommended in order to reduce the processing time. From the *SCP menu* (page 19) select ⚒ `Settings > Processing.`

In the *Settings* (page 110), 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.
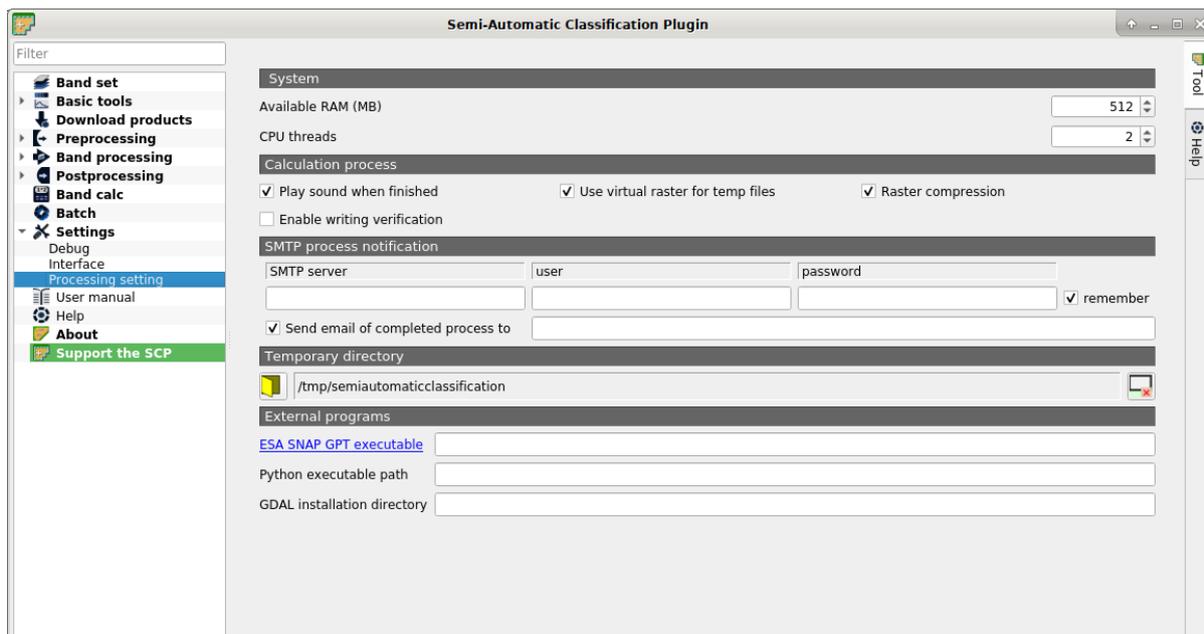
2.3 Installation in Ubuntu Linux

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.
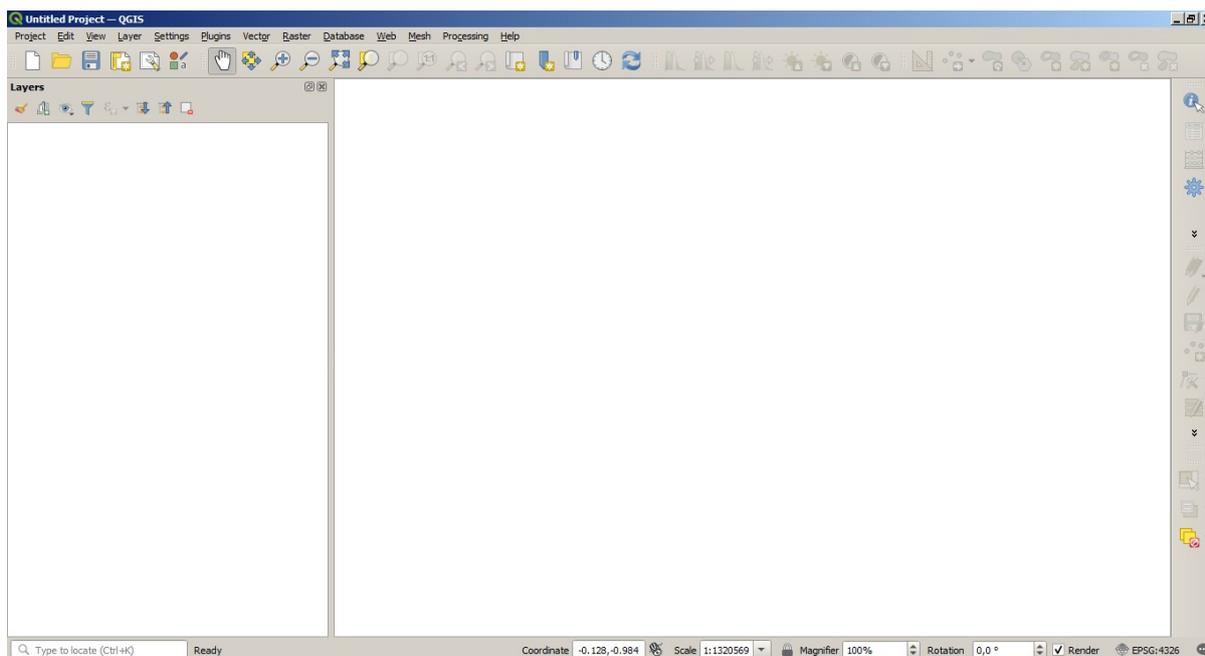
2.3.2 Semi-Automatic Classification Plugin installation
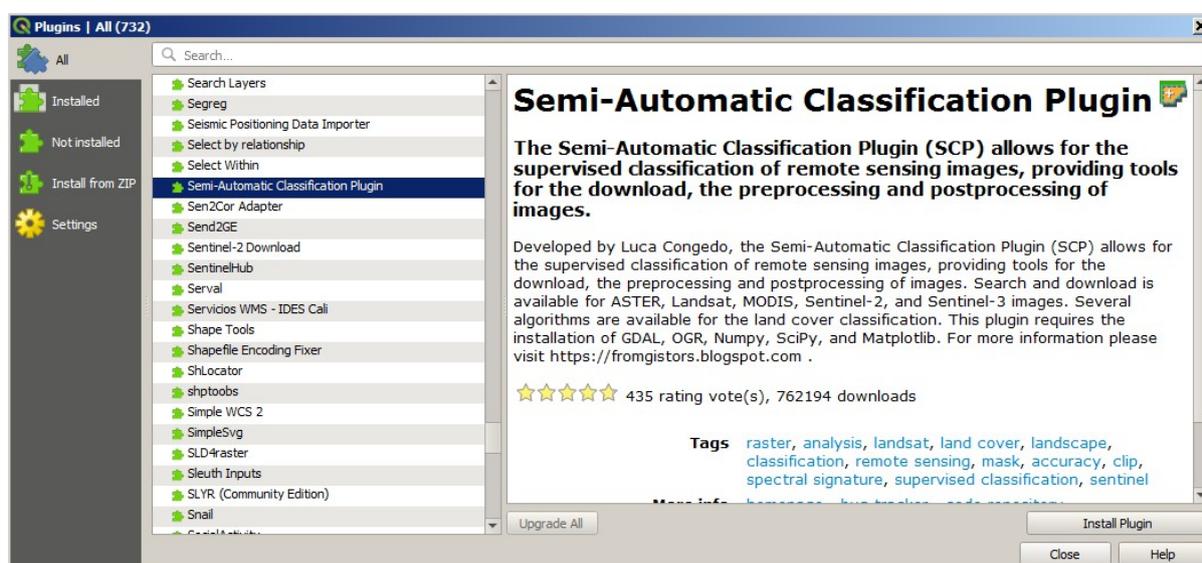
- Run QGIS;

- 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 208) and *How to install the plugin from the official SCP repository?* (page 208).

- 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);
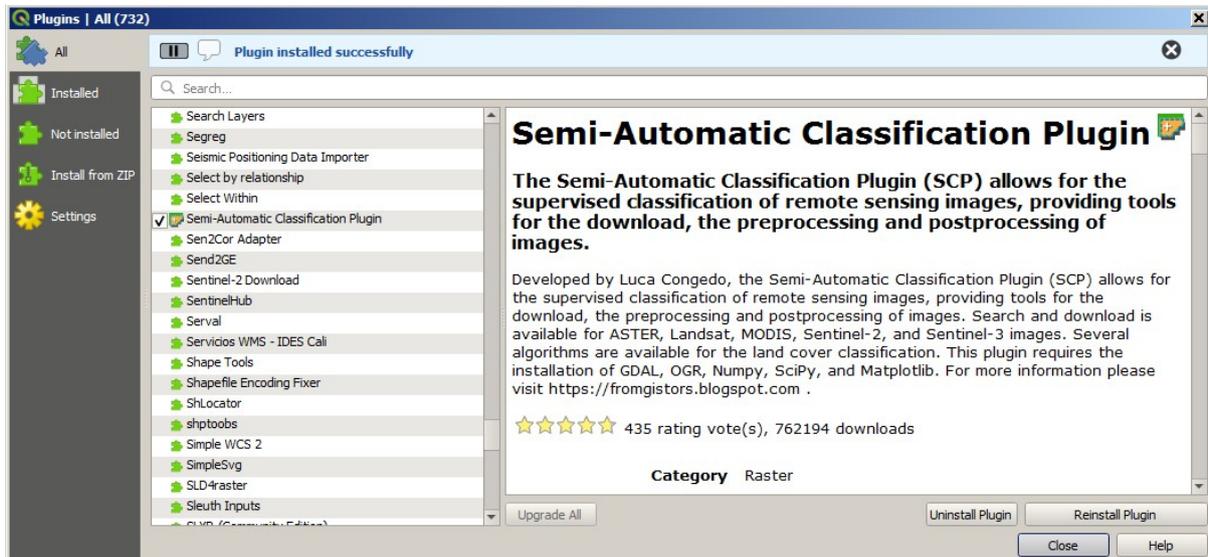
2.3.3 Configuration of the plugin

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.
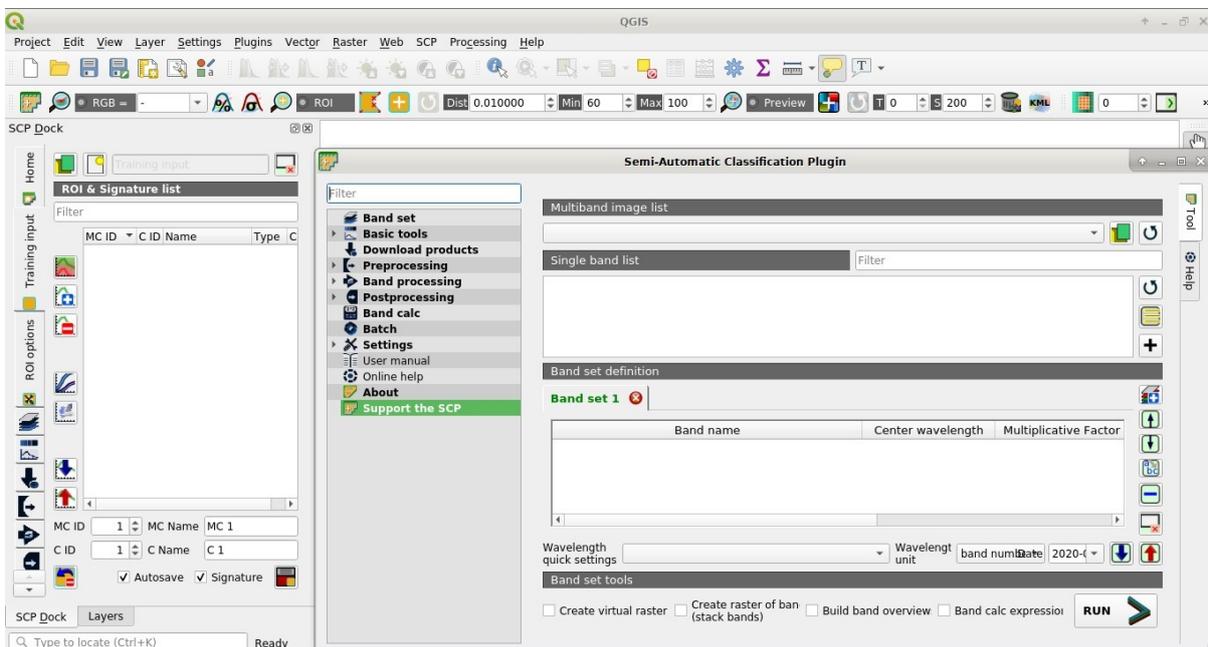
The configuration of available RAM is recommended in order to reduce the processing time. From the *SCP menu* (page 19) select `Settings > Processing`.

In the *Settings* (page 110), 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.
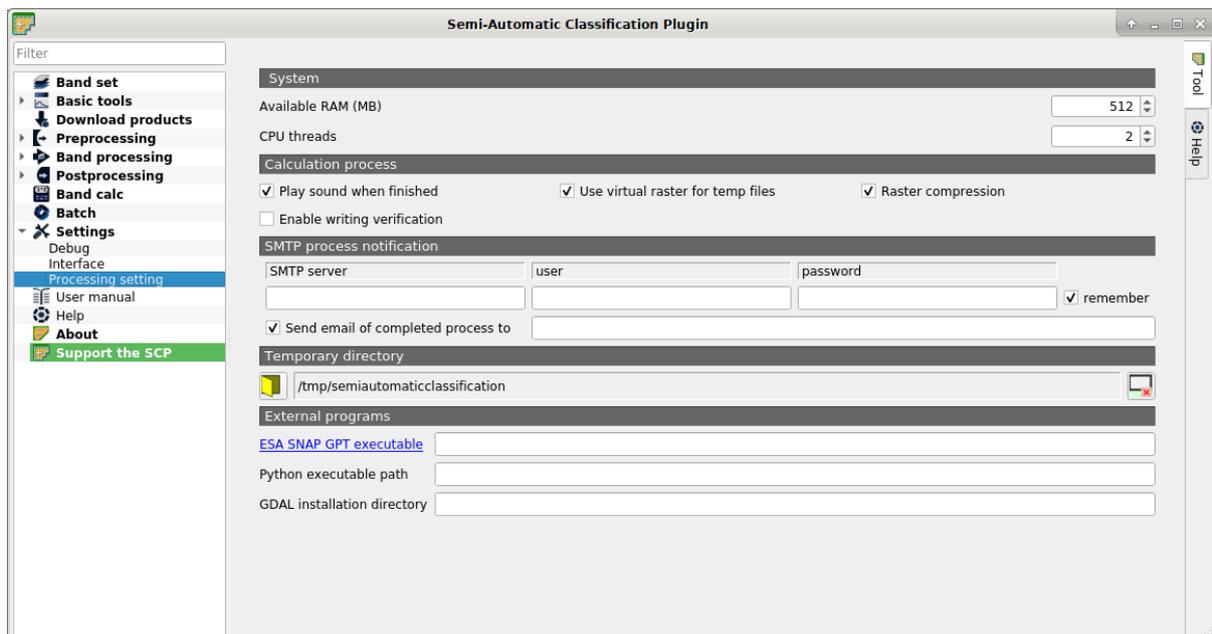
2.4 Installation in Debian Linux

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.
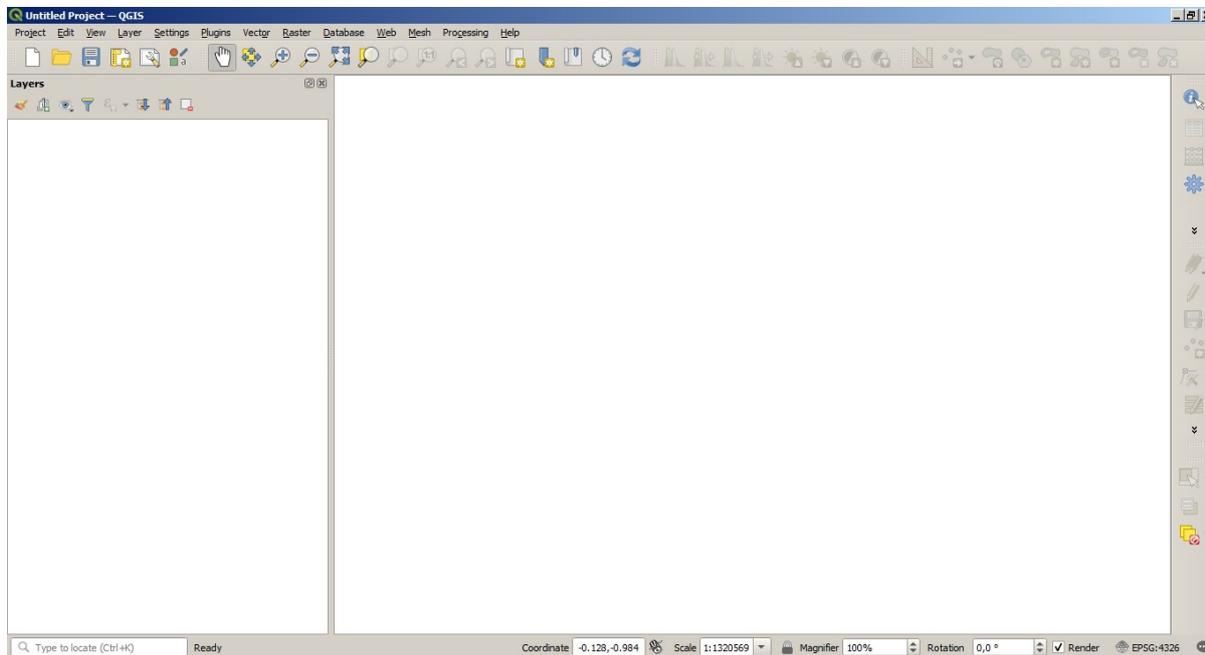
2.4.2 Semi-Automatic Classification Plugin installation

- 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 208) and *How to install the plugin from the official SCP repository?* (page 208).

- 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);
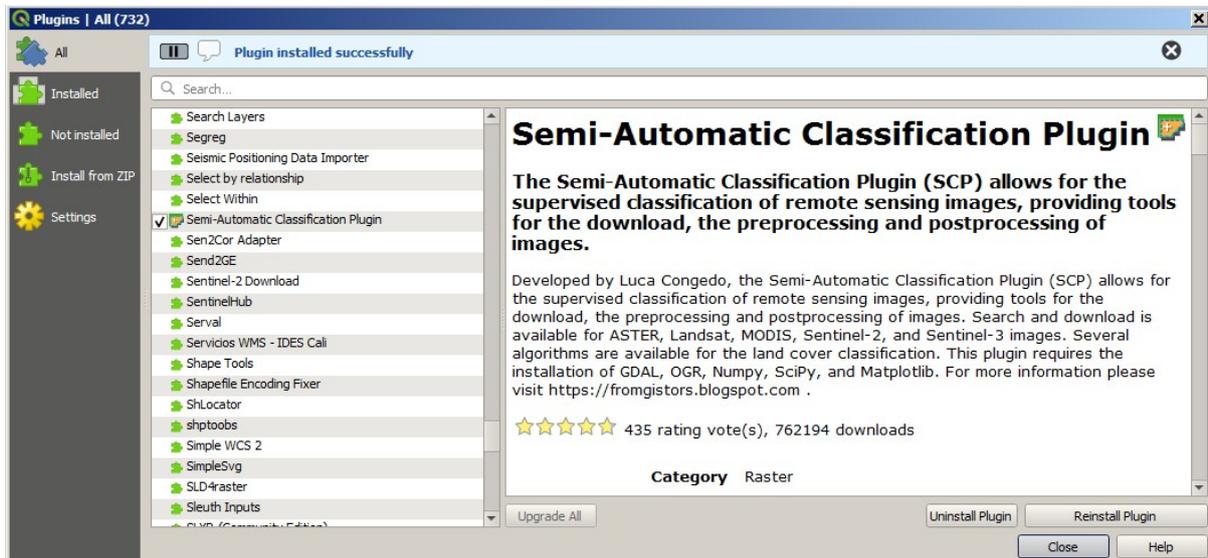

2.4.3 Configuration of the plugin

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.
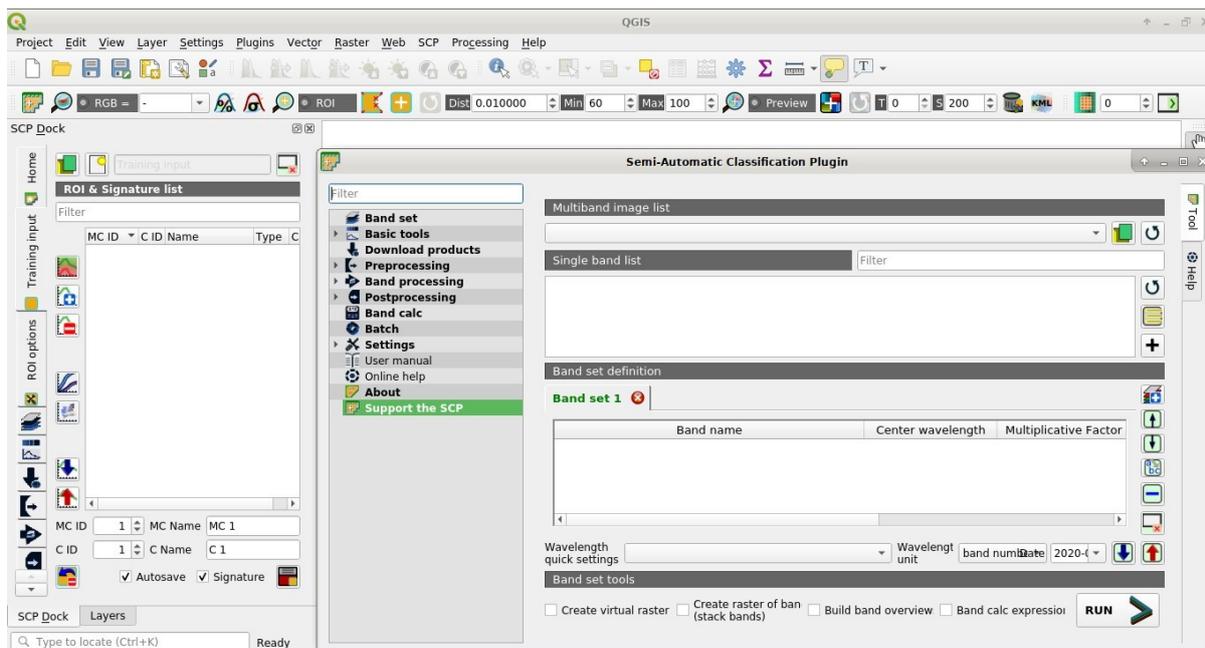
The configuration of available RAM is recommended in order to reduce the processing time. From the *SCP menu* (page 19) select ✖ Settings > Processing.

In the *Settings* (page 110), 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.
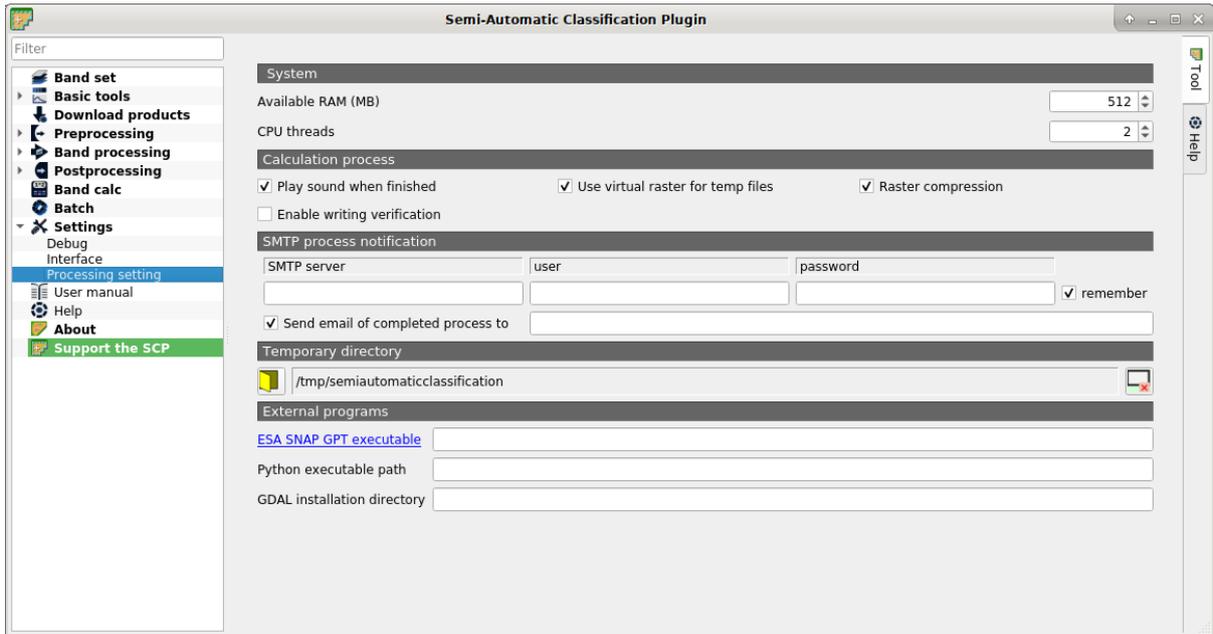
2.5 Installation in Mac OS

2.5.1 QGIS download and installation

- Visit the website KyngChaos and download the latest QGIS disk image (including Python and GDAL). QGIS 3.16 is recommended at the moment.

    WARNING: it is recommended to install only one versions of QGIS; for a clean QGIS installation, uninstall any previous version of QGIS and remove all the related directories.

- Follow the Readme instructions and clean up any previous path settings. Python must be installed prior to GDAL and QGIS.

Now, QGIS is installed.
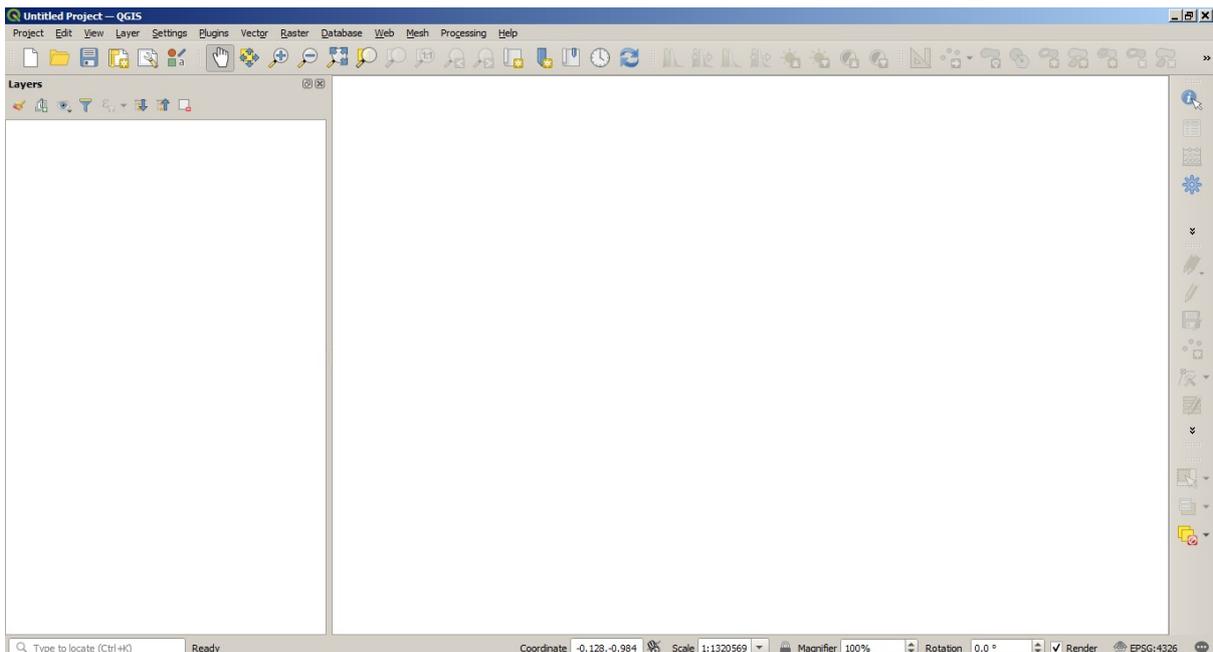
2.5.2 Semi-Automatic Classification Plugin installation

- 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 208) and *How to install the plugin from the official SCP repository?* (page 208).


- 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);
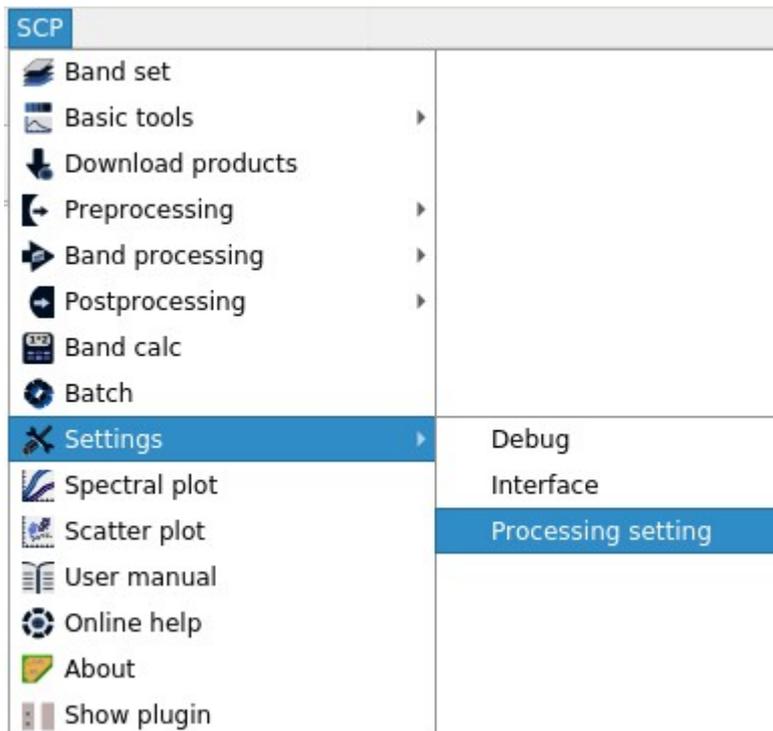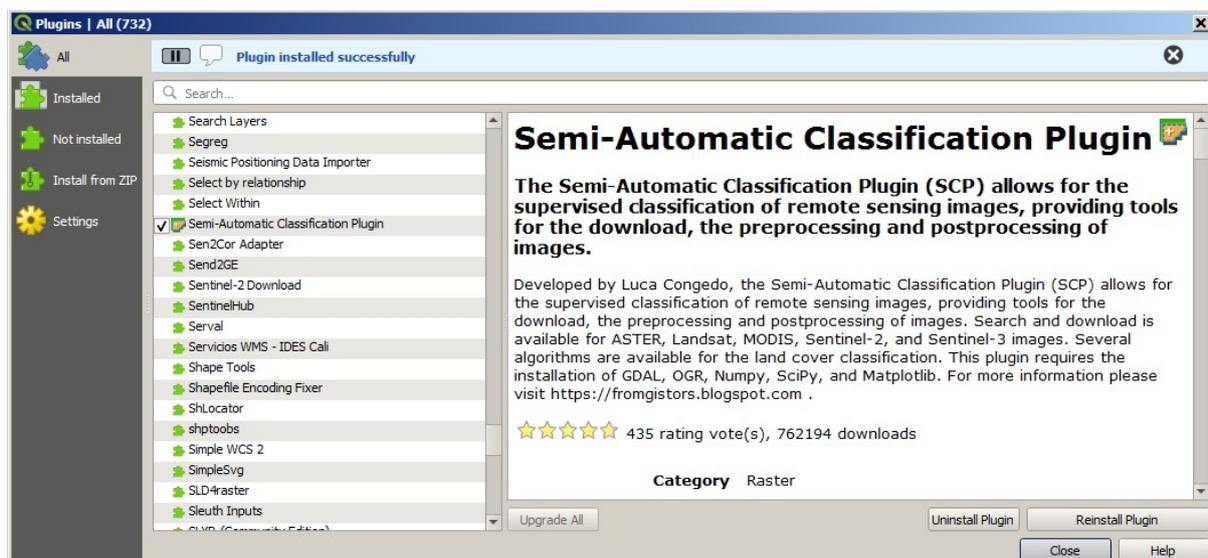
2.5.3 Configuration of the plugin

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.
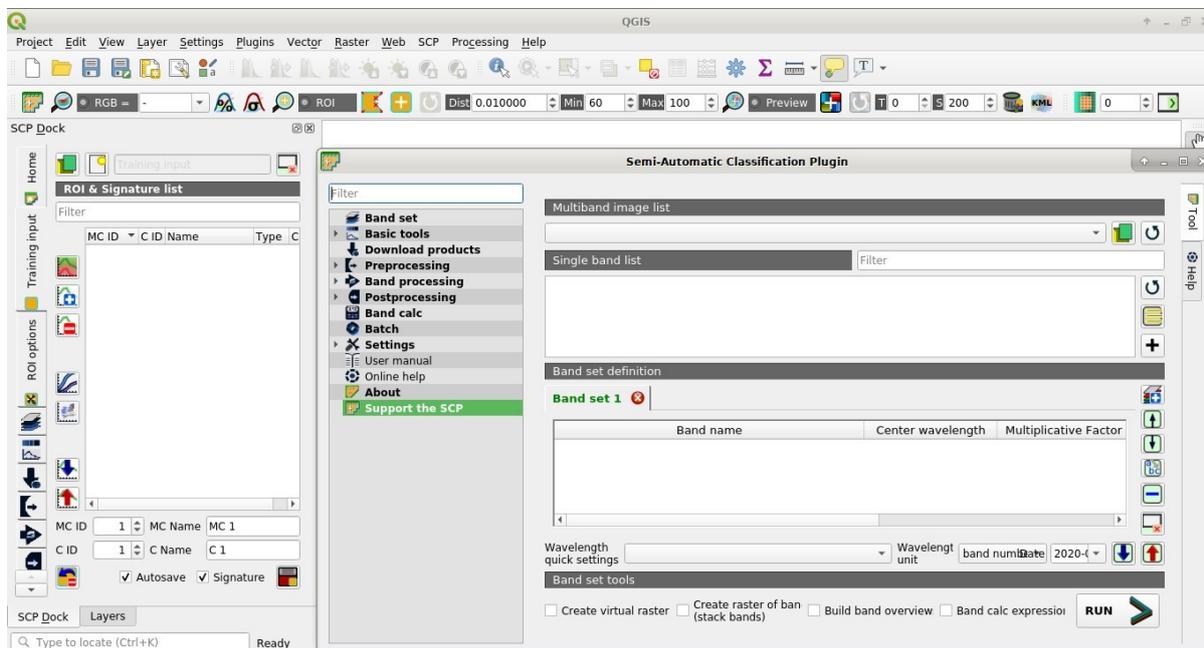
The configuration of available RAM is recommended in order to reduce the processing time. From the *SCP menu* (page 19) select ![icon] Settings > Processing.

In the *Settings* (page 110), 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.
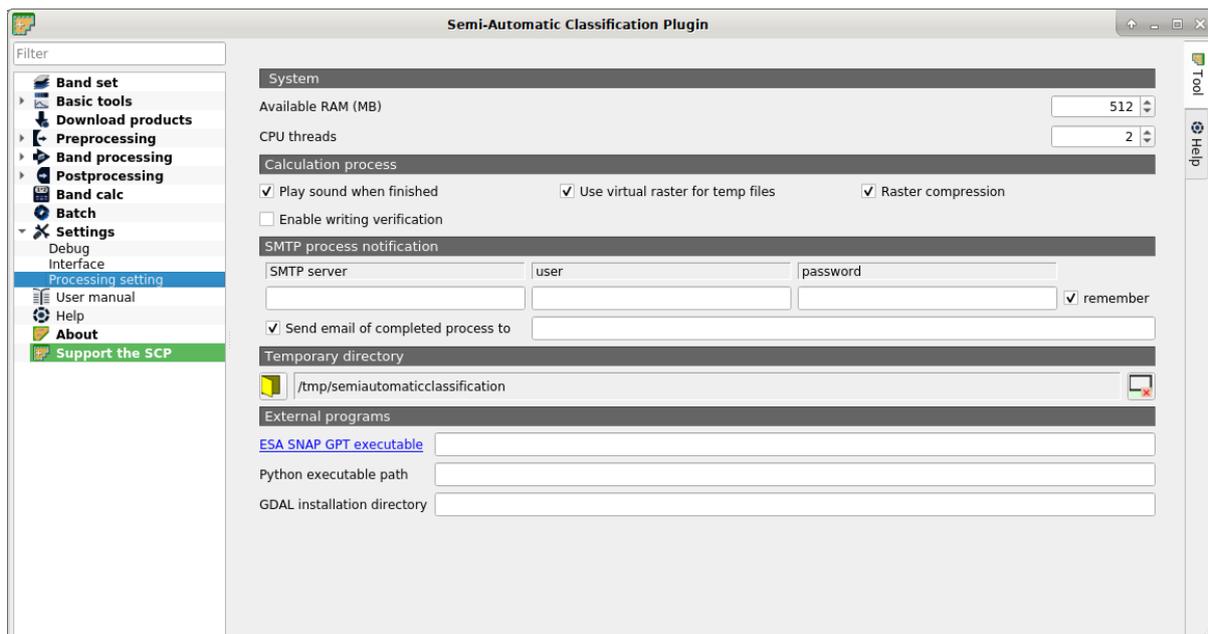
2.5.4 Installation issues

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

A solution is to follow these steps as described in this GIS Stackexchange post :

- Download and install Python from https://www.python.org/downloads/mac-osx/ selecting the macOS 64-bit installer;

- Download and install the complete GDAL installer from https://www.kyngchaos.com/software/frameworks/ ;

  TIP: In case of warnings about malicious software go to the `Apple menu` > `System Preferences` > `Security & Privacy` > `General Tab` > `Allow Anyway`; Python should be in `Library` > `Frameworks` > `Python.framework` ; GDAL should be in `Library` > `Application Support` > `GDAL`

- Open QGIS, go to `Settings` > `Options` > `System` > `Environment` and enable `Use Custom Variables`;

- Select `Prepend`, under `variable` enter `PATH`, under `value` enter the path to GDAL `/Library/Frameworks/GDAL.framework/Programs:/Library/Frameworks/Python.framework/Versions/3.8/bin:`;

  TIP: In case of GDAL was installed through Macports, the path to GDAL should be `/opt/local/bin/`:

- Restart QGIS.

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
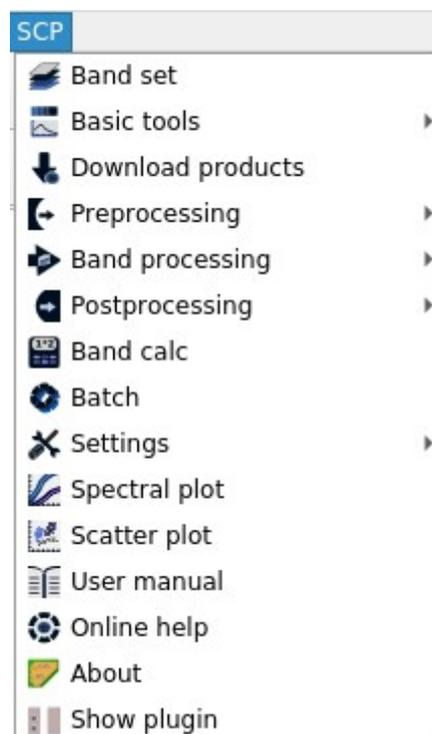
Fig. 1: *SCP menu*

The *SCP menu* allows for the selection of the main functions of the *Main Interface Window* (page 31), the *Spectral Signature Plot* (page 115), and the *Scatter Plot* (page 120).

- *Band set* (page 31);

- *Basic tools* (page 34);

- *Download products* (page 45);

- *Preprocessing* (page 50);

- *Band processing* (page 71);

- *Postprocessing* (page 79);

- *Band calc* (page 93);

- *Batch* (page 101);

- *Settings* (page 110);

- *Spectral Signature Plot* (page 115);

- *Scatter Plot* (page 120);

- *User manual*: open the online user manual in a web browser;

- *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;

- *About*: information about the plugin;

- *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 required for the classification of a *Band set* (page 31). The *Training input* (page 23), 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 157)).

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 37)). 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 29). *Temporary ROI polygons* can be saved in the *Training input* (page 23) along with the spectral signatures of the ROI.

The *Training input* (page 23) 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 Name	MC_info	string
Class ID	C_ID	int
Class Name	C_info	string

TIP: The *Training input* (page 23) is managed by *SCP*, a temporary layer is added to QGIS but the real file is saved and modified during the editing in *SCP*.

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 136)) 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 73). 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 (see *Algorithm* (page 73)) or a part of it, creating a *Classification preview* (page 30).

The *SCP dock* contains the following tabs:

- *Home* (page 21)
    - *SCP news* (page 23)
- *Training input* (page 23)
    - *ROI & Signature list* (page 24)
- *ROI options* (page 27)

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 31);

- *Basic tools* (page 34);

- *Download products* (page 45);

- *Preprocessing* (page 50);

- *Band processing* (page 71);

- *Postprocessing* (page 79);

- *Band calc* (page 93);

- *Batch* (page 101);
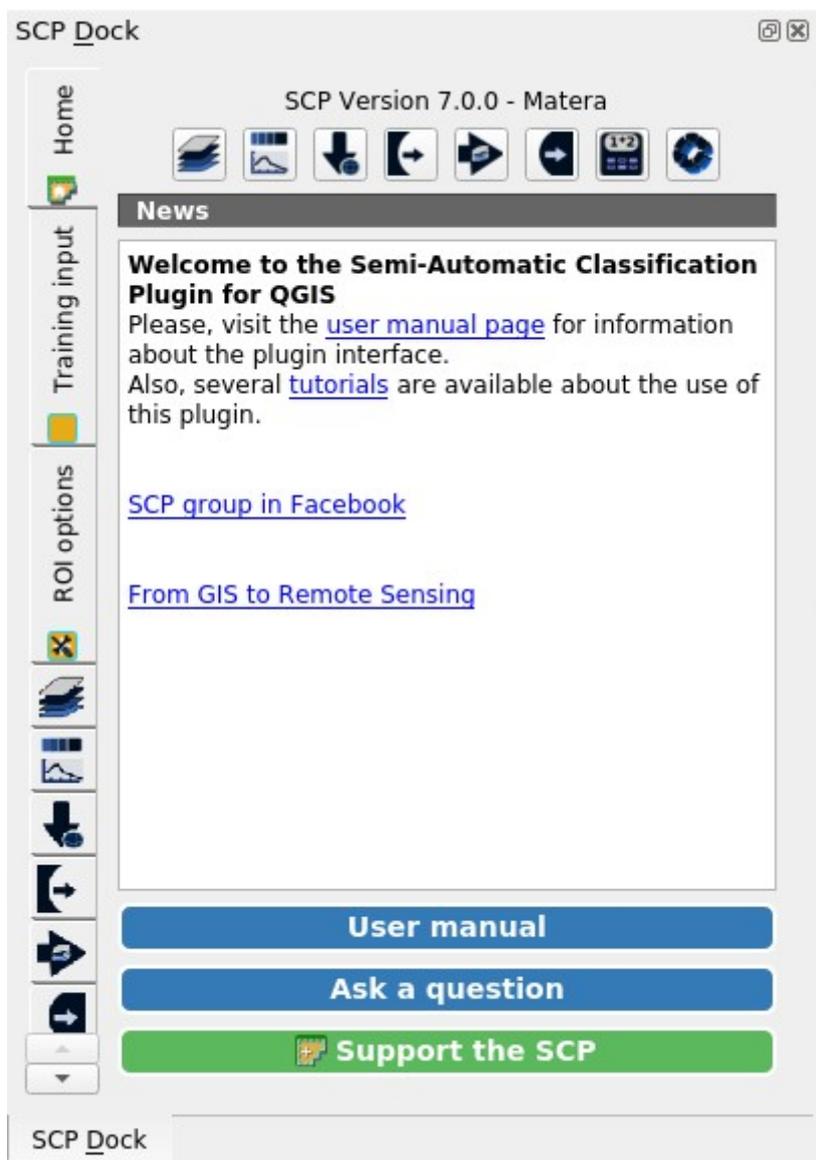
Fig. 2: *Home*

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 113).

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
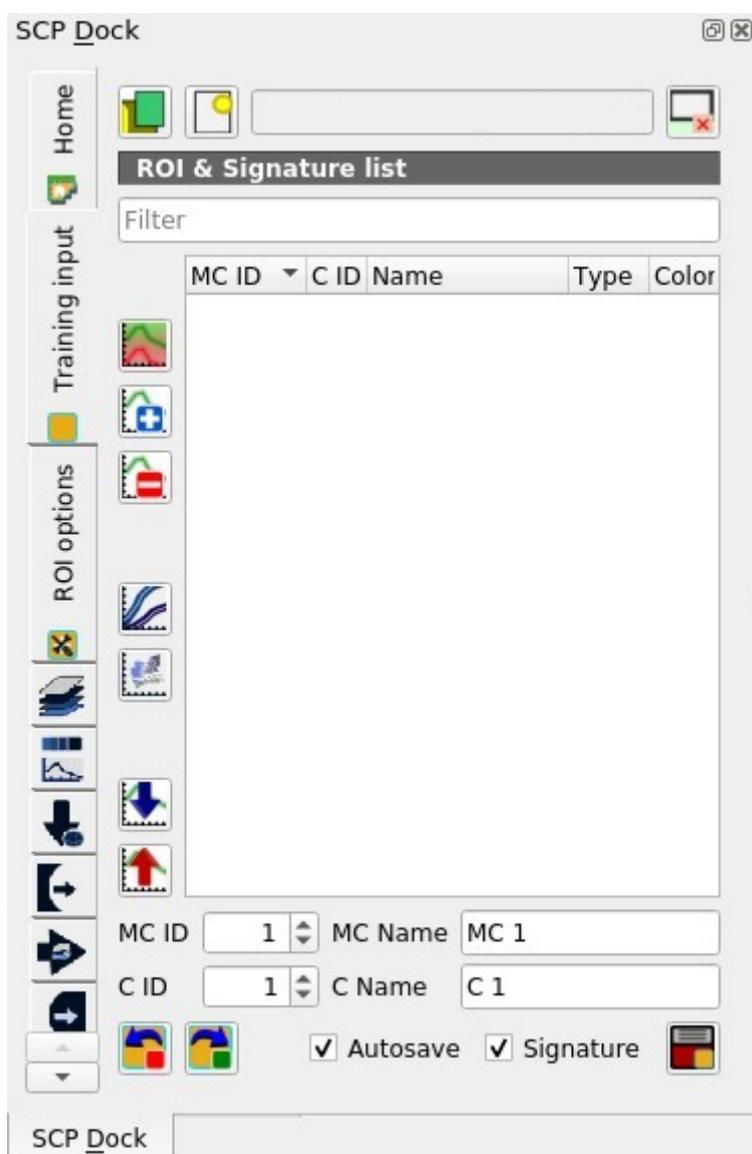
Fig. 3: *Training input*

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 31). 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.

- ![icon]: open a training input file; ROIs and spectral signatures are loaded in *ROI & Signature list* (page 24); the vector part of the training input is loaded in QGIS;

- ![icon]: 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 QGIS project is saved; to use the backup file simply rename it deleting the ending `.backup` extension and open it as training input;

- *Training input* ![T] ● : it displays the path to the training input file;

- ![icon]: remove the training input;

The training input is displayed in QGIS as vector file. ROIs and spectral signatures are displayed in the *ROI & Signature list* (page 24).

> **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

The tab *ROI & Signature list* displays the ROI polygons and spectral signatures contained in the training input file. The tab *ROI & Signature list* is structured as tree list, where every ROI is grouped in the corresponding Macroclass.

Fig. 4: *ROI & Signature list example*

Changes in the *ROI & Signature list* are applied to the file *Training input* (page 23) only when the QGIS project is saved (but there is also the option ![checkbox] *Autosave*). ROIs can be edited, deleted and merged from this list.

If an item is a ROI polygon, double click the item to zoom to that ROI in the map. Items in the list can be highlighted with the mouse left click.

> **TIP**: ROIs and spectral signatures can be imported from other sources (see *Import signatures* (page 37)) and exported (see *Export signatures* (page 36)).

- *Filter* ![T]: set a filter for names;

- ![icon] *ROI & Signature list*:

    – *MC ID*: Macroclass ID is the root of corresponding ROIs and signatures; it can be edited with a single click; if the ID of a spectral signature is set 0, then pixels belonging to this signature are labelled as unclassified; every listed ROIs or signatures has a selection checkbox (only the spectral signatures checked in this list are used for the classification process);

- *C ID*: Class ID; it can be edited with a single click;

- *Name*: Macroclass and Class Name; it can be edited with a single click;

- *Type*: **type of the item:**

    * *R* = only ROI polygon;

    * *S* = only spectral signature;

    * *R<u>S</u>* = both ROI and spectral signature;

- *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;

TIP: According to *Algorithm* (page 73), classifications performed using *C ID* have the colors defined for classes in the *ROI & Signature list* (page 24); classifications performed using *MC ID* have the colors defined for the macroclasses.

- : 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 31);

- : delete highlighted ROIs and signatures;

- : show the ROI spectral signature in the *Spectral Signature Plot* (page 115); spectral signature is calculated from the *Band set* (page 31);

- : add highlighted ROIs to the *Scatter Plot* (page 120);

- : open the tab *Import signatures* (page 37);

- : open the tab *Export signatures* (page 36) and export highlighted items;

ROI & Signature list is complementary to the *Working toolbar* (page 29) and it allows for saving ROIs to the *Training input* (page 23) defining classes and macroclasses. A *Band set* (page 31) must be defined before the ROI creation, and ROI polygons must be inside the area of the *Band set*.

- *MC ID* ⬚ ● : ROI Macroclass ID;

- *MC Name* ⬚ ● : ROI Macroclass Name;

- *C ID* ⬚ ● : ROI Class ID;

- *C Name* ⬚ ● : ROI Class Name;

- : undo of ROI creation from the *Training input* (page 23); it is possible to undo a maximum of 10 actions;

- : redo ROI creation in the *Training input* (page 23);

- ☑ *Autosave* ● : if checked, automatically save the *ROI & Signature list* to the *Training input* (page 23) every time a ROI is saved;

- ☑ *Signature* ⬤ : if checked, while saving a ROI, the spectral signature thereof is calculated (from *Band set* (page 31) pixels under ROI polygon) and saved to *Training input* (page 23) (calculation time depends on the band number of the *active band set* in *Band set* (page 31));

- ▬ : save the temporary ROI to the *Training input* (page 23) using the defined classes and macroclasses; ROI is displayed in the *ROI & Signature list* (page 24);

Right click menu
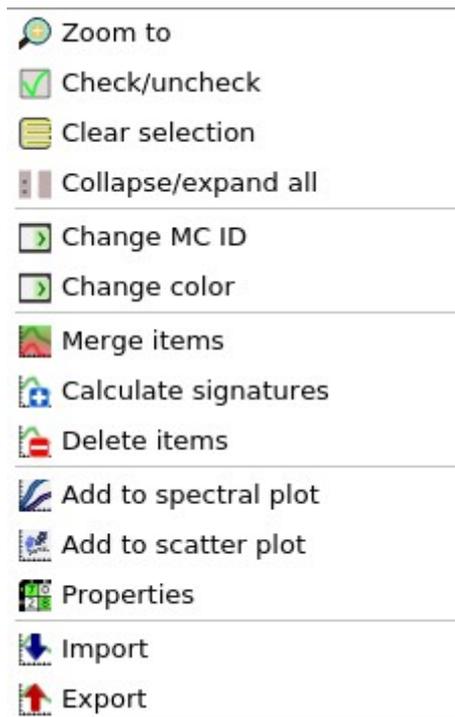
Fig. 5: *Right click menu*

A right click on *ROI & Signature list* (page 24) allows for opening a menu containing several functions to manage ROIs and spectral signatures.

- 🔍 *Zoom to*: zoom to highlighted items (if ROI polygons) in the map;

- ☑ *Check/uncheck*: check or uncheck highlighted items;

- ▤ *Clear selection*: clear selection of highlighted items;

- ▌▌ *Collapse/expand all*: collapse or expand all macroclasses;

- ⟩ *Change MC ID*: edit the macroclass of highlighted items (using the value *MC ID* 1⟐ displayed in *ROI & Signature list* (page 24)); if a macroclass is selected, the function is performed to all the included items;

- ⟩ *Change color*: select a color for the highlighted items; if a macroclass is selected, the function is performed to all the included items;

- *Merge items*: merge highlighted spectral signatures or ROIs obtaining a new signature calculated as the average of signature values for each band (covariance matrix is excluded); if a macroclass is selected, the function is performed to all the included items;

- *Calculate signatures*: calculate spectral signatures of highlighted ROIs using the *active band set* in *Band set* (page 31); if a macroclass is selected, the function is performed to all the included items;

- *Delete items*: delete highlighted ROIs and signatures; if a macroclass is selected, the function is performed to all the included items;

- *Add to spectral plot*: show the ROI spectral signature in the *Spectral Signature Plot* (page 115); spectral signature is calculated from the *Band set* (page 31); if a macroclass is selected, the function is performed to all the included items;

- *Add to scatter plot*: add highlighted ROIs to the *Scatter Plot* (page 120); if a macroclass is selected, the function is performed to all the included items;

- *Properties*: show the properties of highlighted items;

- *Import*: open the tab *Import signatures* (page 37);

- *Export*: open the tab *Export signatures* (page 36) and export highlighted items;

3.2.3 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 29)), the pixel value of selected**

    - 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 31);

    - 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 (`bandset#b4 - bandset#b3`) / (`bandset#b4 + bandset#b3`);

- *Rapid ROI b.* : if checked, temporary ROI is created with region growing using only one *Band set* (page 31) 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-plot*: calculate automatically the temporary ROI spectral signature and display it in the *Spectral Signature Plot* (page 115) (`MC Name` of this spectral signature is set `tempo_ROI`);

- *Auto-refresh ROI*: calculate automatically a new temporary ROI while *Region growing parameters* in the *Working toolbar* (page 29) are being changed;
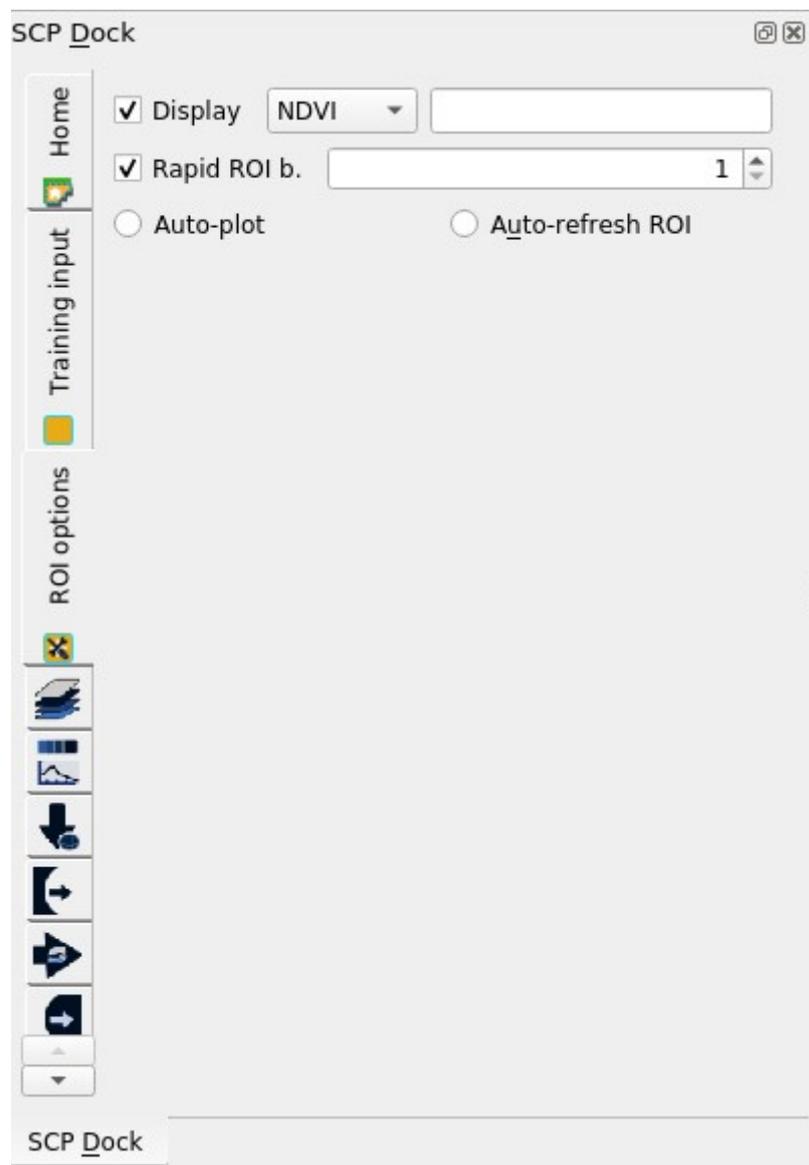
Fig. 6: *ROI options*

3.3 Working toolbar

Fig. 7: *Working toolbar*

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

- *Image control* (page 29)
- *Temporary ROI* (page 29)
- *Classification preview* (page 30)

The functions are described in detail in the following paragraphs.

3.3.1 Image control

- : show the *Main Interface Window* (page 31);

- : zoom the map to the extent of the *active band set* in *Band set* (page 31);
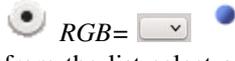
- *RGB=* : use the button to show/hide the *active band set* in *Band set* (page 31) in the map; from the list select a *Color Composite* (page 135) that is applied to the *Band set* (page 31); new color composites can be entered typing the band numbers separated by - or ; or , (e.g. RGB = 4-3-2 or RGB = 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 23). A *temporary ROI* can be drawn manually or using a *Region Growing Algorithm* (page 136) (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 115); 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 or**

- *Dist* $\boxed{1\updownarrow}$ ● : set the interval which defines the maximum spectral distance between the seed pixel and the surrounding pixels (in radiometry unit);

- *Min* $\boxed{1\updownarrow}$ ● : 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* $\boxed{1\updownarrow}$ ● : 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 31), before classifying the entire image which can be time consuming (see *Classification output* (page 74)).

Classification preview is performed according to the parameters defined in *Algorithm* (page 73).

> **WARNING**: ROIs and previews are performed on the active *Band set* (page 31).

In addition to the classification raster, an *Algorithm raster* (page 142) 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 112)) 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 30);

- *Preview*: use the button to show/hide the last *Classification preview* (page 30) in the map;

- : activate the pointer for the creation of a *Classification preview* (page 30); 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 142) of the preview;

- : create a new *Classification preview* (page 30) 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*;

- : create a KML file of the QGIS view;

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 tree menu at the left side or from the *SCP menu* (page 19).

3.4.1 Band set

- *Multiband image list* (page 32)

- *Single band list* (page 32)

- *Band set definition* (page 32)
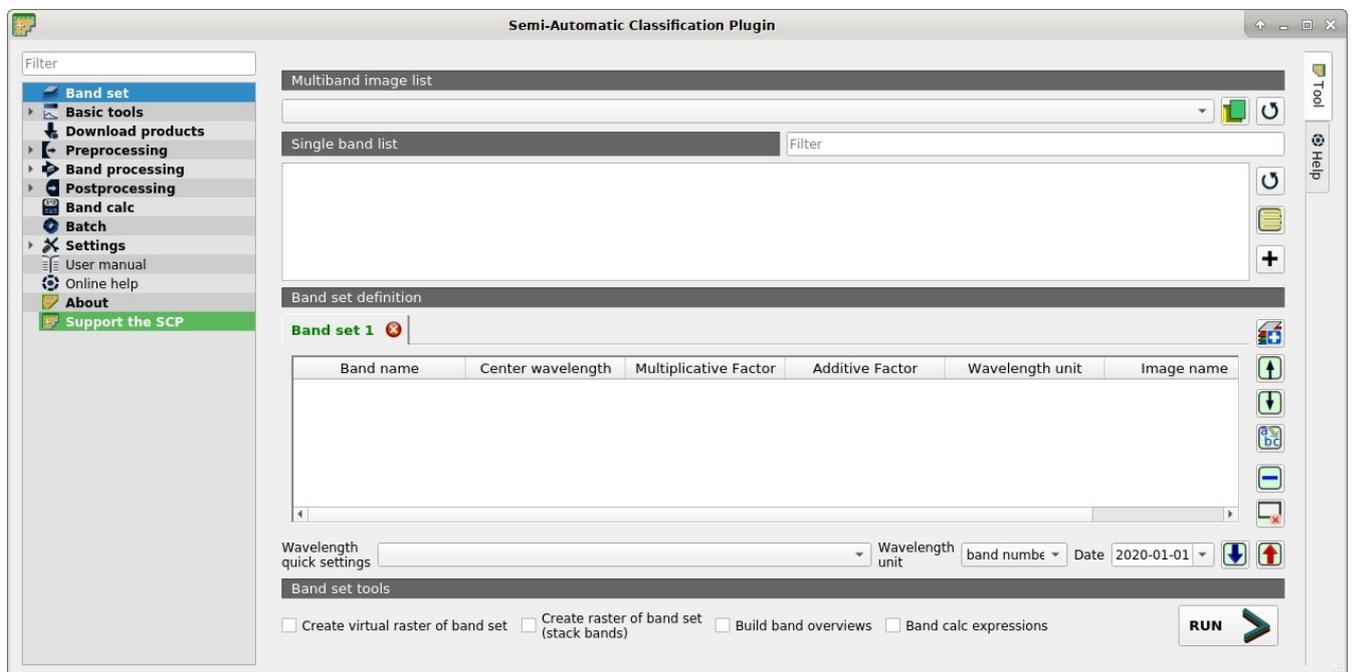
Fig. 8: *Band set*

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 32) with bold green name) is used as input for the tools in *SCP dock* (page 20) and *Working toolbar* (page 29). Other *SCP* tools allow for the selection of *band set* numbers.

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

The tool *Band set list* (page 35) allows for the management of *band sets*.

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*.

- *Filter* : filter the list;

- : 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. `pixel value = original pixel value * multiplicative rescaling factor + 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;

- – *Date* : image acquisition date;

- : 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*;

- *Wavelength quick settings* : **rapid definition of band center wavelength for the following satellite sensors:**

  - – ASTER;
  - – GeoEye-1;
  - – GOES;
  - – Landsat 8 OLI;
  - – Landsat 7 ETM+;
  - – Landsat 4-5 TM;
  - – Landsat 1, 2, and 3 MSS;
  - – MODIS;
  - – Pleiades;
  - – QuickBird;
  - – RapidEye;
  - – Sentinel-2;
  - – Sentinel-3;
  - – SPOT 4, 5, and 6;
  - – WorldView-2 and WorldView-3;

- *Wavelength unit* : **select the wavelength unit among:**
  - – *Band number*: no unit, only band number;
  - – μm: micrometres;
  - – *nm*: nanometres;

- *Date* 1980 ⌄ ● : set the date of acquisition;

- ⬇ : import a previously saved *active band set* from file;

- ⬆ : export the *active band set* to a file;

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

3.4.2 Basic tools

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

Algorithm band weight

- *Band weight* (page 34)
- *Automatic weight* (page 35)
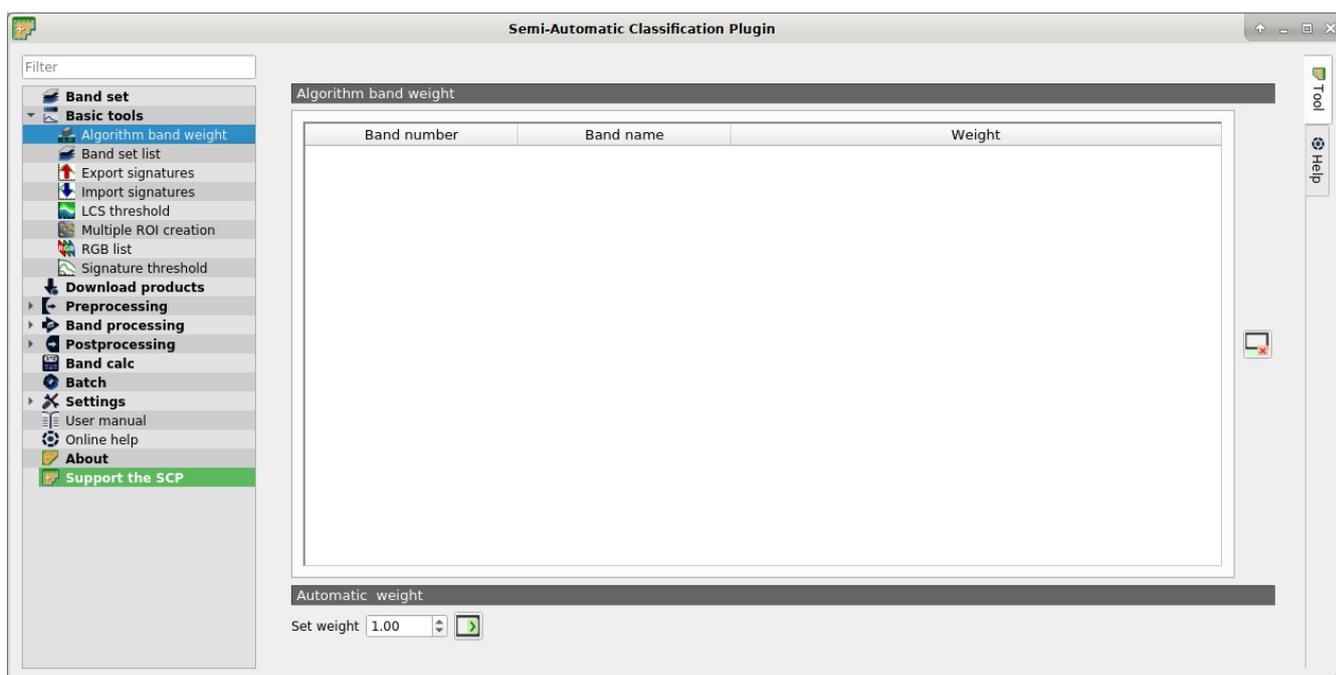
Fig. 9: 🟫 *Algorithm band weight*

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 31).

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

- ![icon]: reset all band weights to 1;

- *Set weight* ![1] ![>] : set the defined value as weight for all the highlighted bands in the table;

Band set list

- *Band set list* (page 35)
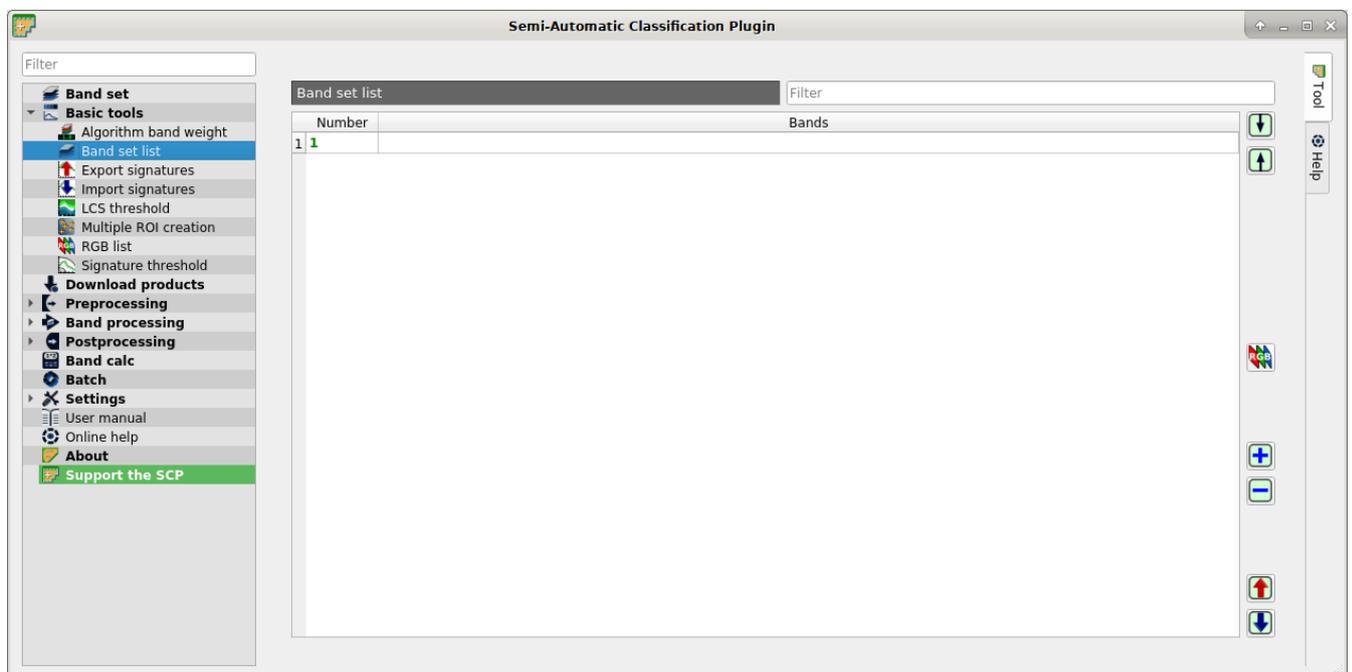
Fig. 10: ![icon] *Band set list*

This tab allows for the management of *band sets* defined in *Band set* (page 31).

It is possible to order or remove multiple *band sets* at once. Double click the list to set the *active band set* (i.e. the tab selected in *Band set definition* (page 32) with bold green name).

It is also possible to export and import multiple *band sets* saved as file `.scpb` .

Band set list

- ![icon] *Band set list*: **table containing the following fields;**

  – *Number* ![icon] : number of the *band set*; cannot be edited;

- – *Bands* ●: bands of the *band set*; cannot be edited;

- ⬆️: move highlighted bands upward;

- ⬇️: move highlighted bands downward;

- 🅁🅶🅱: create a RGB *Color Composite* (page 135) for highlighted *band sets*;

- ➕: add an empty *band set*;

- ➖: remove highlighted *band set*;

- ⬆️: export *band set list* to a file (i.e. `.scpb`);

- ⬇️: import a previously saved *band set list* from file (i.e. `.scpb`);

http://www.youtube.com/watch?v=1PclAtPjyZE
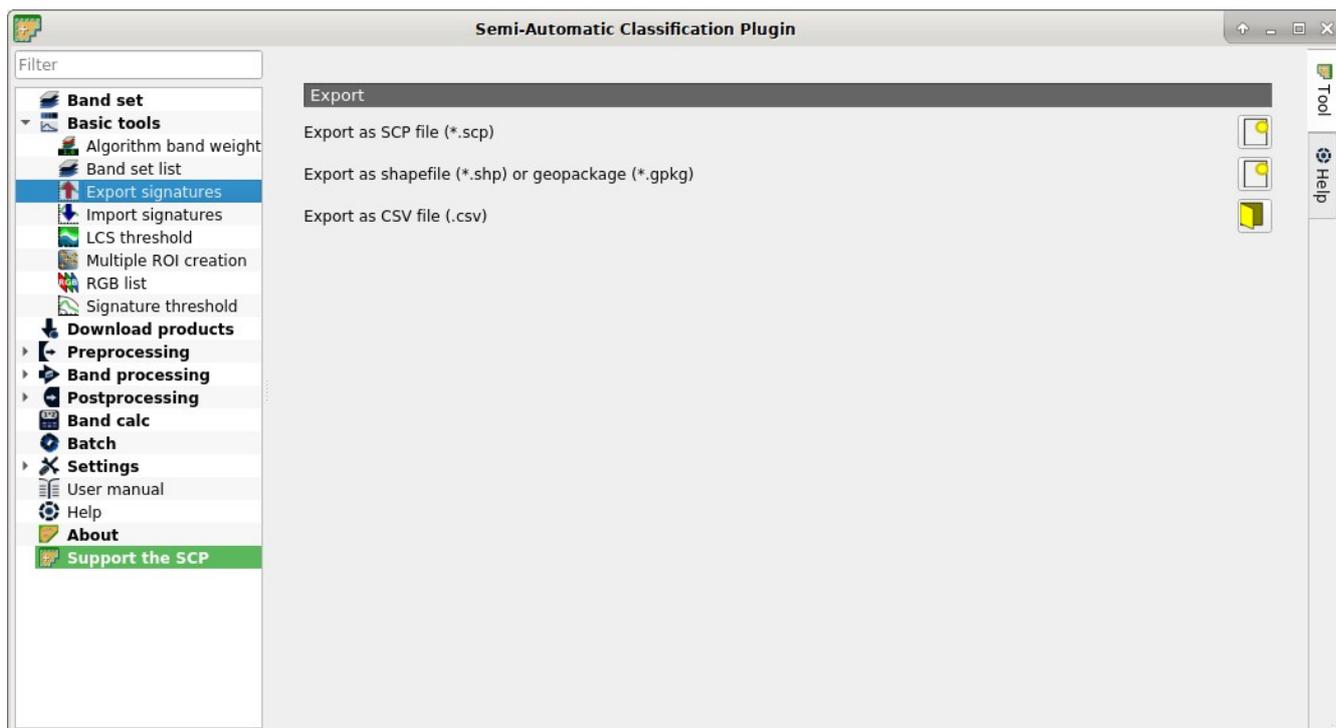
Export signatures

Fig. 11: ⬆️ *Export signatures*

This tool allows for exporting the signatures highlighted in the *ROI & Signature list* (page 24).

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

- *Export as shapefile or geopackage* : export highlighted ROIs (spectral signature data excluded) as a new shapefile (* .shp) or geopackage (* .gpkg);

- *Export as CSV file* : open a directory, and export highlighted spectral signatures as individual CSV files (* .csv) separated by semicolon (;);

Import signatures

- *Import library file* (page 37)
- *Import vector* (page 38)
- *Download USGS Spectral Library* (page 38)

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

Import library file

Fig. 12: *Import library file*

This tool allows for importing spectral signatures from various sources: a previously saved *Training input* (page 23) (.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 31), and added to the *ROI & Signature list* (page 24);

- *Select a file* : open a file to be imported in the *Training input* (page 23);
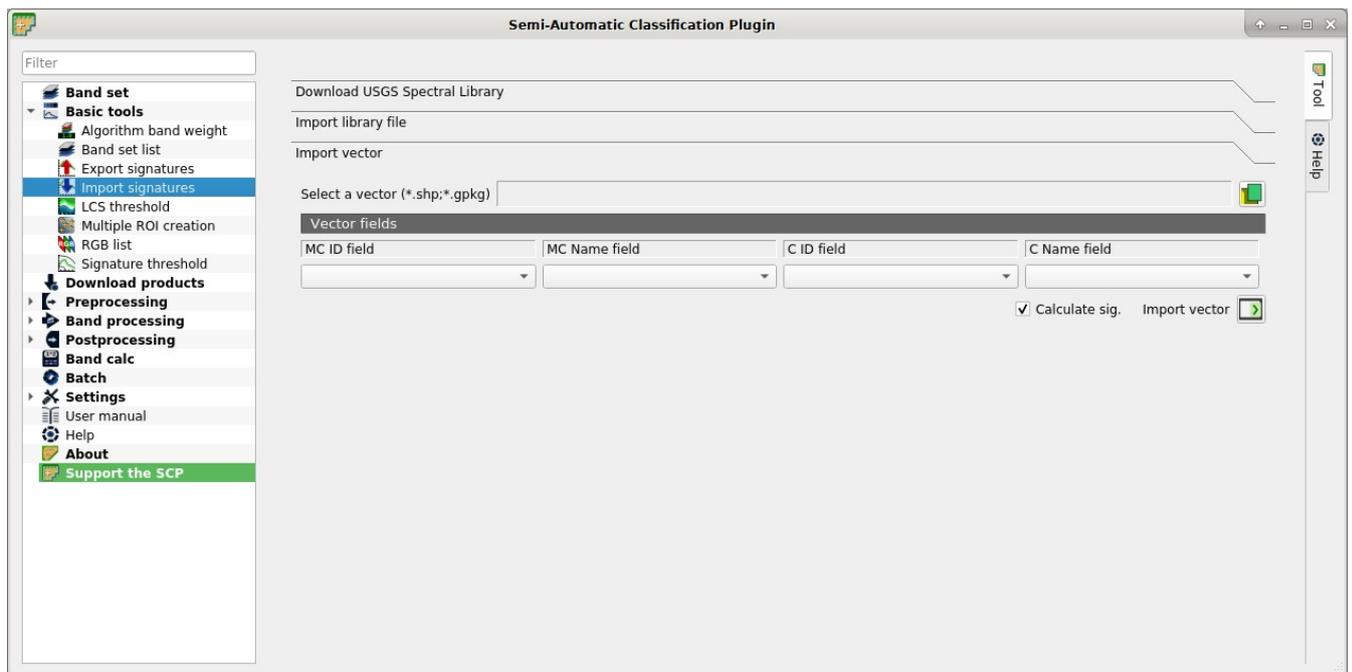
Fig. 13: *Import vector*

Import vector

This tool allows for importing a vector (shapefile or geopackage), selecting the corresponding fields of the *Training input* (page 23).

- *Select a vector* : open a vector;

- *MC ID field* : select the vector field corresponding to MC ID;

- *MC Name field* : select the vector field corresponding to MC Name;

- *C ID field* : select the vector field corresponding to C ID;

- *C Name field* : select the vector field corresponding to C Name;

- *Calculate sig.*: if checked, the spectral signature is calculated while the ROI is saved to *Training input* (page 23);

- *Import vector* : import all the vector polygons as ROIs in the *Training input* (page 23);

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*;
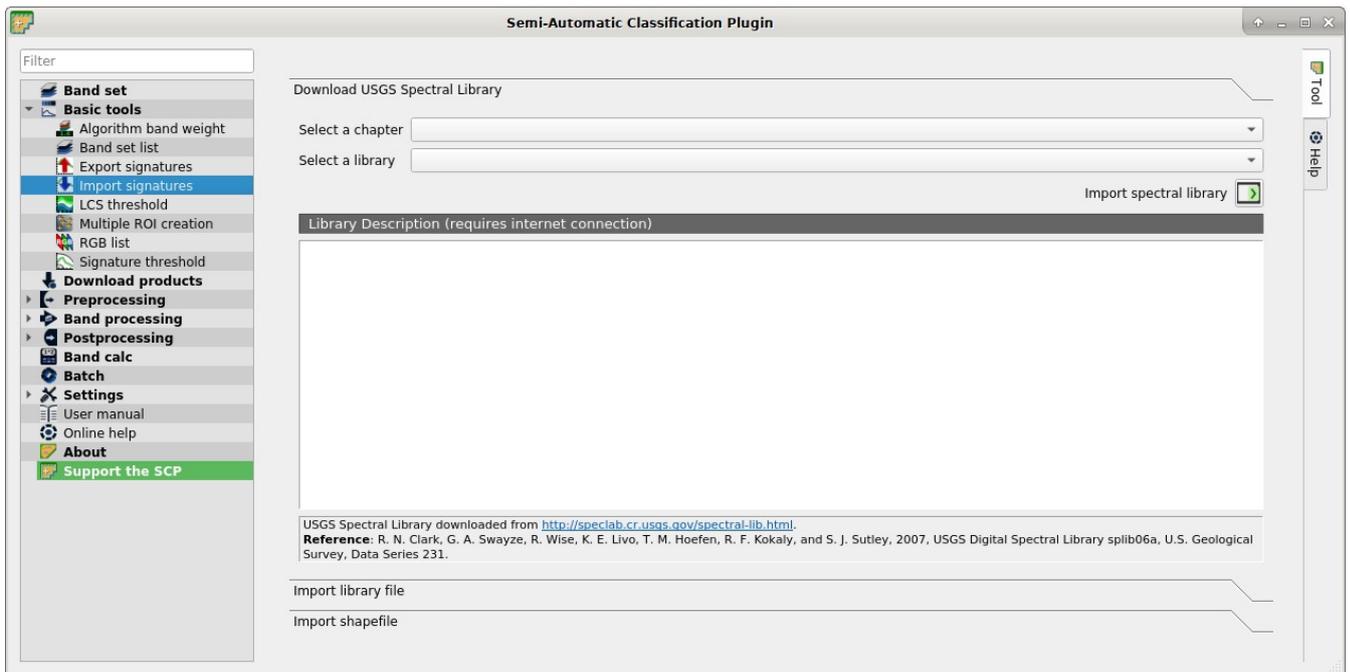
Fig. 14: *Download USGS Spectral Library*

• *Import spectral library* : download the library and add the sampled spectral signature to the *ROI & Signature list* (page 24) 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 31), and added to the *ROI & Signature list* (page 24);

> **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.

LCS threshold

• *LC Signature threshold* (page 39)

• *Automatic thresholds* (page 40)

This tab allows for setting the signature thresholds used by *Land Cover Signature Classification* (page 141). All the signatures contained in the *Training input* (page 23) are listed; also, signature thresholds are saved in the *Training input* (page 23).

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 73). 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 Name*: signature Macroclass Name;
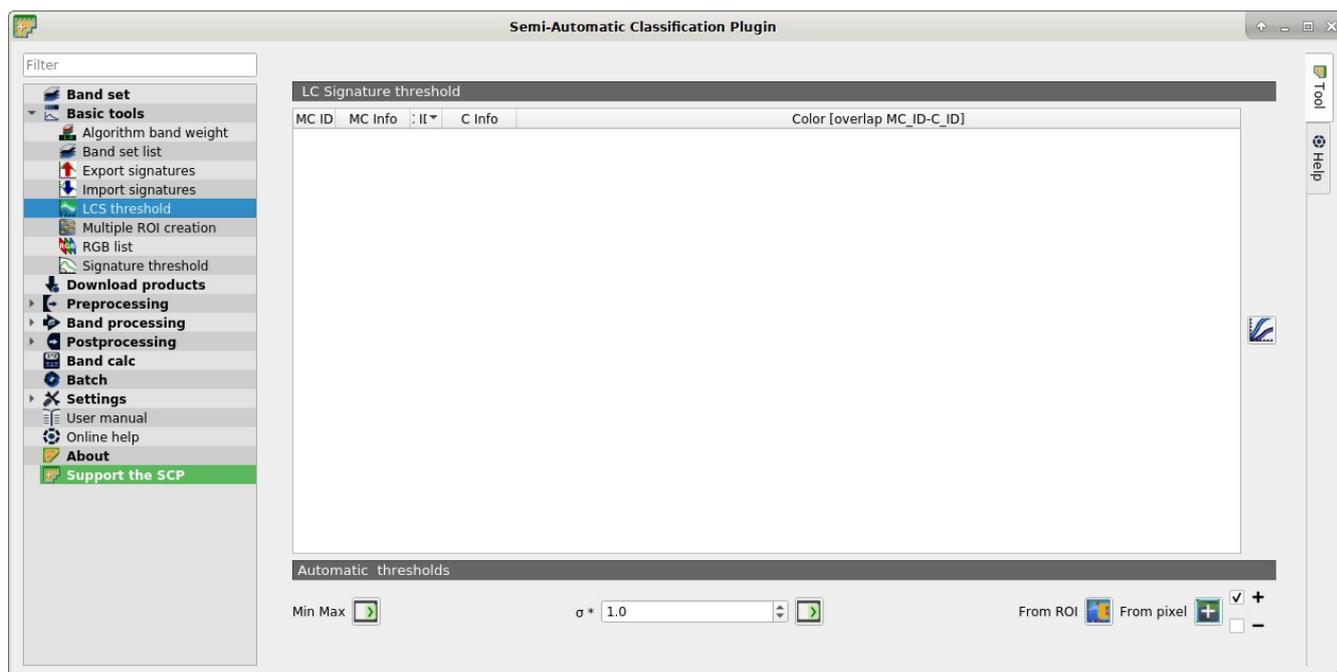
Fig. 15: *LCS threshold*

- – *C ID*: signature Class ID;

- – *C Name*: signature Class Name;

- – *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 141));

- – *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;

- • : show the ROI spectral signature in the *Spectral Signature Plot* (page 115); spectral signature is calculated from the *Band set* (page 31);

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;

- • σ * : set an automatic threshold calculated as (band value + (σ * 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;

Multiple ROI Creation

- *Create random points* (page 41)

- *Point coordinates and ROI definition* (page 42)
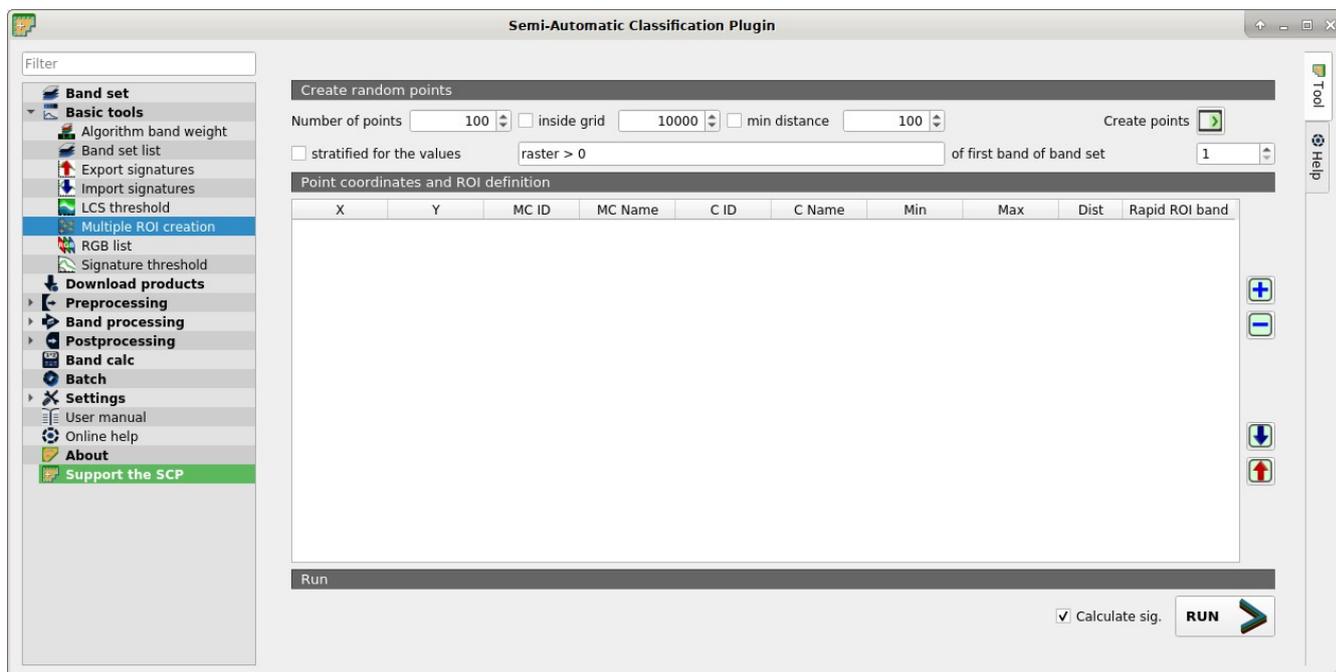
Fig. 16: *Multiple ROI Creation*

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 23). The *active band set* in *Band set* (page 31) 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 Name*: ROI Macroclass Name (text);

    – *C ID*: ROI Class ID (int);

    – *C Name*: ROI Class Name (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 24) ;

- : 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 Name`, `Class ID`, `C Name`, `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;

- *Calculate sig.*: if checked, the spectral signature is calculated while the ROI is saved to *Training input* (page 23);

- *RUN* : start the ROI creation process for all the points and save ROIs to the *Training input* (page 23);

RGB list

This tab allows for managing the RGB *Color Composite* (page 135) used in the list *RGB=* of the *Image control* (page 29).
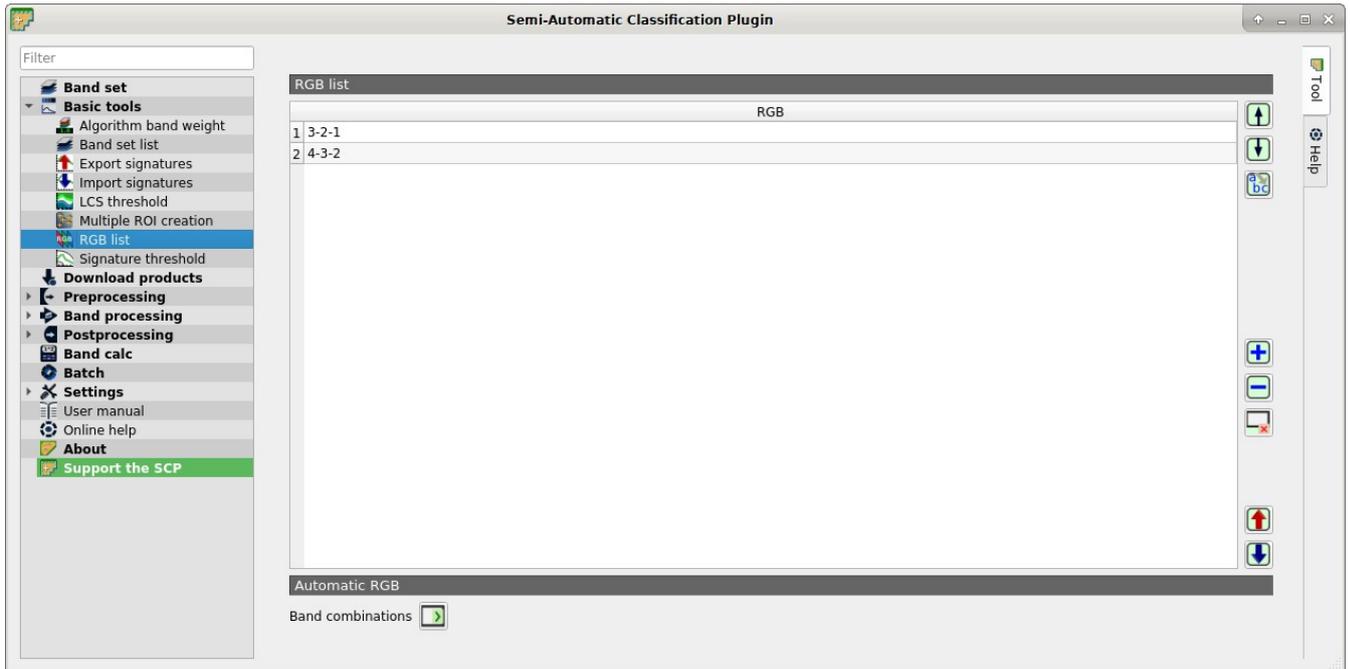
Fig. 17: *RGB list*

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 43) (e.g. 1-2-3, 1-2-4, . . . , 3-2-1);

Signature threshold

- *Signature threshold* (page 44)

- *Automatic thresholds* (page 45)
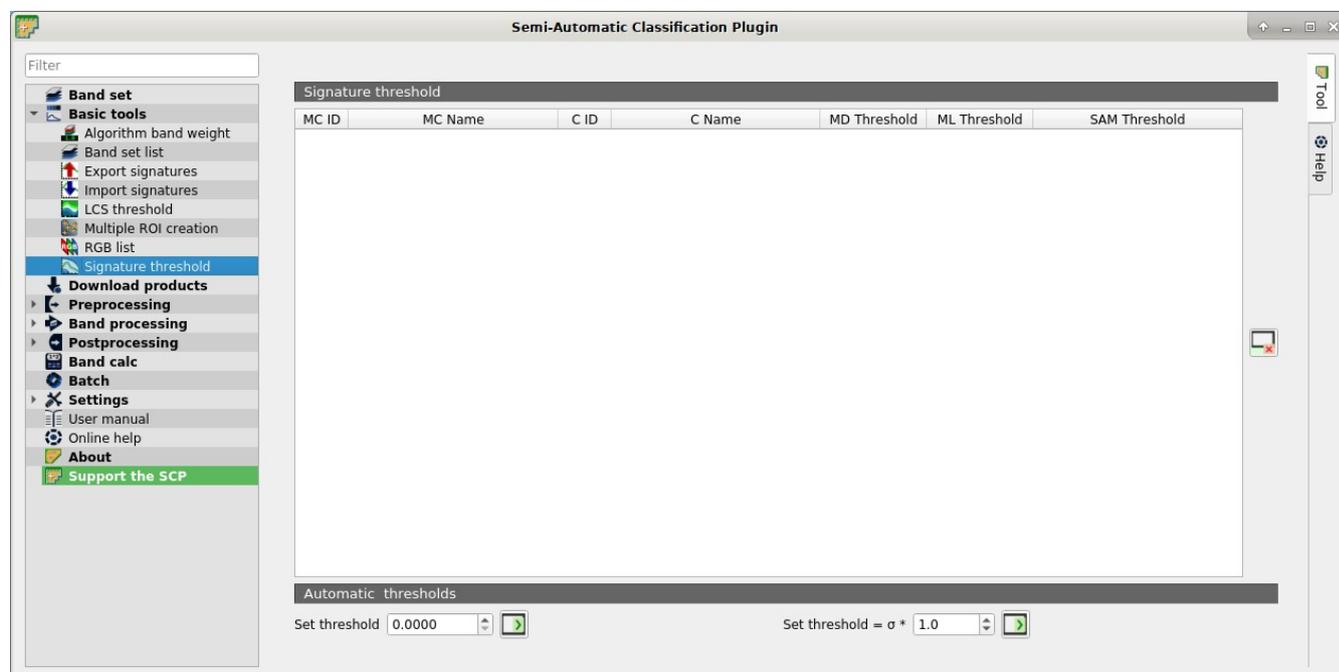
Fig. 18: *Signature threshold*

This tab allows for the definition of a classification threshold for each spectral signature. All the signatures contained in the *Training input* (page 23) are listed. Thresholds defined in this tool are applied to classification only if *Threshold* value in *Algorithm* (page 73) 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 23).

If threshold is 0 then no threshold is applied and all the image pixels are classified. Depending on the selected *Algorithm* (page 73) 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 Name*: signature Macroclass Name;

    – *C ID*: signature Class ID;

    – *C Name*: signature Class Name;

– *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* = σ * : for all the highlighted signatures, set an automatic threshold calculated as the distance (or angle) between mean signature and (mean signature + (σ * v)), where σ is the standard deviation and v is the defined value; currently works for Minimum Distance and Spectral Angle Mapping;

3.4.3 Download products

- *Login data* (page 46)
    - *Login https://ers.cr.usgs.gov* (page 46)
    - *Login https://urs.earthdata.nasa.gov* (page 47)
    - *Login Sentinels* (page 47)
- *Search* (page 47)
    - *Search parameters* (page 47)
    - *Product list* (page 49)
    - *Download* (page 49)
- *Download options* (page 50)

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 129) images (from 1 MSS to 8 OLI) acquired from the 80s to present days;

- *Sentinel-1 Satellites* (page 134) images (GRD) acquired from 2014 to present days;

- *Sentinel-2 Satellite* (page 130) images (Level-1C and Level-2A) acquired from 2015 to present days;

- *Sentinel-3 Satellite* (page 131) images (OLCI Level-1B OL_1_EFR) acquired from 2016 to present days;

- *ASTER Satellite* (page 131) images (Level 1T) acquired from 2000 to present days;

- *MODIS Products* (page 132) images (MOD09GQ, MYD09GQ, MOD09GA, MYD09GA, MOD09Q1, MYD09Q1, MOD09A1, MYD09A1) acquired from 2000 to present days;

- *GOES Products* (page 133) images (GOES 16 and GOES 17 Full Disk L1b Radiance) acquired from 2017 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 USGS , Google Cloud Storage Landsat .

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.

GOES products are downloaded through Amazon AWS Open Data .

For Sentinel-1, Sentinel-2, and Sentinel-3 the search is performed through the Copernicus Open Access Hub (using the Data Hub API). Sentinel-2 are downloaded from Google Cloud Storage if available.

Please notice that Sentinel products older than 12 months may be archived in Long Term Archives) and should be requested through the Copernicus Open Access Hub .

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
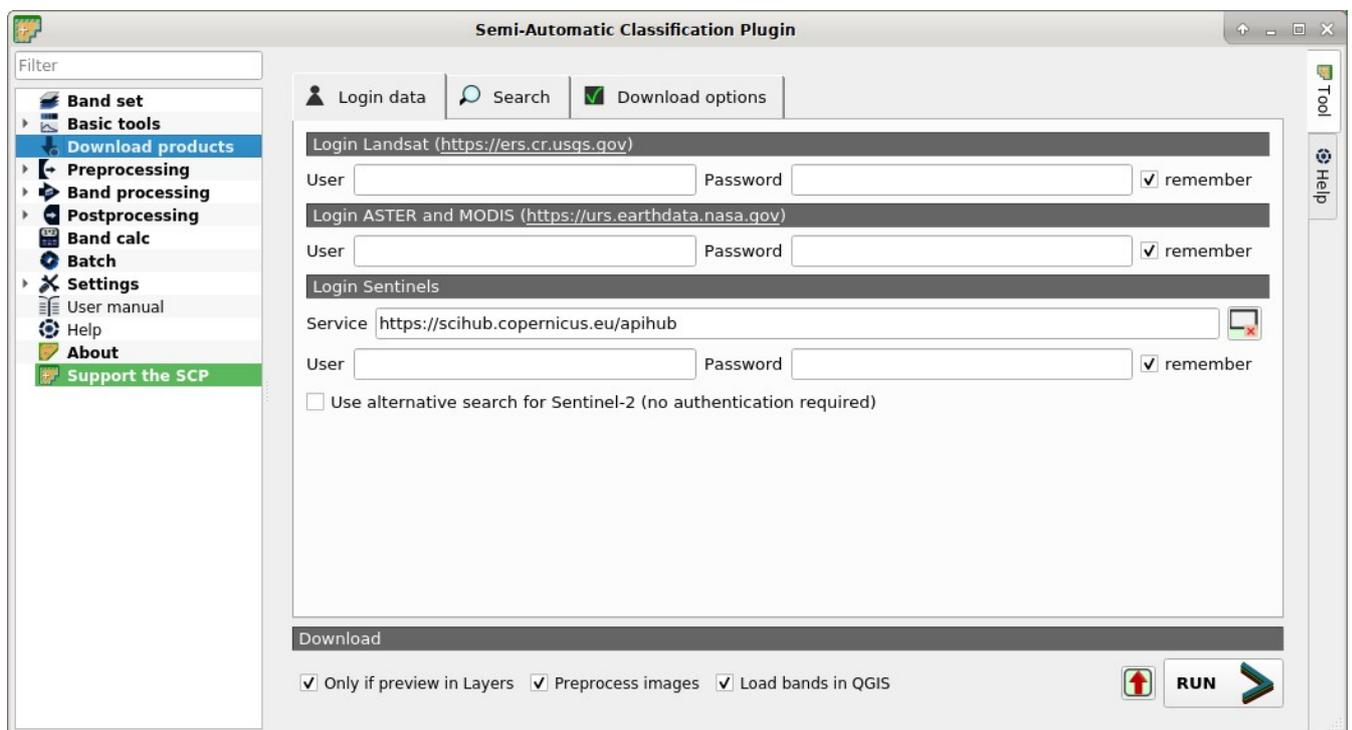
Fig. 19: *Login data*

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* [T] 🟢 : enter the user name;

- *Password* [T] 🟢 : 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* ⬜**T** 🟢 : enter the user name;

- *Password* ⬜**T** 🟢 : enter the password;

- ☑ *remember*: remember user name and password in QGIS;

Login Sentinels

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.

For searching Sentinel-2 images it is possible to use a service that does not require authentication.

- *Service* ⬜**T** 🟢 : 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.nsdc.fmi.fi , https://data.sentinel.zamg.ac.at);

- ⬜❌: reset the default service;

- *User* ⬜**T** 🟢 : enter the user name;

- *Password* ⬜**T** 🟢 : enter the password;

- ☑ *remember*: remember user name and password in QGIS;

- ☑ *Use alternative search for Sentinel-2 (no authentication required)* 🟢 : if checked, use the CREO-DIAS Finder API for searching (from https://creodias.eu/eo-data-finder-api-manual the database is accessible free and anonymously, and open for anonymous access to everyone, no authorization is used); more information about Copernicus DIAS platforms at https://www.copernicus.eu/en/access-data/dias ;

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. For Sentinel-2 it is possible to avoid the definition of a search by entering a granule name in the *Advanced search* ⬜**T** .

- *UL* ⬜1↕ ⬜1↕ : set the UL longitude X (Lon) and the UL latitude Y (Lat);

- *LR* ⬜1↕ ⬜1↕ : set the LR longitude X (Lon) and the LR latitude Y (Lat);
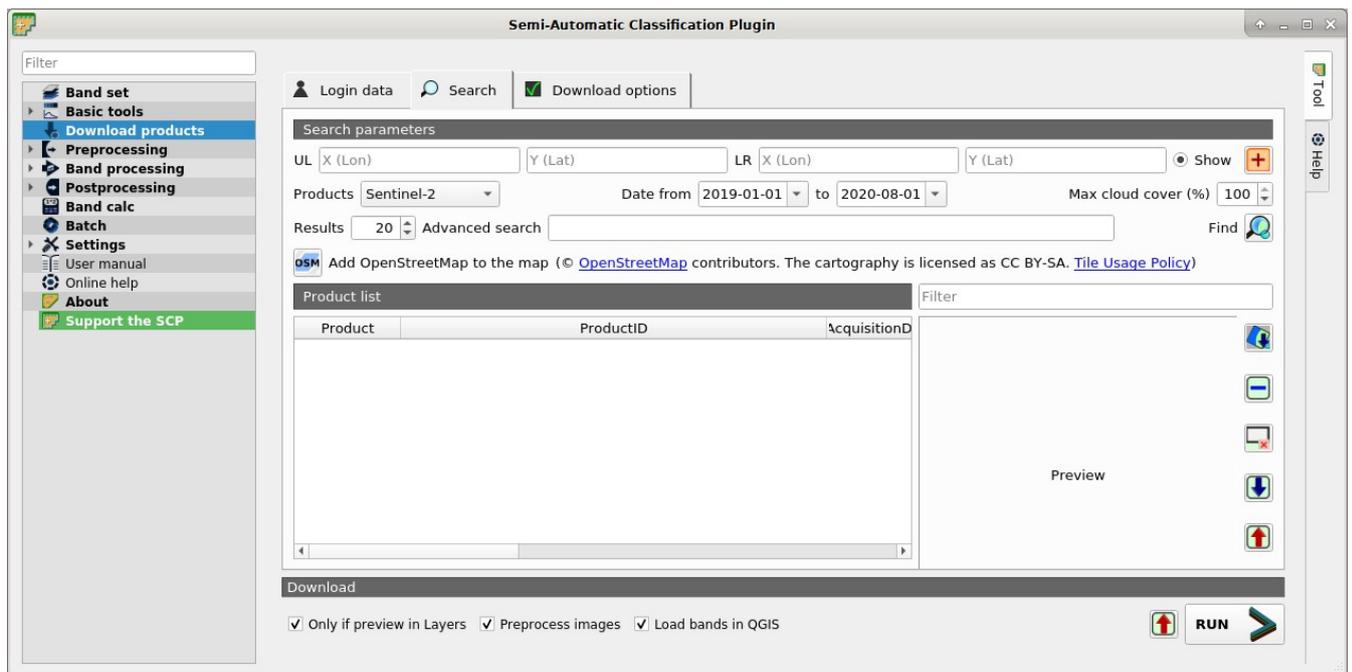
Fig. 20: *Search*

- *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;

- *Advanced search* : some services (e.g. Sentinel-2) allows for entering search parameters; for instance, it is possible to enter the name of a granule (e.g. 33TTG) without defining a search area in order to get the results of that granule; Sentinel-2 level 2A can be filtered entering `S2A_MSIL2A*` ;

- *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 49); 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 (not all the products include image previews). 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 (not all the products include a preview);

- : 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 49). 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 49) 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 53);

- *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 49);

Download options
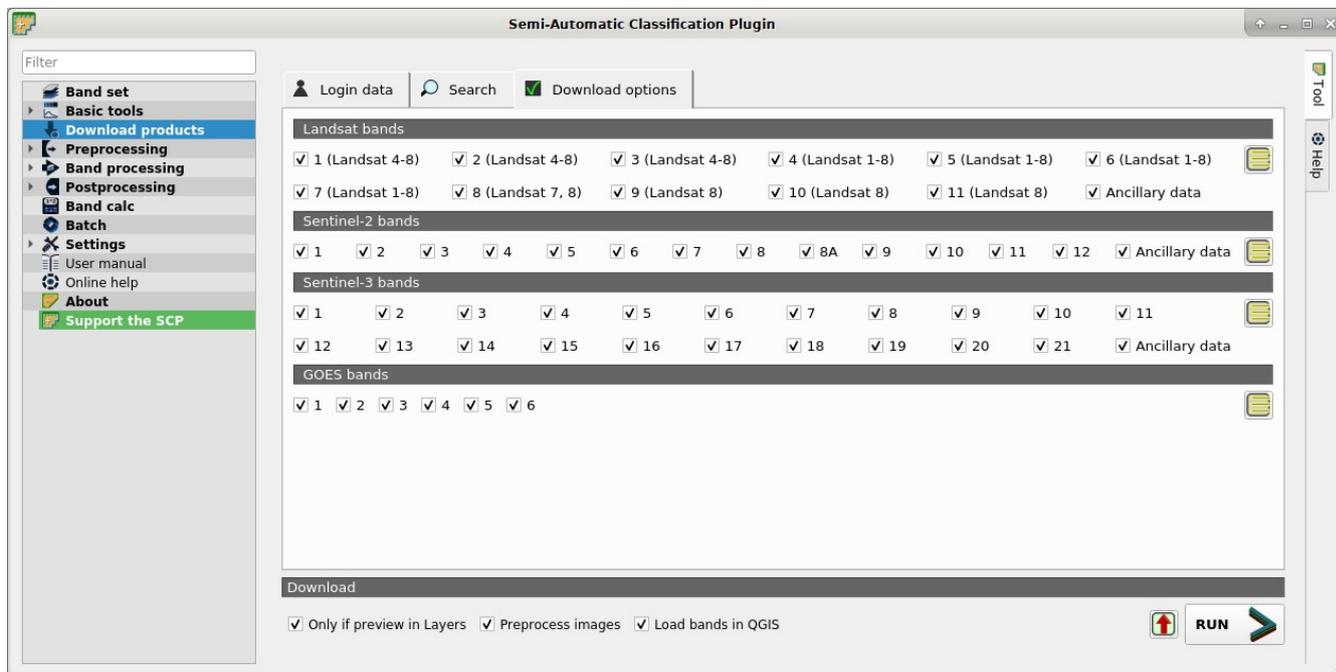
Fig. 21: *Download options*

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.

ASTER

- *ASTER conversion* (page 51)

- *Metadata* (page 51)
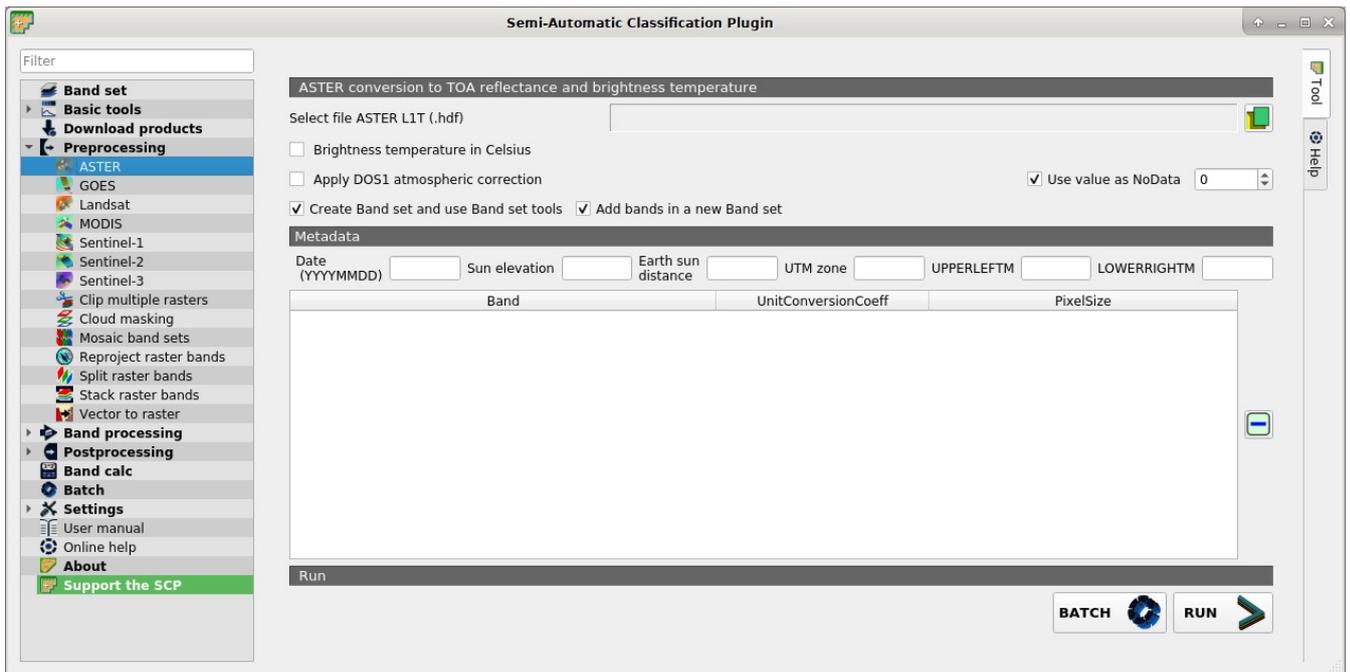
Fig. 22: *ASTER*

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 150)).

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

ASTER conversion

- *Select file ASTER L1T* : select an ASTER image (file .hdf);

- *Apply DOS1 atmospheric correction*: if checked, the *DOS1 Correction* (page 151) is applied to all the bands;

- *Use value as NoData* : 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, bands are added to the active *Band set* after the conversion; also, the *Band set* is processed according to the tools checked in the *Band set* (page 31);

- *Add bands in a new Band set*: if checked, bands are added to a new empty *Band set* after the conversion;

Metadata

All the bands found in the *Select file ASTER L1T* are listed in the table *Metadata*. For information about *Metadata* fields visit the ASTER page .

- *Date* : date of acquisition (e.g. 20130415);

- *Sun elevation* 1⟨⟩: Sun elevation in degrees;

- *Earth sun distance* 1⟨⟩: Earth Sun distance in astronomical units (automatically calculated if *Date* is filled;

- *UTM zone* [T]: UTM zone code of the image;

- *UPPERLEFTM* [T]: coordinates of the upper left corner of the image;

- *LOWERRIGHTM* [T]: coordinates of the lower right corner of the image;

- [−]: remove highlighted bands from the table *Metadata*;

- [table containing the following fields;]

    – *Band*: band name;

    – *UnitConversionCoeff*: value for radiance conversion;

    – *PixelSize*: solar irradiance of band;

- *BATCH* : add this function to the *Batch* (page 101);

- *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;

GOES

- *GOES conversion* (page 53)

- *Metadata* (page 53)
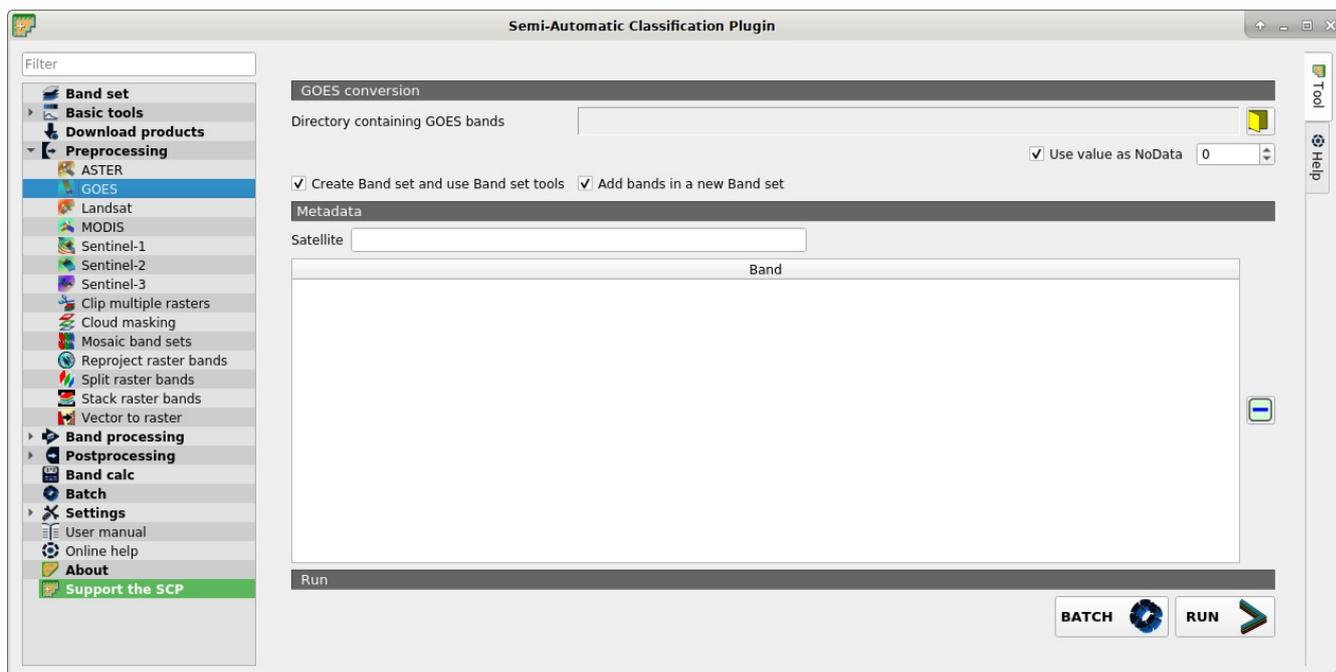
Fig. 23: GOES

This tab allows for the conversion of **GOES** images provided in netCDF4 (.nc) format inside a directory.

GOES conversion

- *Directory containing GOES bands* : open a directory containing GOES bands; names of bands must end with the corresponding number;

- *Use value as NoData* : if checked, pixels having `NoData` value are not counted during conversion; it is useful when image has a black border (usually pixel value = 0);

- *Create Band set and use Band set tools*: if checked, bands are added to the active *Band set* after the conversion; also, the *Band set* is processed according to the tools checked in the *Band set* (page 31);

- *Add bands in a new Band set*: if checked, bands are added to a new empty *Band set* after the conversion;

Metadata

All the bands found in the *Directory containing GOES bands* are listed in the table *Metadata*.

- *Satellite* : satellite name (e.g. GOES);

- : remove highlighted bands from the table *Metadata*;

- [table containing the following fields;]

    - *Band*: band name;

- *BATCH* : add this function to the *Batch* (page 101);

- *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;

Landsat

- *Landsat conversion to TOA reflectance and brightness temperature* (page 54)
- *Metadata* (page 55)

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 150)).

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

Pan-sharpening is also available; for more information read *Pan-sharpening* (page 147). The panchromatic band is preprocessed only if pansharpening is checked.

> **WARNING**: For the best spectral precision you should download the Landsat Level-2 Data Products (Surface Reflectance) from https://earthexplorer.usgs.gov .
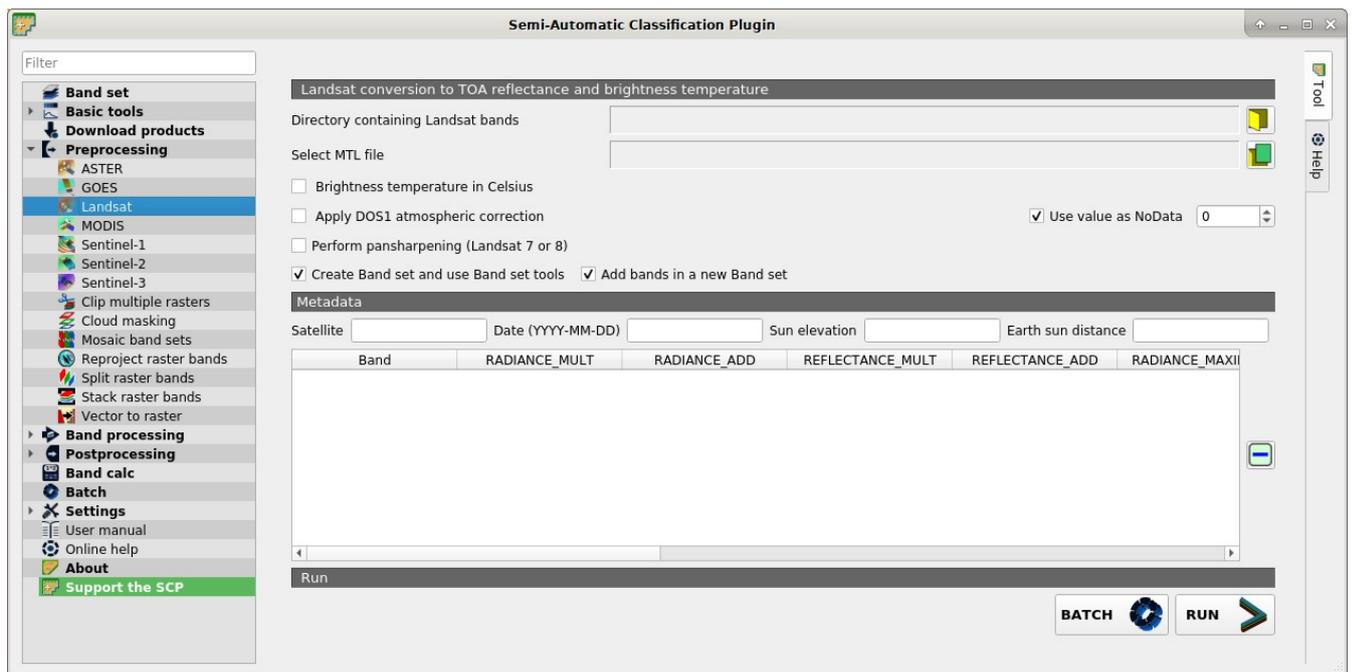
Fig. 24: *Landsat*

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 55) 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 55) automatically;

- *Brightness temperature in Celsius*: if checked, convert brightness temperature to Celsius (if a Landsat thermal band is listed in *Metadata* (page 55)); if unchecked temperature is in Kelvin;

- *Apply DOS1 atmospheric correction*: if checked, the *DOS1 Correction* (page 151) is applied to all the bands (thermal bands excluded);

- *Use value as NoData* : 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 147) of Landsat bands;

- *Create Band set and use Band set tools*: if checked, bands are added to the active *Band set* after the conversion; also, the *Band set* is processed according to the tools checked in the *Band set* (page 31);

- *Add bands in a new Band set*: if checked, bands are added to a new empty *Band set* after the conversion;

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* ▭ᵀ: satellite name (e.g. Landsat8);

- *Date* ▭ᵀ: date of acquisition (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;

- *BATCH* ▭: add this function to the *Batch* (page 101);

- *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

- *MODIS conversion* (page 56)
- *Metadata* (page 56)

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.
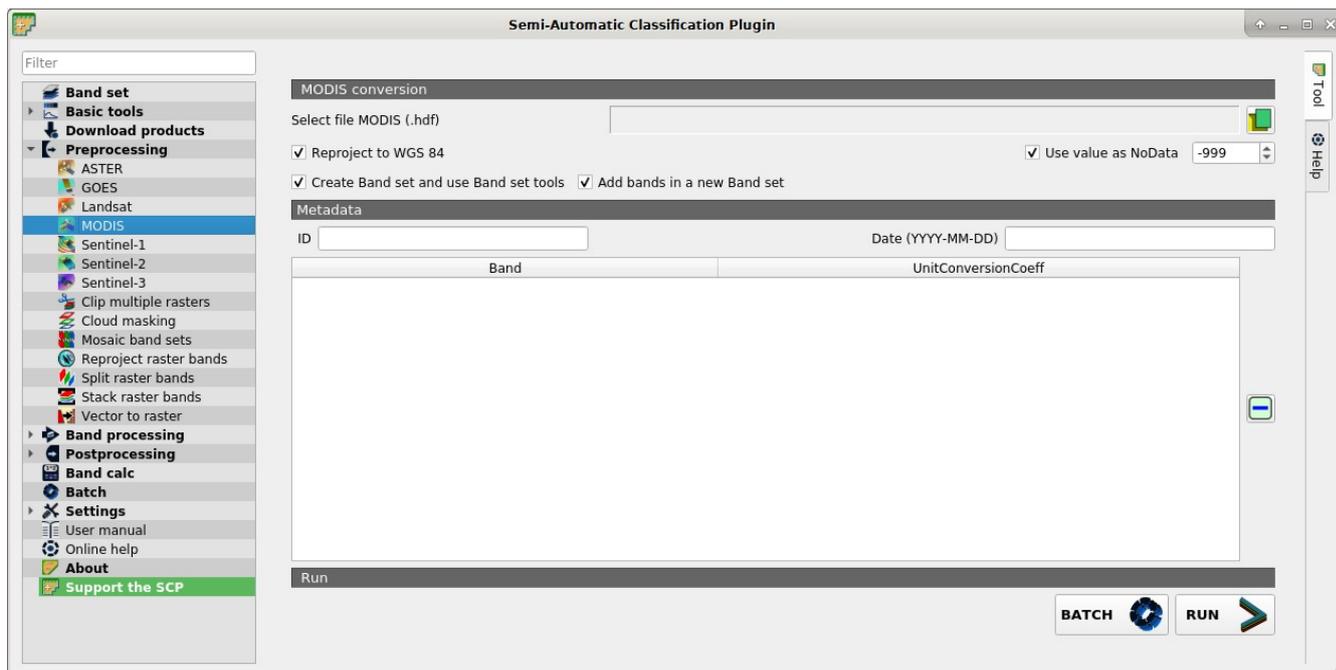
Fig. 25: *MODIS*

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 value as NoData* : 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 = -999);

- *Create Band set and use Band set tools*: if checked, bands are added to the active *Band set* after the conversion; also, the *Band set* is processed according to the tools checked in the *Band set* (page 31);

- *Add bands in a new Band set*: if checked, bands are added to a new empty *Band set* after the conversion;

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;

- *Date* : date of acquisition (e.g. 2013-04-15);

- : remove highlighted bands from the table *Metadata*;

- *Metadata*: **table containing the following fields;**

    – *Band*: band name;

    – *UnitConversionCoeff*: value for conversion;

- *BATCH* : add this function to the *Batch* (page 101);

- *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-1

- *Sentinel-1 conversion* (page 57)
- *Metadata* (page 58)
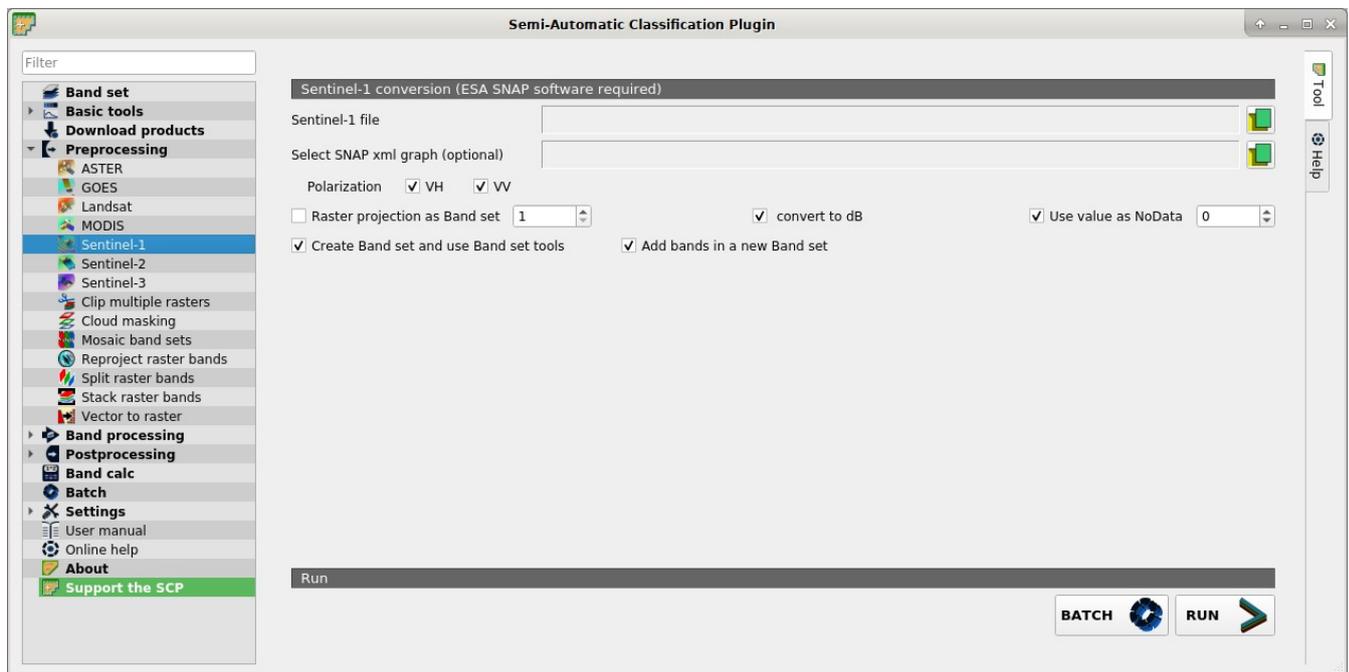
Fig. 26: Sentinel-1

This tab allows for the conversion of **Sentine-1** images, in particular *Sentinel-1 Satellites* (page 134) images (GRD) VV and VH polarizations. For the processing method please read *Sentinel-1 preprocessing* (page 134).

These processes are performed through the SNAP Graph Processing Tool (GPT) and a graph file .xml . Therefore, SCP requires ESA SNAP to perform the preprocessing. For the installation of ESA SNAP, please visit this page http://step.esa.int/main/download/snap-download/ .

The path to the SNAP gpt executable must be entered in settings *Processing* (page 113).

Sentinel-1 conversion

- *Sentinel-1 file* : open a Sentinel-1 file (.zip);

- *Select SNAP xml graph (optional)* : select a custom graph file (.xml) to be used for preprocessing; predefined variables for the xml graph can be: `$input` for the input file, `$polarization` for VV

or VH polarization if only one polarization is checked, `$output` for the output file (`$outputVV` and `$outputVH` if both polarizations are checked);

- Polarization ☑ *VV* ☑ *VH*: if checked, process VV and VH polarizations;

- ☑ *Raster projection as Band set* 1⌄ : if checked, project the raster to the same coordinate reference system as a band set (default WGS 84);

- ☑ *convert to dB*: if checked, convert values to dB;

- ☑ *Use value as NoData* 1⌄ : if checked, pixels having `NoData` value are not counted during conversion;

- ☑ *Create Band set and use Band set tools*: if checked, bands are added to the active *Band set* after the conversion; also, the *Band set* is processed according to the tools checked in the *Band set* (page 31);

- ☑ *Add bands in a new Band set*: if checked, bands are added to a new empty *Band set* after the conversion;

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* T : satellite name (e.g. Landsat8);

- *Date* T : date of acquisition (e.g. 2013-04-15);

- *Sun elevation* 1⌄ : Sun elevation in degrees;

- *Earth sun distance* 1⌄ : 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;

- *BATCH* : add this function to the *Batch* (page 101);

- *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

- *Sentinel-2 conversion* (page 60)

- *Metadata* (page 60)

Fig. 27: *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 150)). 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 60) are automatically filled;

- *Select metadata file* : select the metadata file which is a .xml file whose name contains MTD_MSIL1C); this is optional and can be generally ignored;

- *Apply DOS1 atmospheric correction*: if checked, the *DOS1 Correction* (page 151) is applied to all the bands;

- *Use value as NoData* : 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);

- *Preprocess bands 1, 9, 10*: if checked, preprocess also bands 1, 9, 10 (i.e. 60m bands);

- *Create Band set and use Band set tools*: if checked, bands are added to the active *Band set* after the conversion; also, the *Band set* is processed according to the tools checked in the *Band set* (page 31);

- *Add bands in a new Band set*: if checked, bands are added to a new empty *Band set* after the conversion;

    TIP: in order to convert L2A images you should move all the .jp2 files inside the same directory and rename the files with the band number in the ending of the name (e.g. from name_02_10m.jp2 to name_02.jp2).

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;

- *BATCH* : add this function to the *Batch* (page 101);

- *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

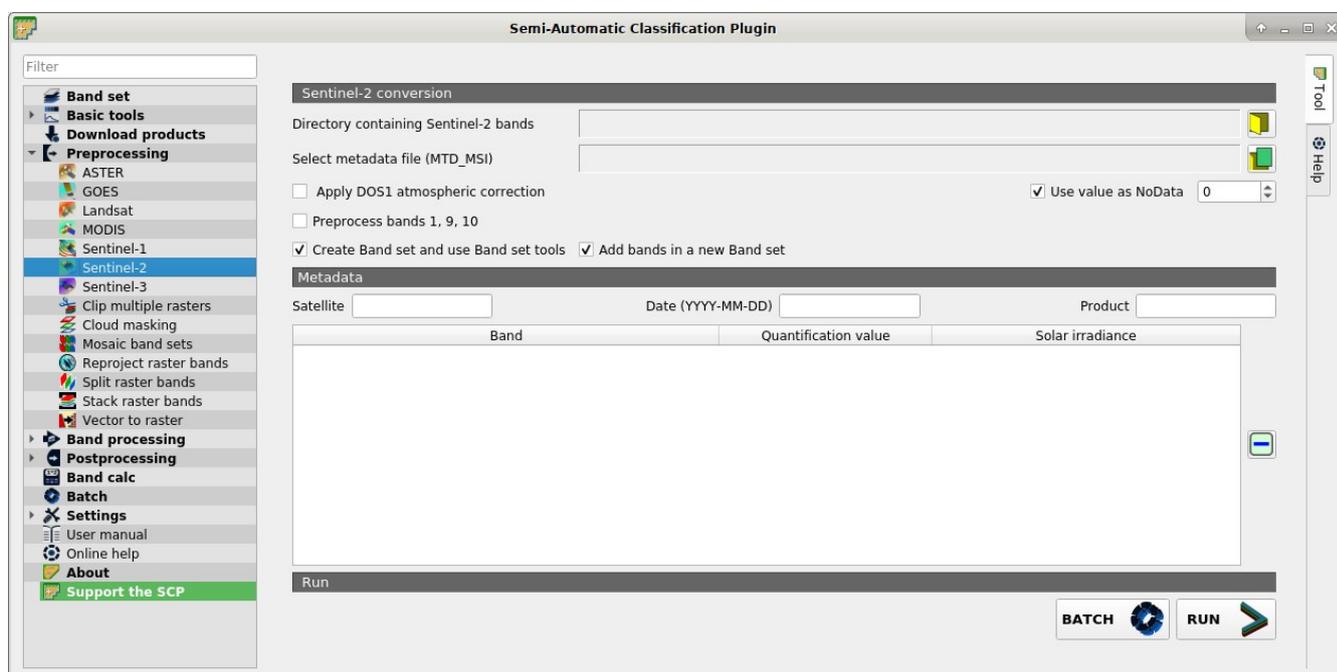- *Sentinel-3 conversion* (page 61)

- *Metadata* (page 62)
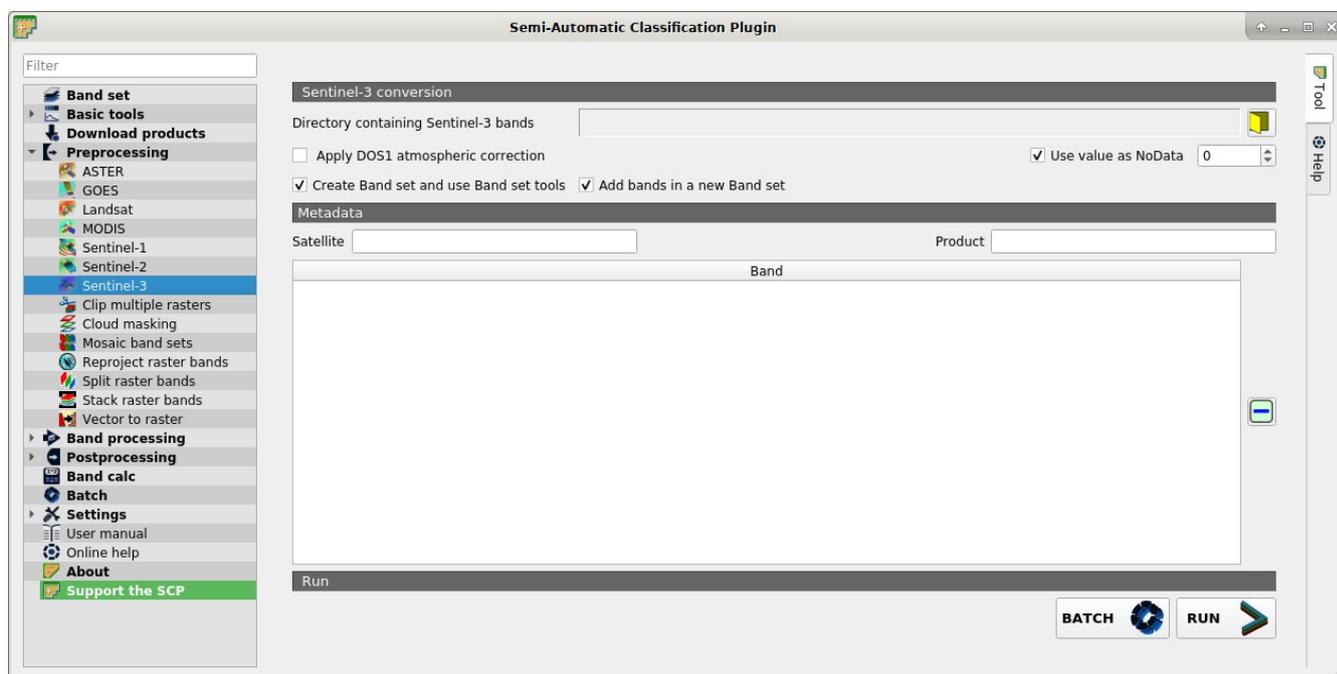
Fig. 28: *Sentinel-3*

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 150)). 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.

> **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 151) is applied to all the bands;

- *Use value as NoData* : 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, bands are added to the active *Band set* after the conversion; also, the *Band set* is processed according to the tools checked in the *Band set* (page 31);

- [✓] *Add bands in a new Band set*: if checked, bands are added to a new empty *Band set* after the conversion;

Metadata

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

- *Satellite* [T]: satellite name (e.g. Sentinel-3A);

- *Product* [T]: product name (e.g. OLCI);

- [—]: remove highlighted bands from the table *Metadata*;

- [⊡] *Metadata*: **table containing the following fields;**

    – *Band*: band name;

- *BATCH* [⊙]: add this function to the *Batch* (page 101);

- *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;

Clip multiple rasters

- *Clip band set* (page 63)

- *Clip coordinates* (page 63)
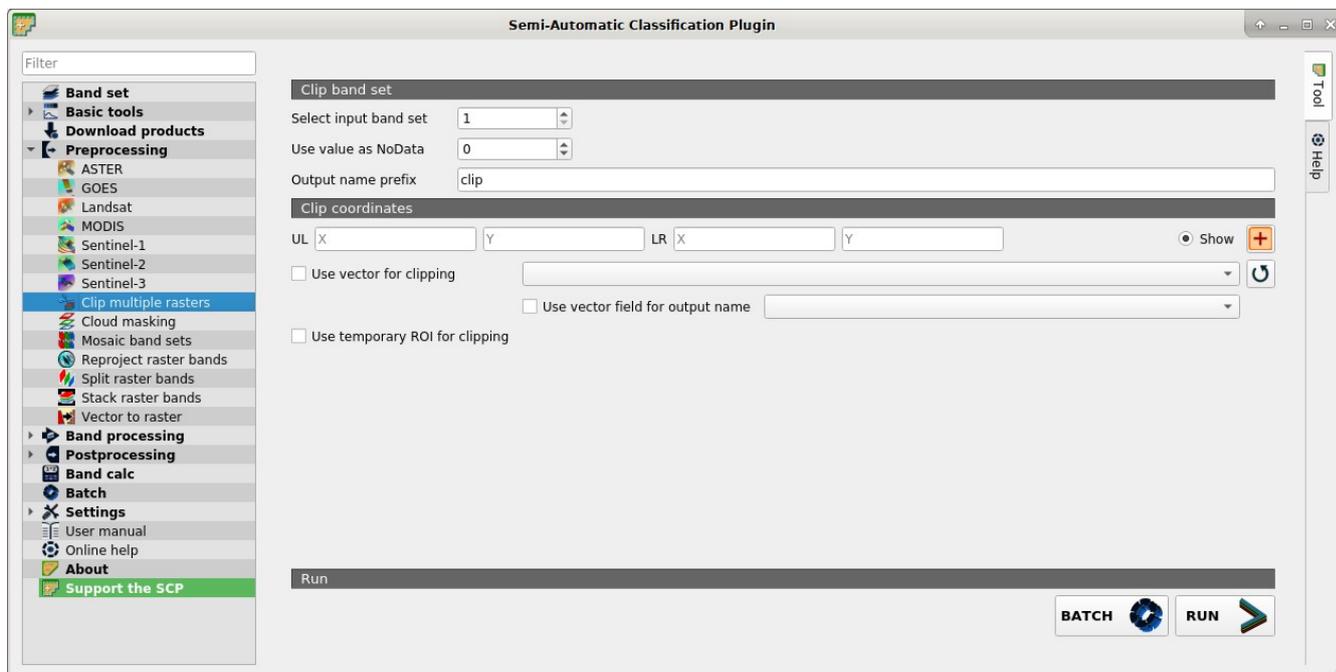
Fig. 29: [✂] *Clip multiple rasters*

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

Clip band set

- *Select input band set* [1 ⌄] : select the input *Band set* (page 31) to be clipped;

- [✓] *Use value as NoData* [1 ⌄] : if checked, set the value for `NoData` pixels (e.g. pixels outside the clipped area);

- *Output name prefix* [T] : set the prefix for output file names (default is `clip`);

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* [1 ⌄] : set the UL X coordinate;

- *UL Y* [1 ⌄] : set the UL Y coordinate;

- *LR X* [1 ⌄] : set the LR X coordinate;

- *LR Y* [1 ⌄] : 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* (page 29) for clipping; UL and LR coordinates are ignored;

- [↻] : refresh layer list;

- *BATCH* [◉] : add this function to the *Batch* (page 101);

- *RUN* [⟩] : choose an output destination and clip rasters in the selected `Band set`;

Cloud masking

- *Mask of band set* (page 64)
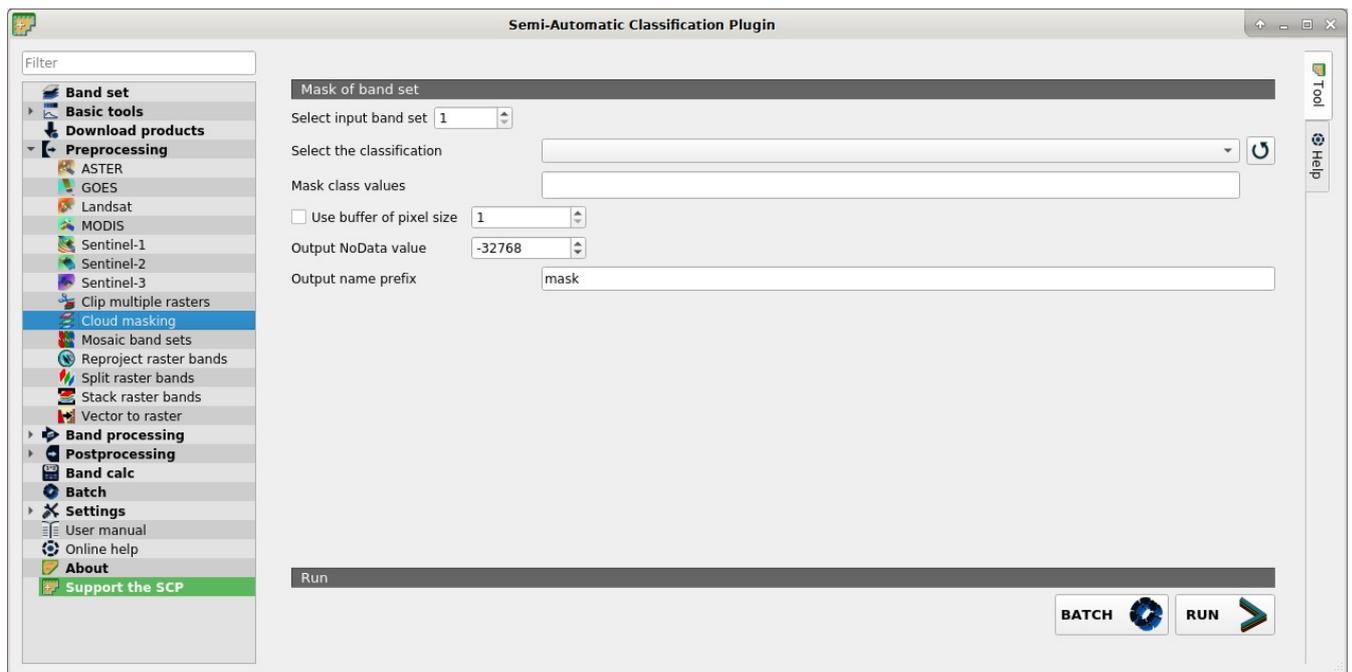
Fig. 30: *Cloud masking*

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 31). NoData is set in all the bands of the *Band set* (page 31) for pixels corresponding to clouds.

Mask of band set

- *Select input band set* 1◇: select the input *Band set* (page 31) 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* T: 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* 1◇: 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;

- *Output NoData value* 1◇: set the value of NoData pixels corresponding to clouds;

- *Output name prefix* T: set the prefix for output file names (default is mask);

- *BATCH* : add this function to the *Batch* (page 101);

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

Mosaic band sets

> • *Mosaic of band sets* (page 65)
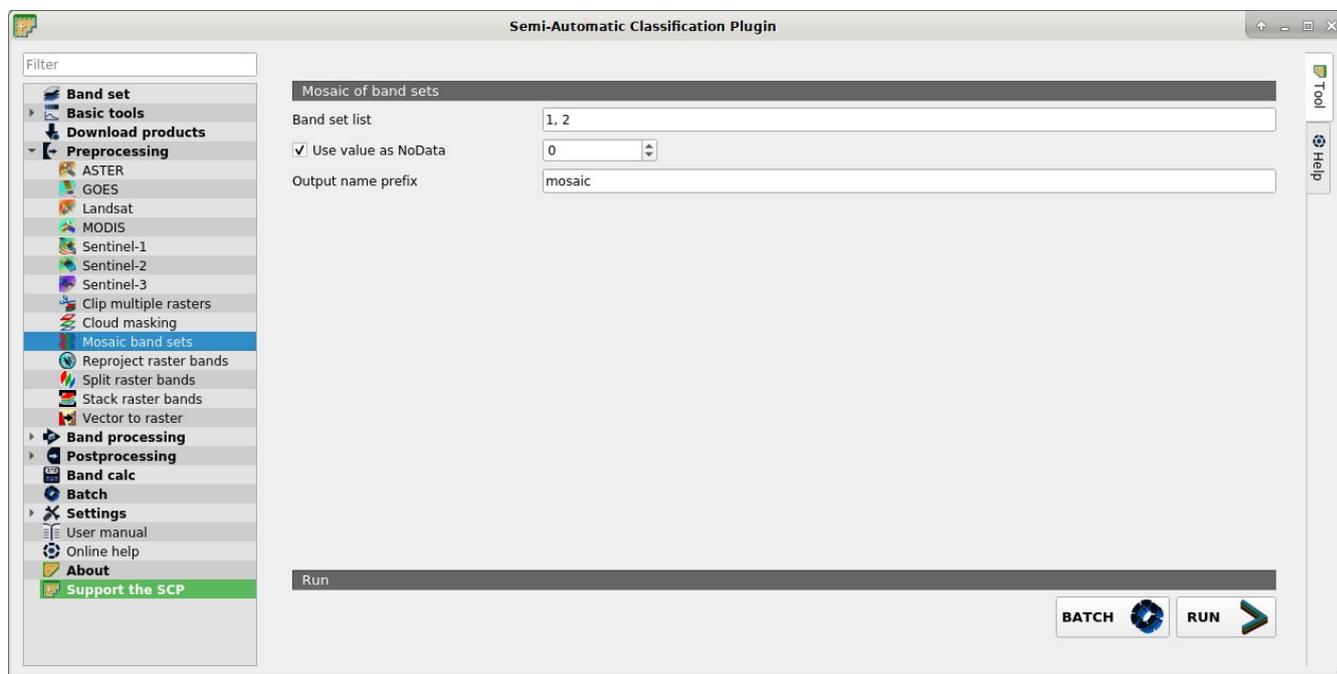
Fig. 31: *Mosaic band sets*

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 31). 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.

Mosaic of band sets

- *Band set list* T : list if band sets defined in the *Band set* (page 31); in case of overlapping images, the pixel values of the first band set in the list are assigned.

- ✓ *Use value as NoData* 1◇ : if checked, set the value of NoData pixels, ignored during the calculation;

- *Output name prefix* T : set the prefix for output file names (default is mosaic);

- *BATCH* : add this function to the *Batch* (page 101);

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

Neighbor pixels

> • *Neighbor pixels* (page 66)
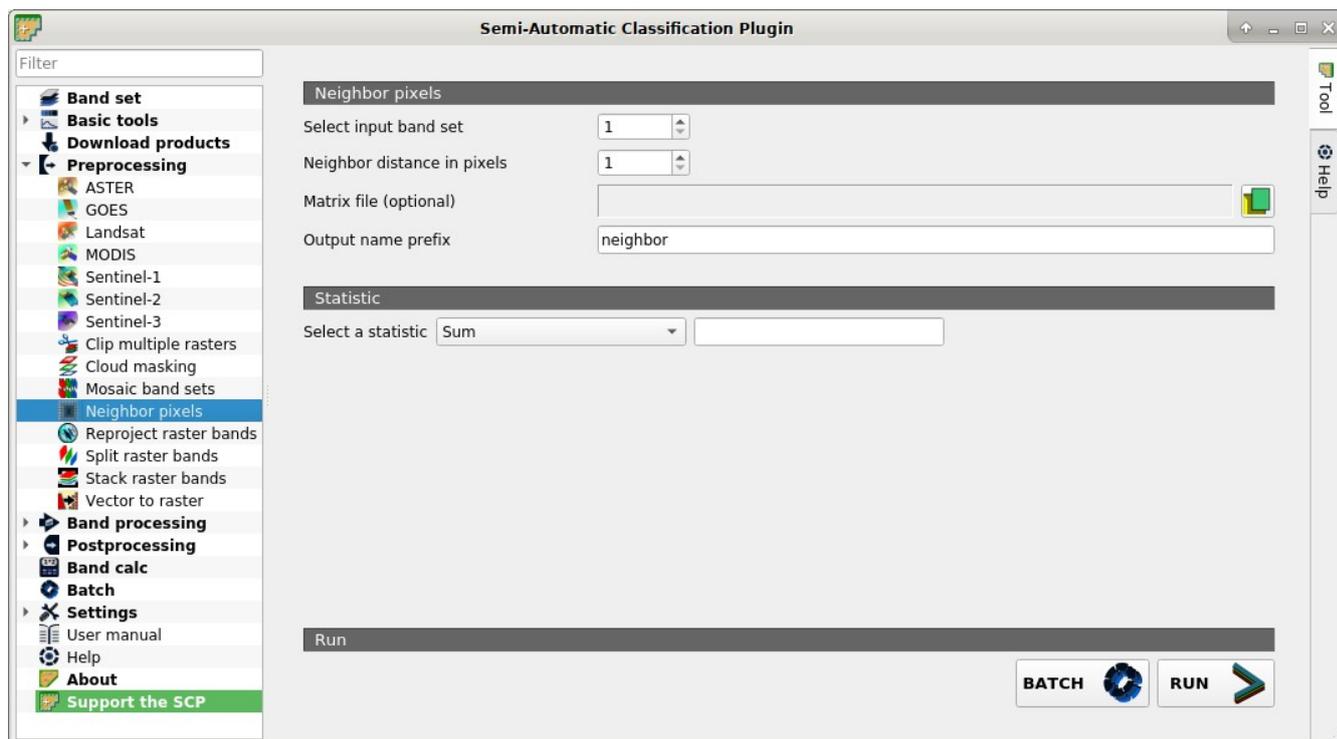
Fig. 32: *Neighbor pixels*

This tool allows for the calculation of several neighbor pixels statistics for every band of a band set defined in the *Band set* (page 31).

The statistics are calculated for every pixel of the input raster considering the values of the neighbor pixels. Neighbor pixels are defined through a distance or through a custom matrix.

For example, the following matrix represents the neighbor pixels within a distance of 1 pixel from a central pixel, resulting in a 3x3 matrix.

Neighbor	Neighbor	Neighbor
Neighbor	**Center**	Neighbor
Neighbor	Neighbor	Neighbor

Several statistics are available. The statistic Sum will result in a raster convolution. For instance, this can be useful to apply an image filter to all the bands a band set for photointerpretation.

An output band is created for every band in the band sets.

Neighbor pixels

- *Select input band set* : select the input *Band set* (page 31);

- *Neighbor distance in pixels* : use a square matrix centred in one pixel considering all the neighbor pixels within this distance; e.g. a value of 1 results in a 3x3 matrix with weight 1 in every cell; a value of 2 results in a 5x5 matrix with weight 1 in every cell, such as:

1	1	1	1	1
1	1	1	1	1
1	1	1	1	1
1	1	1	1	1
1	1	1	1	1

- *Matrix file (optional)* : open a text file (.txt or .csv) containing a matrix structure; the text file must be a list of numbers separated by commas, representing the columns, and each line represents a row of the matrix; `nan` can be entered for `NoData` values that will be excluded from the calculation; following an example of matrix file:

```
nan,1,nan
1,1,1
nan,1,nan
```

Resulting in the following matrix:

NoData	1	NoData
1	1	1
NoData	1	NoData

- *Output name prefix* **T**: set the prefix for output file names (default is `neighbor`);

Statistic

- *Select a statistic* **T**: select a statistic; available options are `Sum`, `Max`, `Min`, `Count`, `Mean`, `Median`, `Percentile`, `StandardDeviation`; for `Percentile` a value can be entered;

- *BATCH* : add this function to the *Batch* (page 101);

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

Reproject raster bands

- *Reproject raster bands* (page 67)

This tab allows for reprojecting bands in a *Band set* (page 31) and perform other raster operations.

Reproject raster bands

- *Select input band set* : select the input *Band set* (page 31) to be reprojected;

- *Align to raster* *same extent as reference* : if *Align to raster* is checked, use the same coordinate reference system and pixel size as the selected reference; if *same extent as reference* is checked, the output extent will be the same as the reference;

- : refresh layer list;
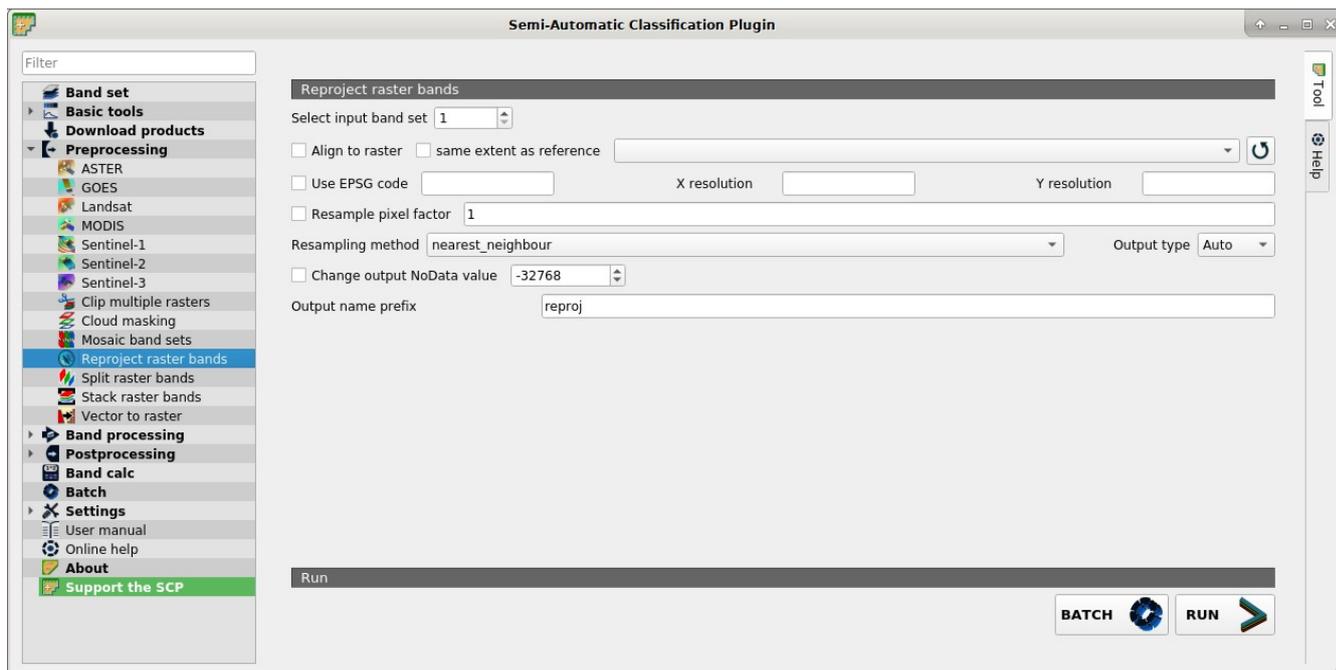
Fig. 33: *Reproject raster bands*

- *Use EPSG code* T *X resolution* T *Y resolution* T : if checked, use the EPSG code for defining the output coordinate reference system with *X resolution* and *Y resolution*;

- *Resample pixel factor* T : if checked, new pixel size will be the original size times this factor;

- *Resampling method* : select the resampling method; options are `nearest_neighbour`, `average`, `sum`, `maximum`, `minimum`, `mode`, `median`, `first_quartile`, `third_quartile`;

- *Output type* : select the output raster type; options are `Auto` (same as input), `Float32`, `Int32`, `UInt32`, `Int16`, `UInt16`, `Byte`;

- *Change output NoData value* : if checked, set a new value for `NoData` pixels;

- *Output name prefix* T : set the prefix for output file names (default is `reproj`);

- *BATCH* : add this function to the *Batch* (page 101);

- *RUN* : choose an output destination and start the process;

Split raster bands

- *Raster list* (page 69)

Split a multiband raster to single bands.
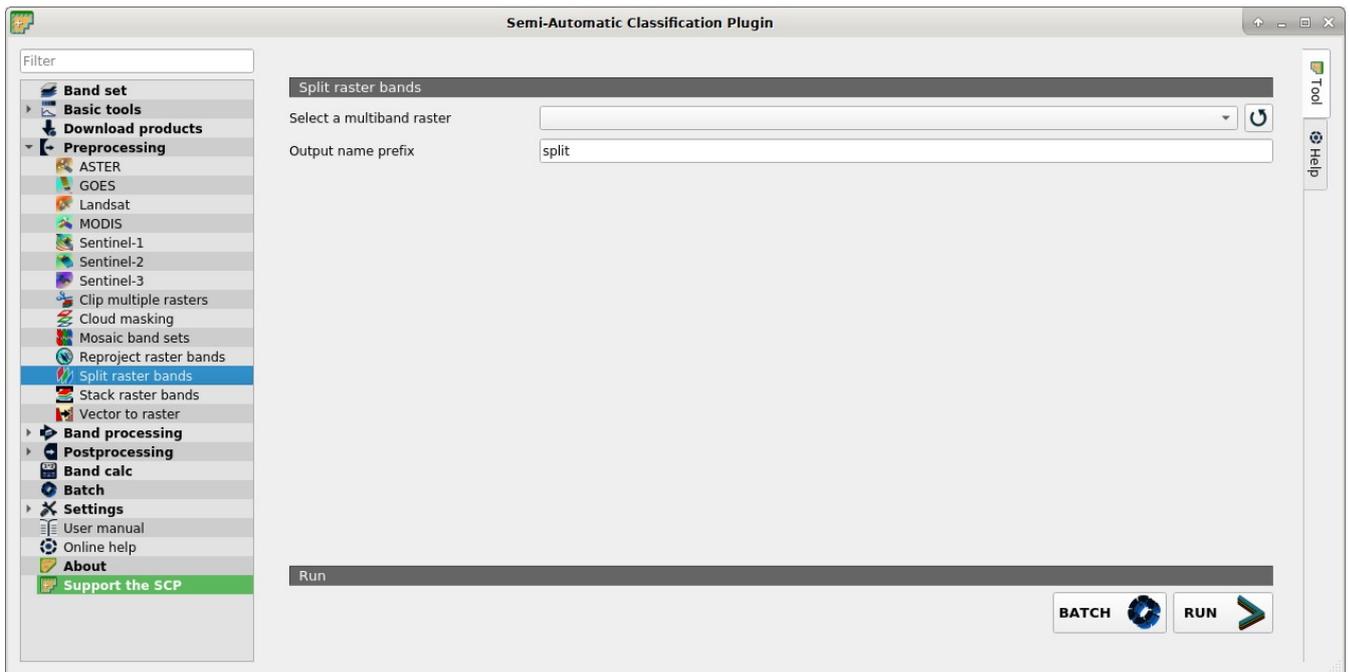
Fig. 34: *Split raster bands*

Raster list

- *Select a multiband raster* [⌄] : select the input raster;

- [↻] : refresh layer list;

- *Output name prefix* [T] : set the prefix for output file names (default is `split`);

- *BATCH* [●] : add this function to the *Batch* (page 101);

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

Stack raster bands

- *Stack band set* (page 69)

Stack all the bands in a *Band set* (page 31) into a multiband raster.

Stack band set

- *Select input band set* [1⌄] : select the input *Band set* (page 31) to be stacked;

- *BATCH* [●] : add this function to the *Batch* (page 101);
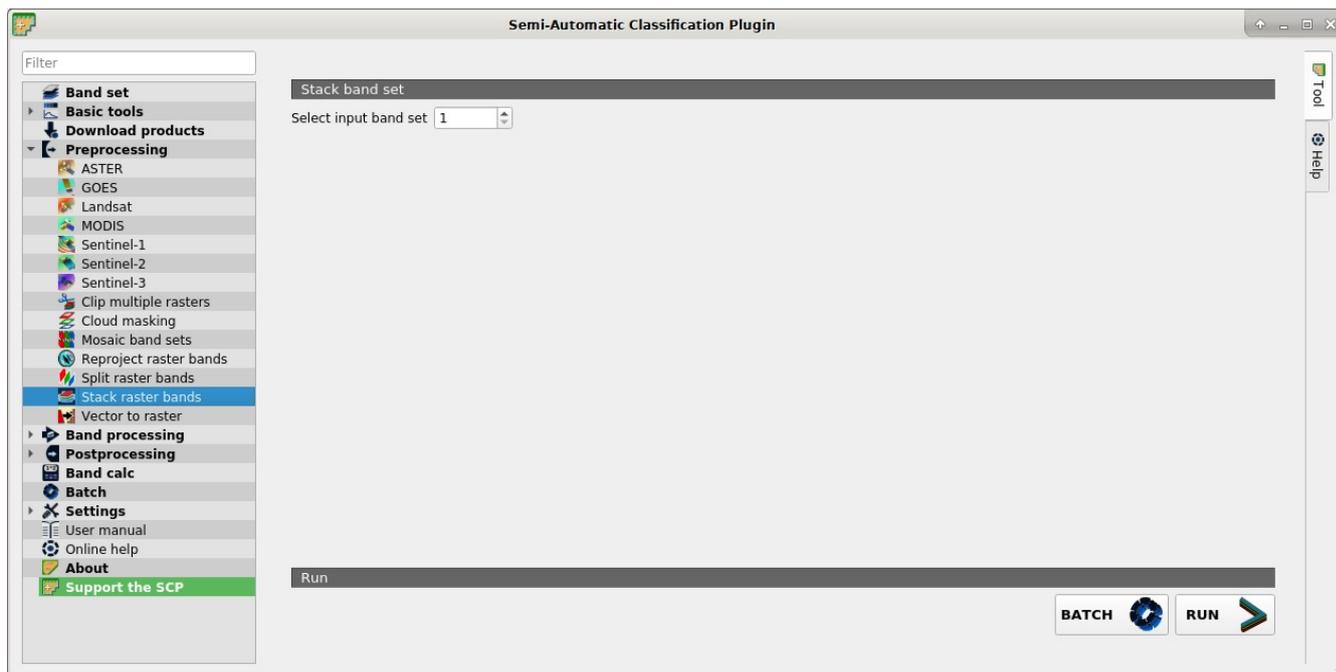
Fig. 35: *Stack raster bands*

- *RUN* : choose the output destination and stack selected raster;

Vector to raster

- *Convert vector to raster* (page 70)

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

Convert vector to raster

- *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* 1⌄ : 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;
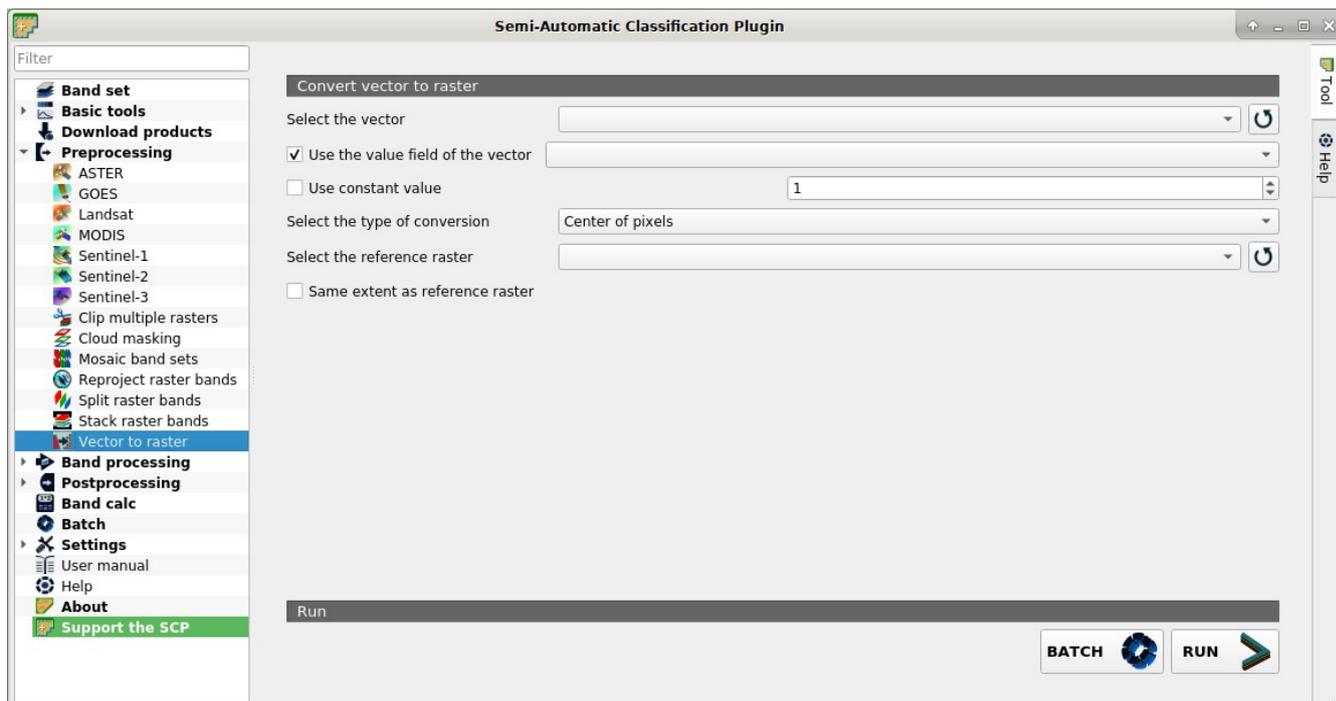
Fig. 36: *Vector to raster*

- *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;

- *Same extent as reference raster*: the output raster will have the same extent as reference raster;

- *BATCH* : add this function to the *Batch* (page 101);

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

3.4.5 Band processing

The tab *Band processing* provides several functions that can be applied to the *Band set* (page 31).

Band combination

- *Combination of band values* (page 72)

This tab allows for the combination of bands loaded in a *Band set* (page 31). 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 an text file.
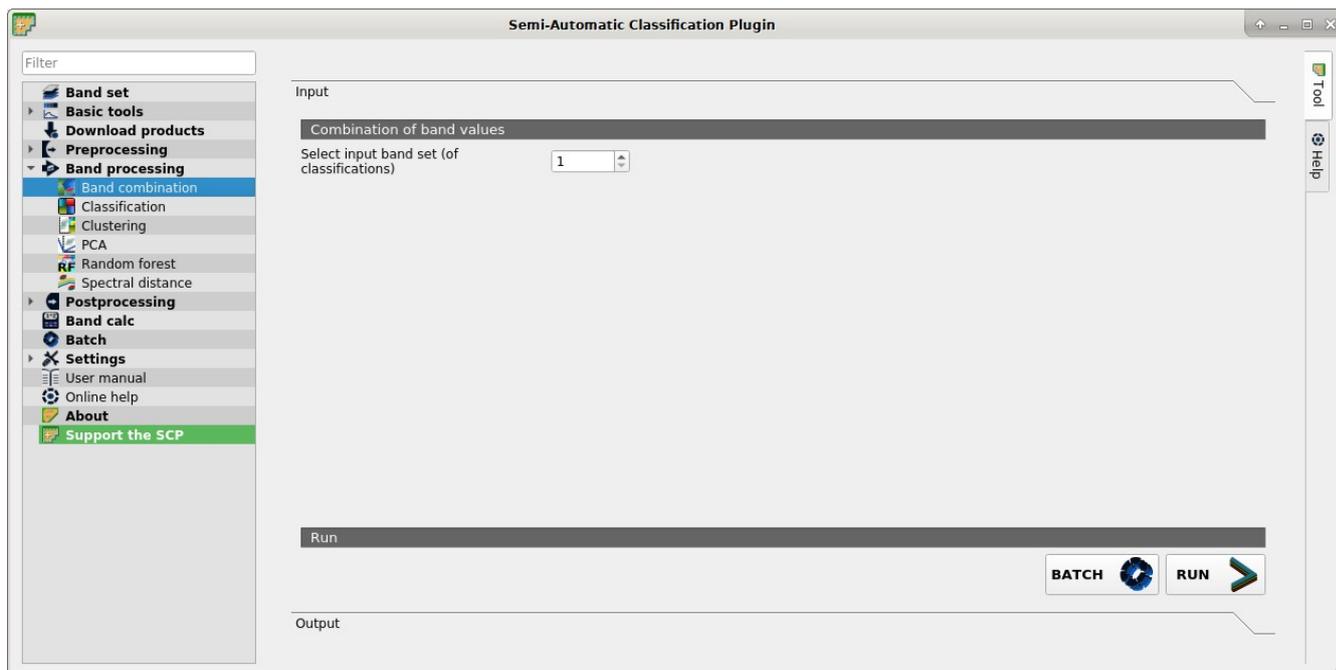
Fig. 37: *Band combination*

Combination of band values

- *Select input band set (of classifications)* : select the input *Band set* (page 31);

- *BATCH* : add this function to the *Batch* (page 101);

- *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;

Classification

- *Classification* (page 72)
- *Algorithm* (page 73)
- *Land Cover Signature Classification* (page 74)
- *Classification output* (page 74)

This tab allows for the classification of the *Band set* (page 31) using the spectral signatures checked in *ROI & Signature list* (page 24). Several classification options are set in this tab which affect the classification process also during the *Classification preview* (page 30).

This tool allows for the use of the following algorithms: Minimum Distance, Maximum Likelihood, Spectral Angle Mapping. `Random Forest` is available in the *Random Forest* (page 77) tab.

Classification

- *Select input band set* : select the input *Band set* (page 31) to be classified;
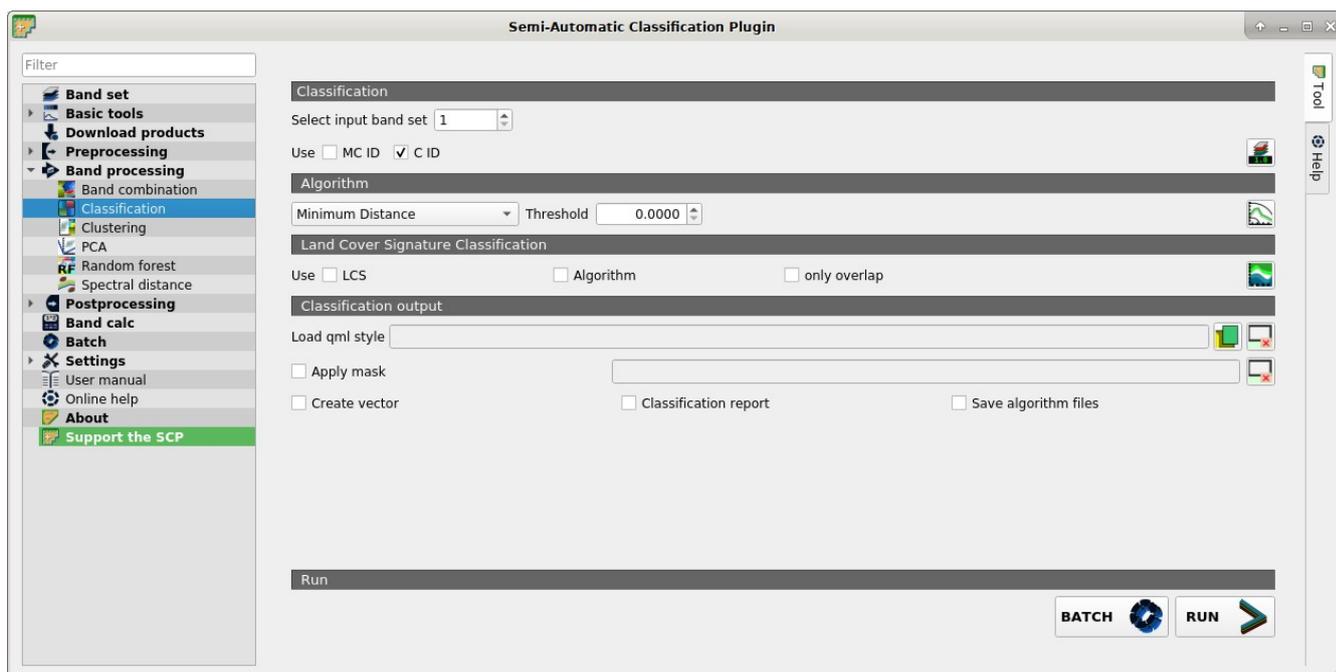
Fig. 38: *Classification*

- *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 34) for the definition of band weights;

Algorithm

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

- ⌄ ● : available *Classification Algorithms* (page 137) are:

  - *Minimum Distance* (page 137);

  - *Maximum Likelihood* (page 138);

  - *Spectral Angle Mapping* (page 139);

- *Threshold* 1↕ ● : **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);

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

- ⌇ : open the *Signature threshold* (page 44) for the definition of signature thresholds;

Land Cover Signature Classification

Land Cover Signature Classification (page 141) is a classification that can be used as alternative or in combination with the *Algorithm* (page 73) (see *LCS threshold* (page 39)). 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 73) is used for unclassified pixels of the *Land Cover Signature Classification*; if *only overlap* is checked, the selected *Algorithm* (page 73) 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 39);

Classification output

Classification output allows for the classification of the *Band set* (page 31) according to the parameters defined in *Algorithm* (page 73).

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 83));

- ☑ *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 82));

- ☑ *Save algorithm files* : if checked, the *Algorithm raster* (page 142) 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;

- *BATCH* : add this function to the *Batch* (page 101);

- *RUN* : choose the output destination and start the image classification;

Clustering
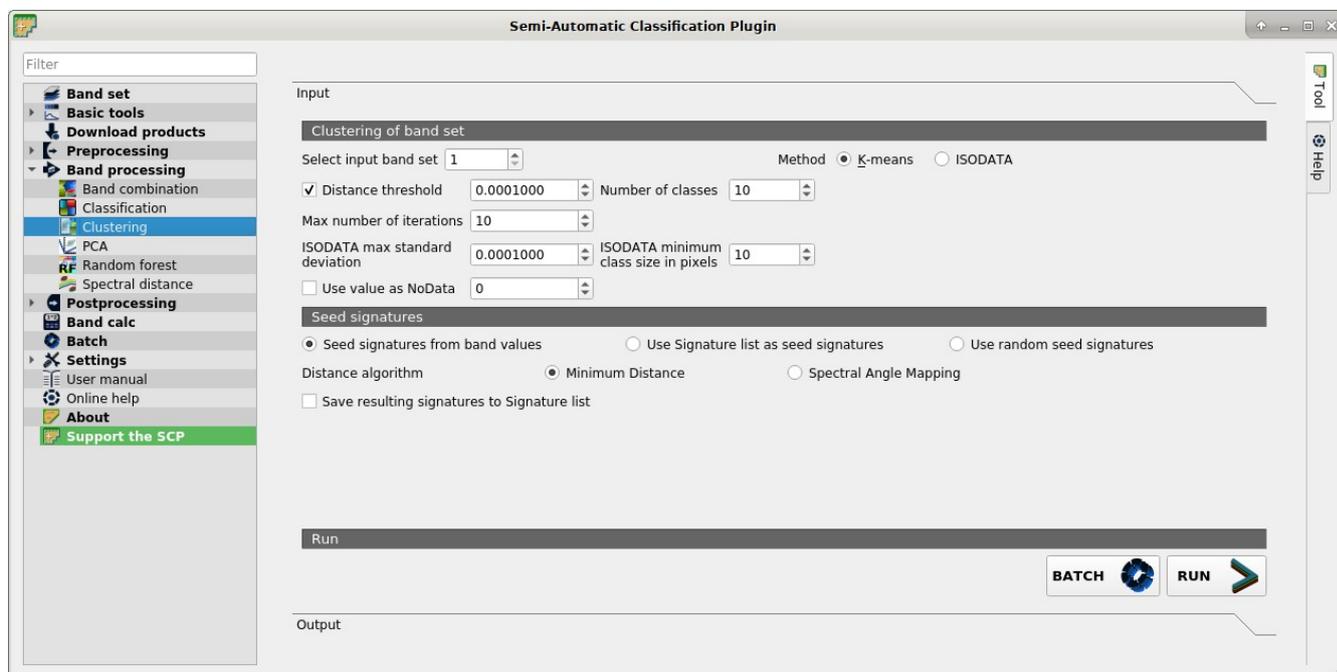
Fig. 39: *Clustering*

This tab allows for the *Clustering* (page 148) of a *Band set* (page 31). In particular, *K-means* (page 148) and *ISODATA* (page 148) methods are available.

A report .txt is saved along with the classification, containing the class spectral signature and the spectral distance thereof.

Clustering of band set

- *Select input band set* ⌷1⌷: select the input *Band set* (page 31);

- *Method* ◉ *K-means* ◉ *ISODATA*: select the clustering method *K-means* (page 148) or *ISODATA* (page 148);

- ☑ *Distance threshold* ⌷1⌷: 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* ⌷1⌷: number of desired output classes;

- *Max number of iterations* ⌷1⌷: maximum number of iterations if *Distance threshold* is not reached;

- *ISODATA max standard deviation* ⌷1⌷: maximum standard deviation considered for splitting a class, for *ISODATA* algorithm only;

- *ISODATA minimum class size in pixels* ⌷1⌷: desired minimum class size in pixels, for *ISODATA* algorithm only;

- *Use value as NoData* : 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 31) to get spectral signatures; the option *Use Signature list as seed signatures* uses the spectral signatures checked in *ROI & Signature list* (page 24); the option *Use random seed signatures* randomly selects the spectral signatures of pixels in the *Band set* (page 31);

- *Distance algorithm* *Minimum Distance* *Spectral Angle Mapping*: select *Minimum Distance* (page 137) or * *Spectral Angle Mapping* (page 139) for spectral distance calculation;

- *Save resulting signatures to Signature list*: if checked, save the resulting spectral signatures in the *ROI & Signature list* (page 24);

- *BATCH* : add this function to the *Batch* (page 101);

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

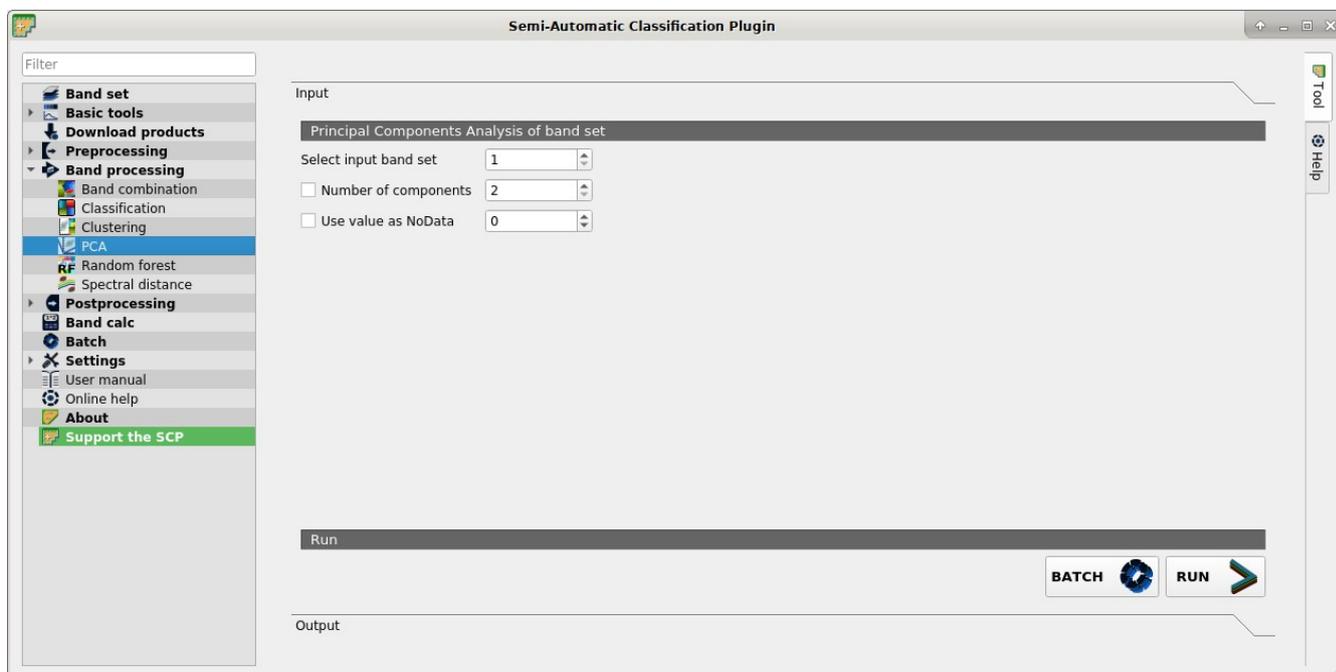### PCA

- *Principal Component Analysis of Band set* (page 77)

Fig. 40: *PCA*

This tab allows for the PCA (*Principal Component Analysis* (page 146)) of bands loaded in the *Band set*.

A report .txt is saved along with the PCA bands, containing the covariance matrix, correlation matrix, eigen vectors, and eigen values.

Principal Component Analysis of Band set

- *Select input band set* [1⟳] : select the input *Band set* (page 31);

- [✔] *Number of components* [1⟳] : if checked, set the number of calculated components; if unchecked, all the components are calculated;

- [✔] *Use value as NoData* [1⟳] : if checked, set the value of `NoData` pixels, ignored during the calculation;

- *BATCH* ⬤ : add this function to the *Batch* (page 101);

- *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;

Random Forest

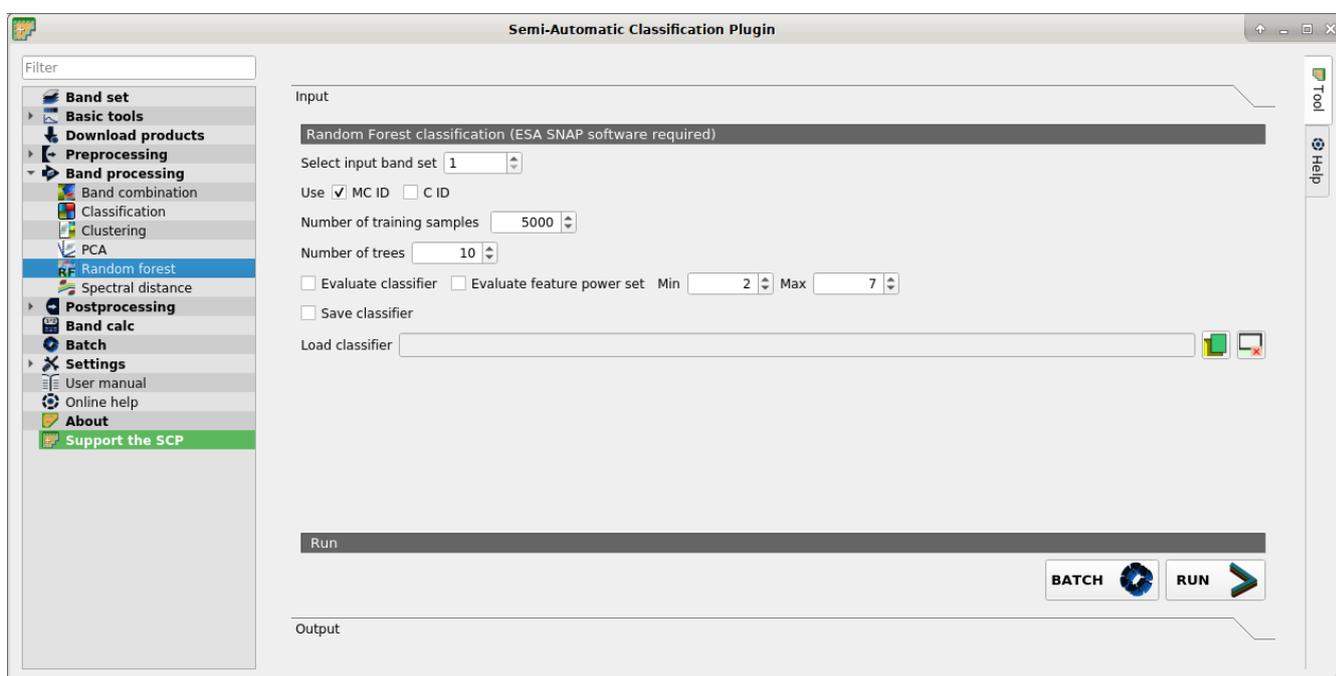- *Random Forest classification* (page 78)

Fig. 41: *Random forest*

This tool allows for the *Random Forest* (page 143) classification, based on a *Band set* (page 31) and *Training input* (page 23).

ESA SNAP is required. The *ESA SNAP GPT executable* must be defined in *External programs* (page 114) settings.

Random Forest classification

- *Select input band set* 1↕ : select the input *Band set* (page 31) to be classified;

- *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);

- *Number of training samples* 1↕ : set the number of training data (pixels) randomly used to traing the model; it should be set lower than total training input pixels;

- *Number of trees* 1↕ : set the number of decision trees; a higher number allows for more accurate models, but it also increases the calculation time;

- ✔ *Evaluate classifier*: if checked, the classifier is evaluated;

- ✔ *Evaluate feature power set Min* 1↕ *Max* 1↕ : if checked, evaluate the power set of input features (e.g. Gini decrease), according to the contribution thereof to the model; *Min* and *Max* are used as thresholds for power sets; it can increase the calculation time;

- ✔ *Save classifier*: if checked, save the classifier for later use;

- *Load classifier* T 🟩 : open a previously saved classifier; if loaded, the input *Band set* (page 31) is directly classified using this classifier;

- ❌ : clear the classifier;

- *BATCH* 🔵 : add this function to the *Batch* (page 101);

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

Spectral distance

- *Spectral distance of band sets* (page 78)

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 (0-1) of values below and above the threshold.

Spectral distance of band sets

- *Select first input band set* 1↕ : select the first input *Band set* (page 31);

- *Select second input band set* 1↕ : select the second input *Band set* (page 31);

- *Distance algorithm* ⦿ *Minimum Distance* ⦿ *Spectral Angle Mapping*: select *Minimum Distance* (page 137) or * *Spectral Angle Mapping* (page 139) for spectral distance calculation;

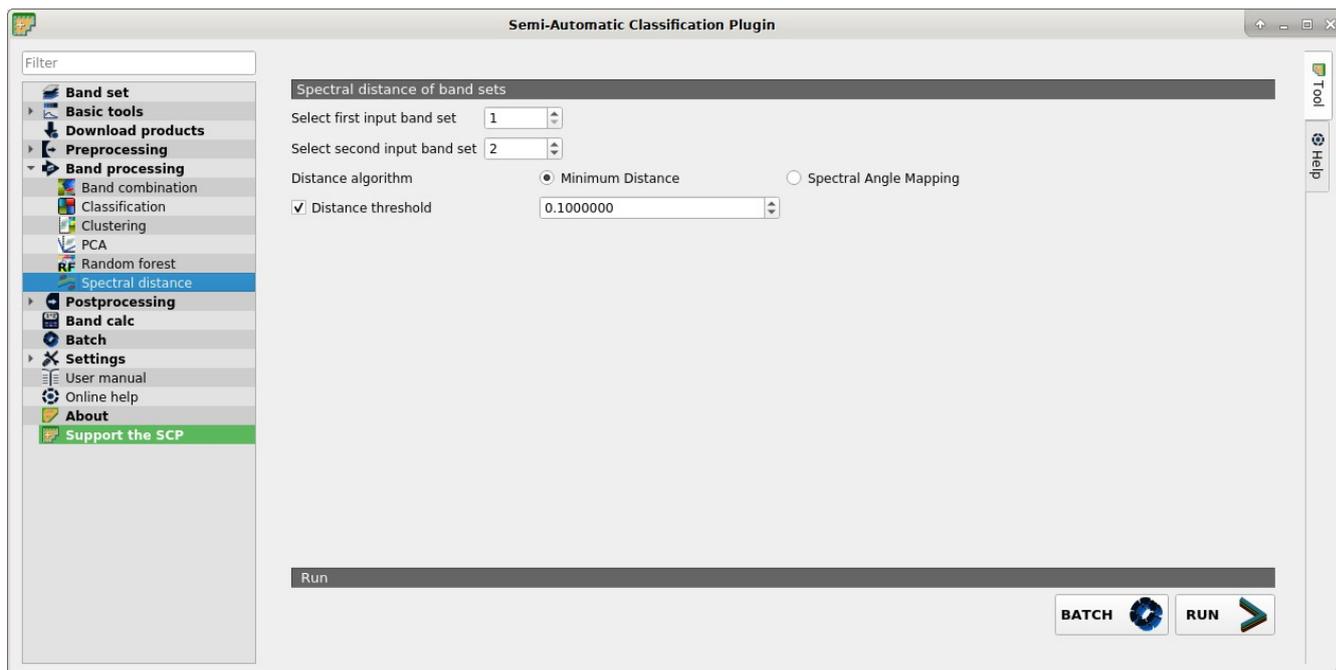- ✔ *Distance threshold* 1↕ : if checked, a binary raster of values below and above the threshold is created;

Fig. 42: *Spectral distance*

- *BATCH* : add this function to the *Batch* (page 101);

- *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

- *Accuracy assessment* (page 80)

This tab allows for the validation of a classification (read *Accuracy Assessment* (page 145)).

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.
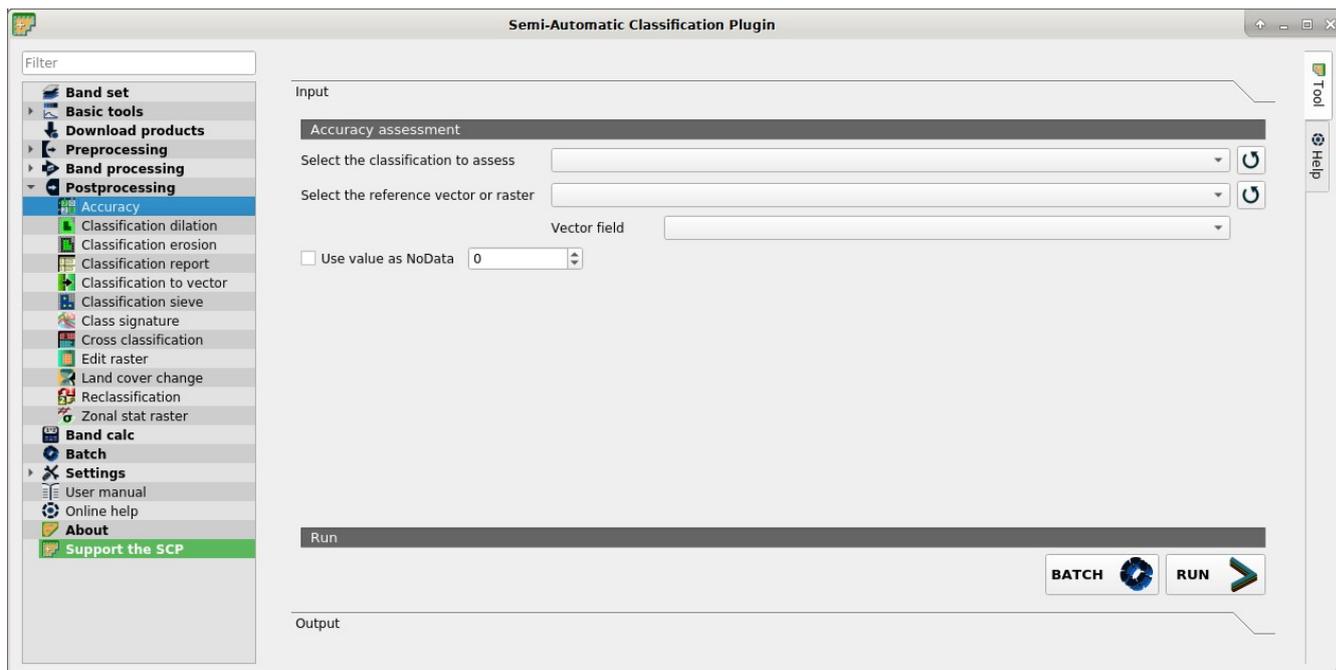
Fig. 43: *Accuracy*

Accuracy assessment

- *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;

- ☑ *Use value as NoData* 1⬍ : if checked, pixels having `NoData` value are excluded from the calculation;

- *BATCH* 🔵 : add this function to the *Batch* (page 101);

- *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;

Classification dilation

- *Classification dilation* (page 81)

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.
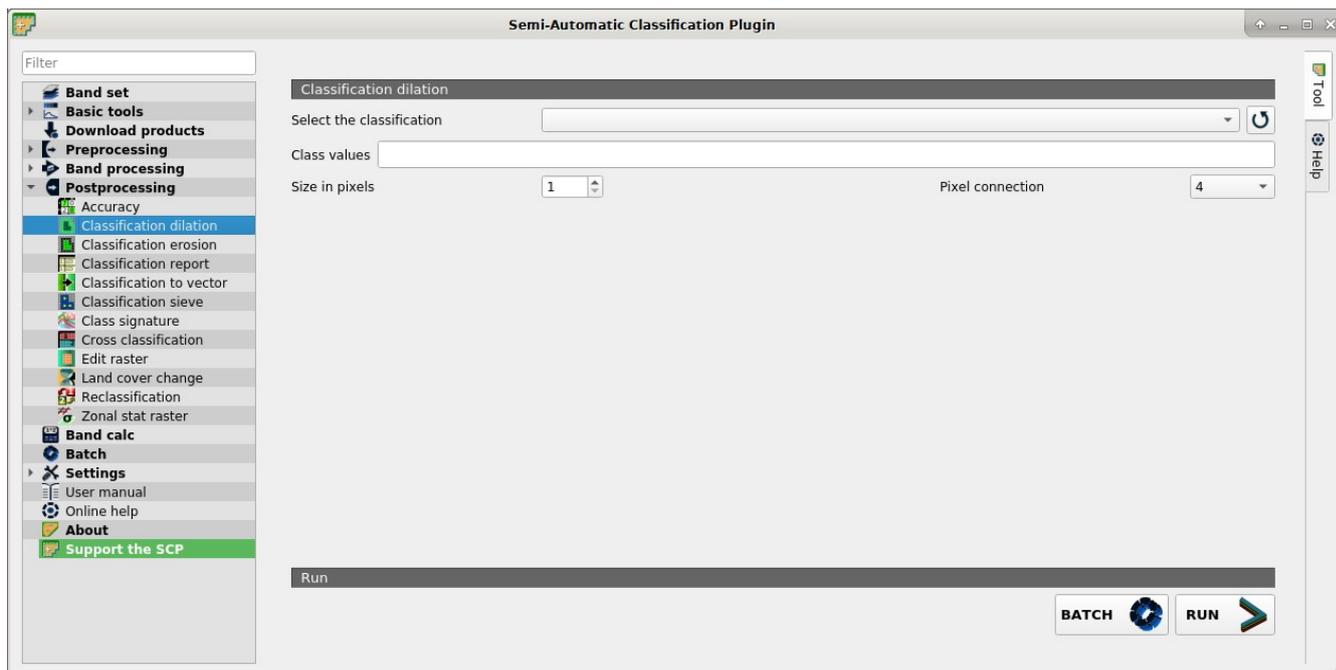
Fig. 44: *Classification dilation*

Classification dilation

- *Select the classification* [⌄]: select a raster (already loaded in QGIS);

- ↻ : refresh layer list;

- *Class values* [T]: 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* [1⌄]: 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;

- *BATCH* : add this function to the *Batch* (page 101);

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

Classification erosion

- *Classification erosion* (page 82)

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.
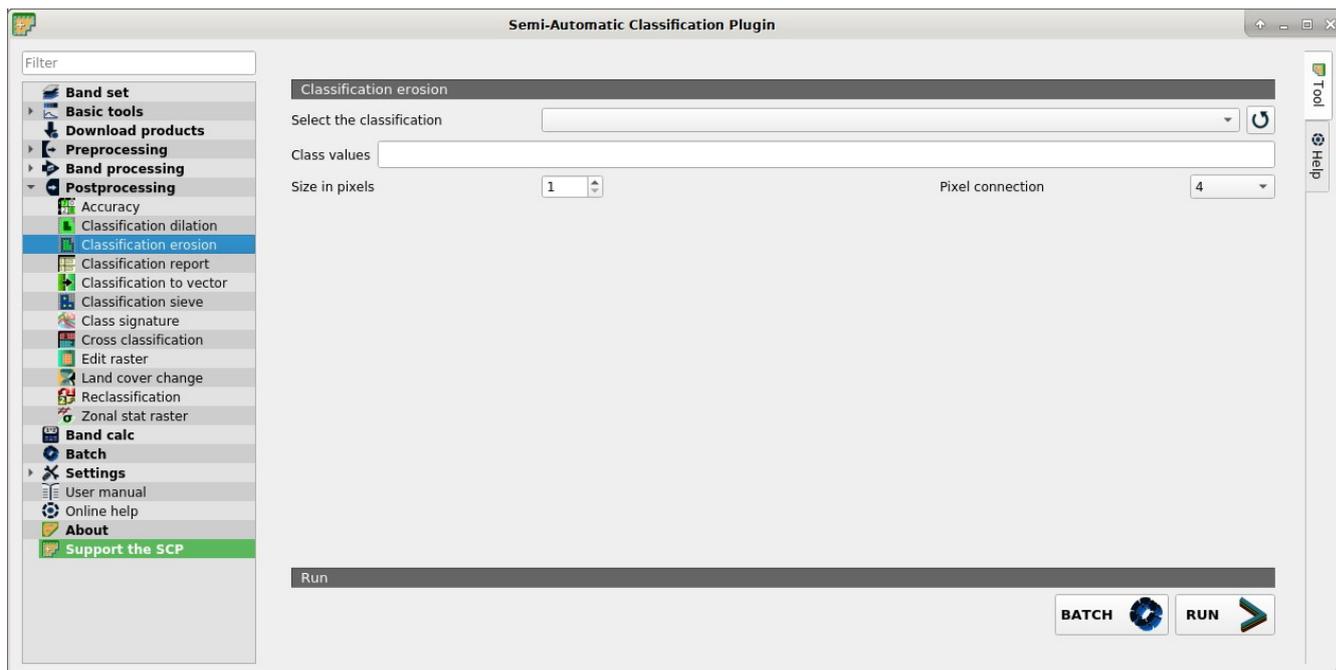
Fig. 45: *Classification erosion*

Classification erosion

- *Select the classification* [⌄]: select a raster (already loaded in QGIS);

- [↻] : refresh layer list;

- *Class values* [T]: 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* [1⌄]: 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;

- *BATCH* [⟳]: add this function to the *Batch* (page 101);

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

Classification report

- *Classification report* (page 83)

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).

Fig. 46: *Classification report*

Classification report

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

- : refresh layer list;

- *Use value as NoData* : if checked, `NoData` value will be excluded from the report;

- *BATCH* : add this function to the *Batch* (page 101);

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

Classification to vector

- *Classification to vector* (page 83)
- *Symbology* (page 84)

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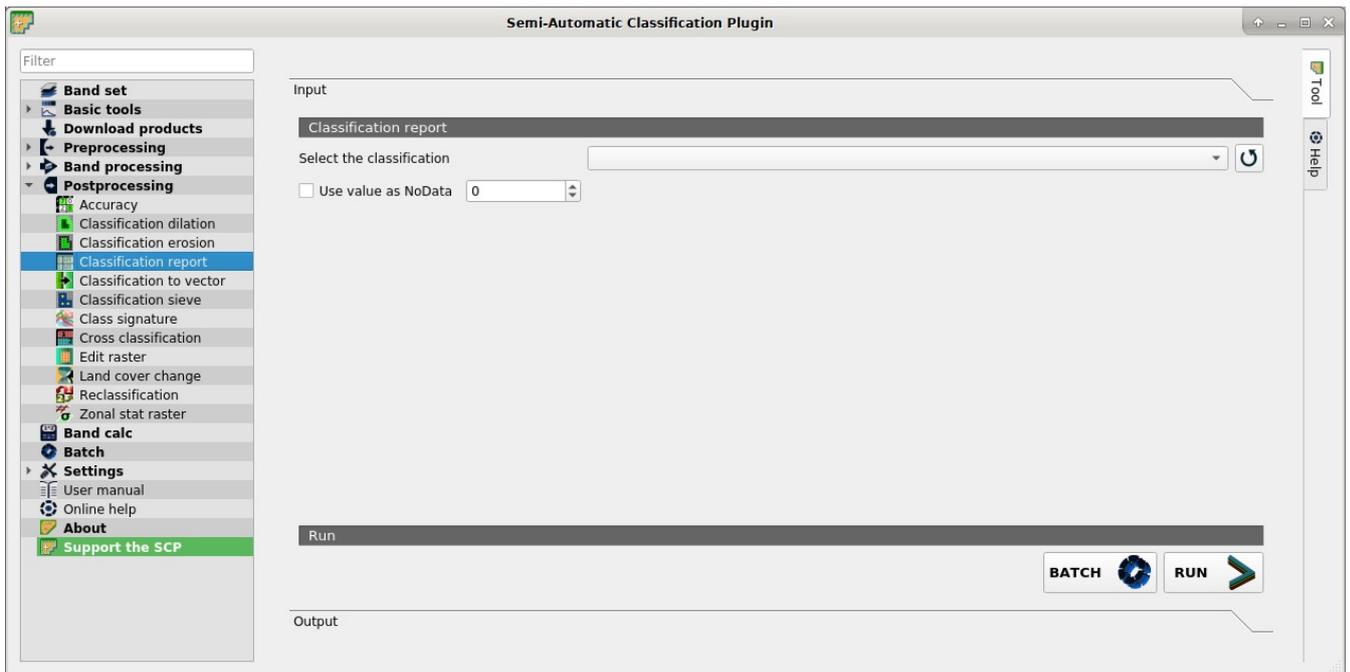
Classification to vector

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

- : refresh layer list;
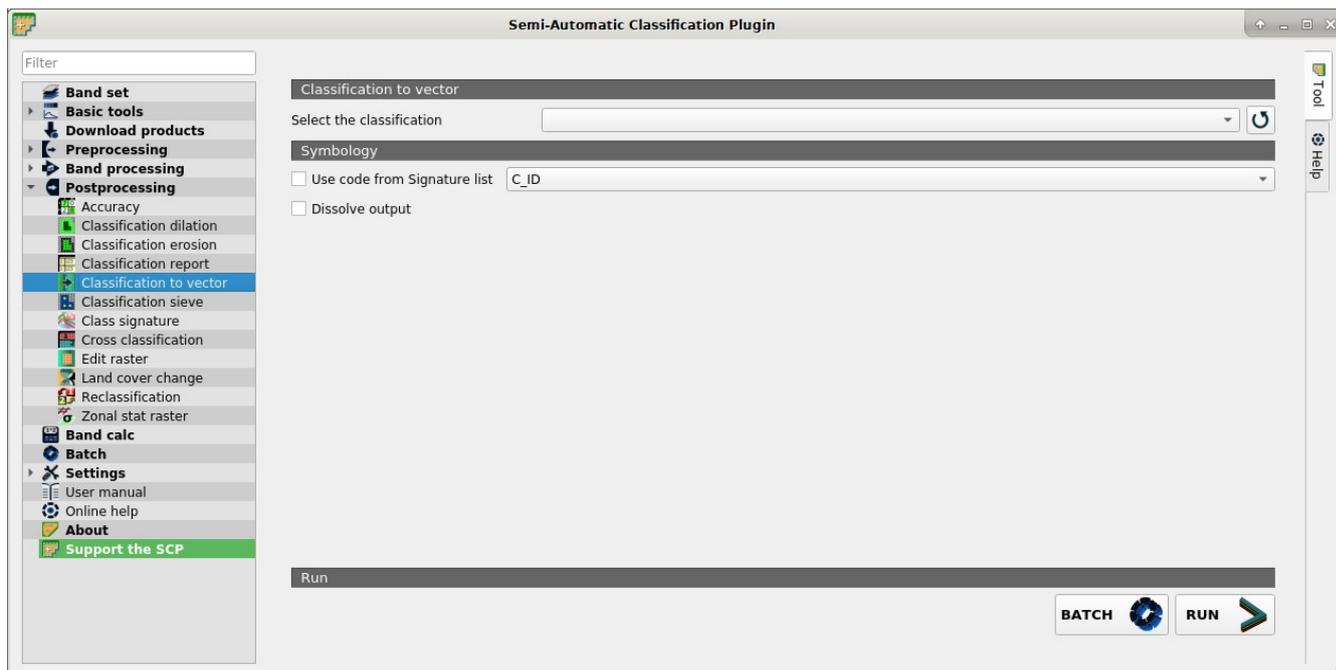
Fig. 47: *Classification to vector*

Symbology

- *Use code from Signature list* **: if checked, color and class information are defined from** *ROI & Signature list* (p

  - `MC ID`: use the ID of macroclasses;

  - `C ID`: use the ID of classes;

- *BATCH* : add this function to the *Batch* (page 101);

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

Classification sieve

- *Classification sieve* (page 84)

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.

Classification sieve

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

- : refresh layer list;

Fig. 48: *Classification sieve*
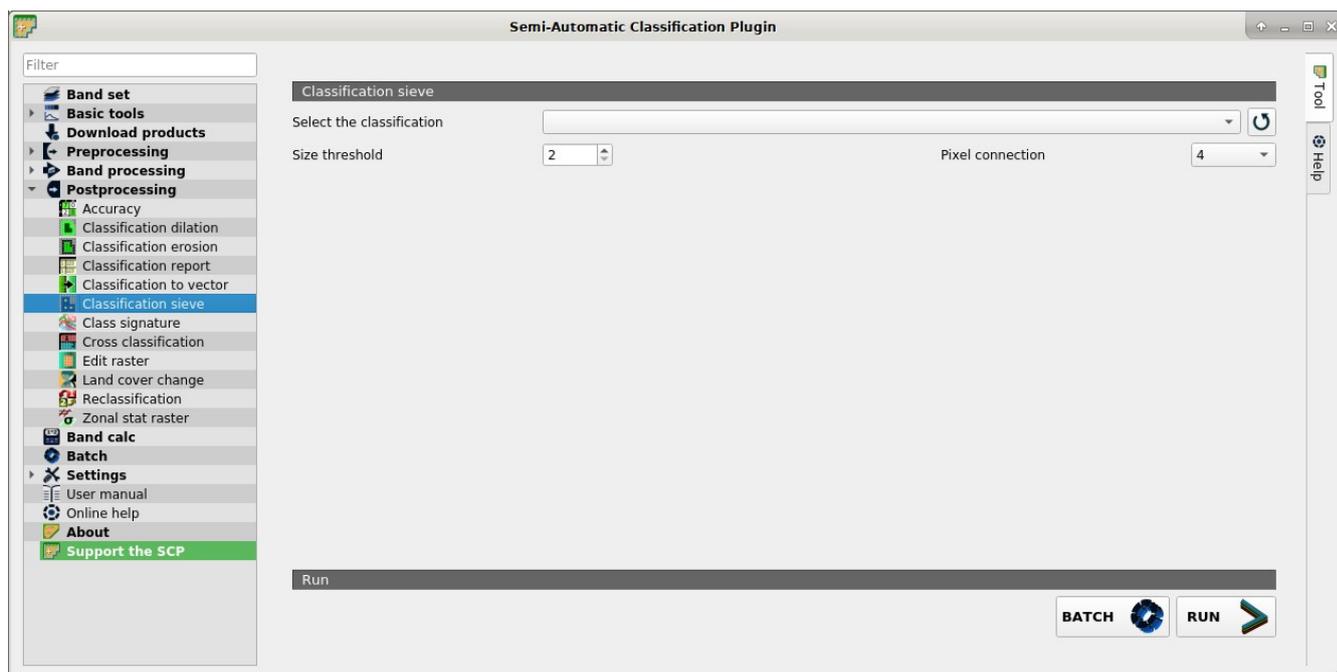
- *Size threshold* : size of the patch to be replaced (in pixel unit); all patches smaller than the selected number of pixels will be replaced by the value of the largest neighbour patch;

- *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;

- *BATCH* : add this function to the *Batch* (page 101);

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

Class signature

This tab allows for the calculation of the mean spectral signature of each class in a classification using a *Band set* (page 31).

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

- : refresh layer list;

- *Select input band set* : select the input *Band set* (page 31) for spectral signature calculation;

- *Save resulting signatures to Signature list*: if checked, save the resulting spectral signatures to *ROI & Signature list* (page 24);

- *BATCH* : add this function to the *Batch* (page 101);

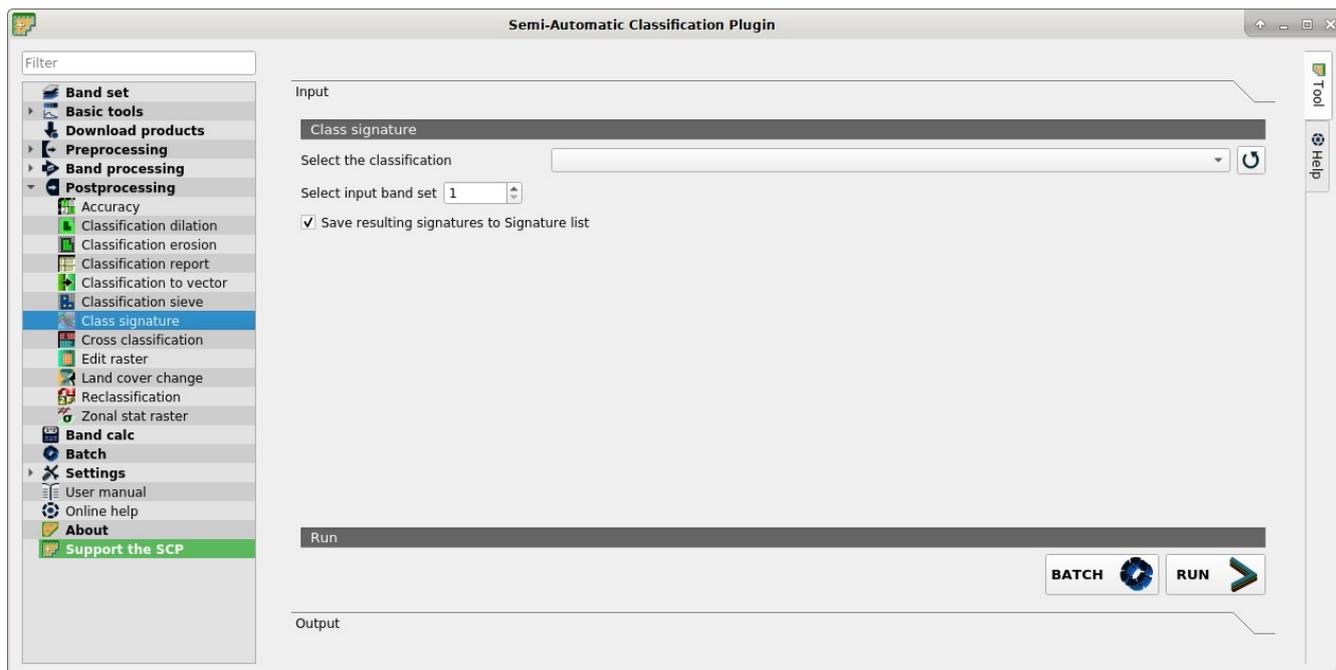- *RUN* : choose the output destination and start the conversion;

Fig. 49: *Class signature*

Cross classification

> • *Input* (page 86)

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 value as NoData* : 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;
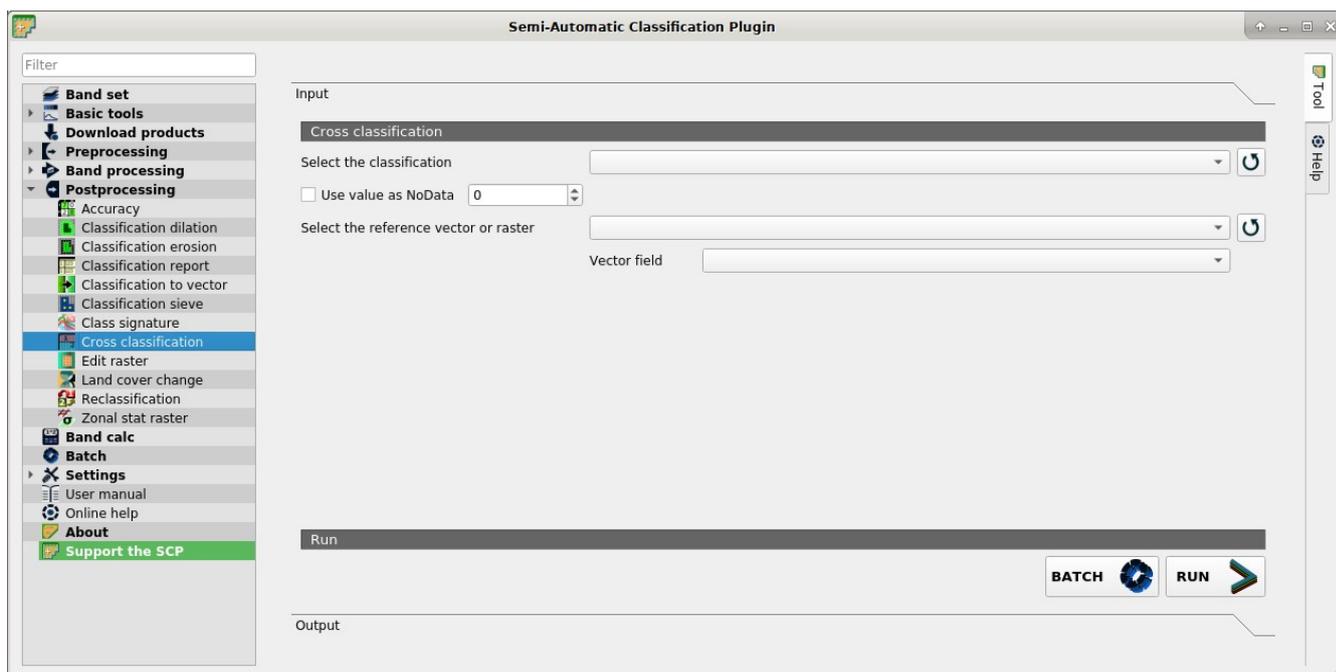
Fig. 50: *Cross classification*

- *BATCH* : add this function to the *Batch* (page 101);

- *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;

Edit raster

- *Edit raster* (page 87)
- *Edit raster values* (page 88)
- *Edit options* (page 88)

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

> **WARNING**: 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 123) is available for easing the raster editing using multiple values.

Edit raster

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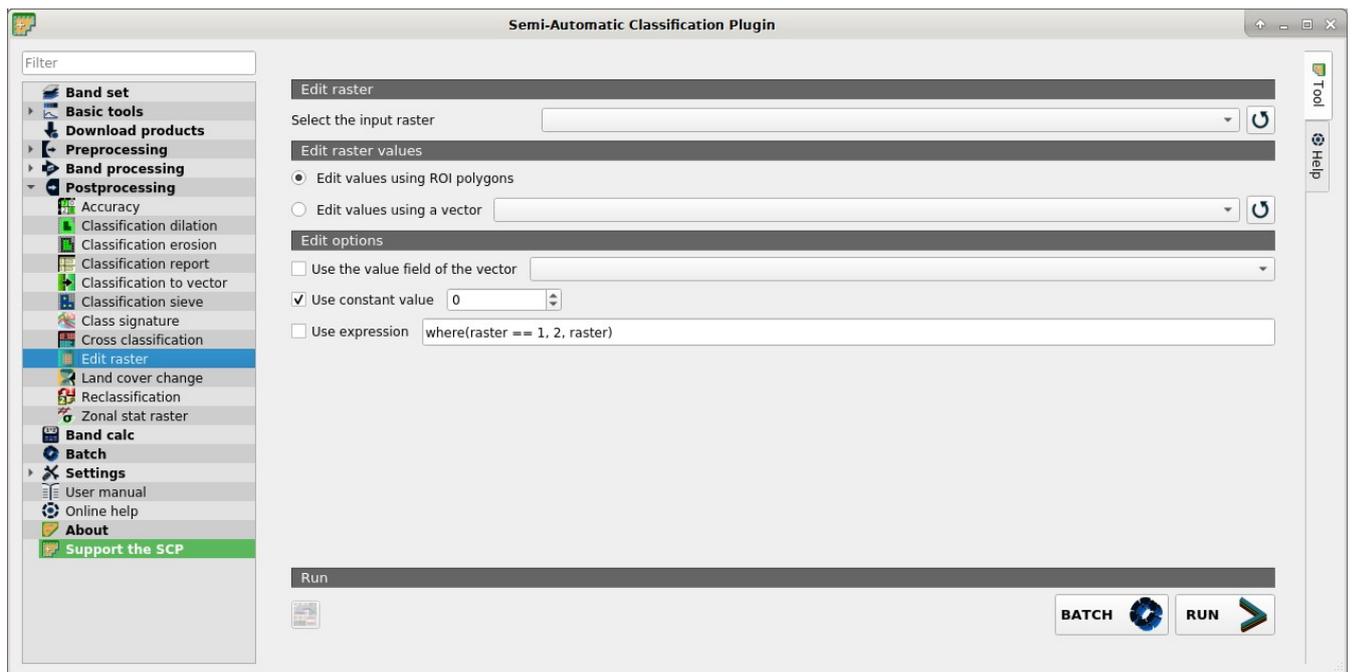
- : refresh layer list;

Fig. 51: *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;

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

- *RUN* : edit the raster;
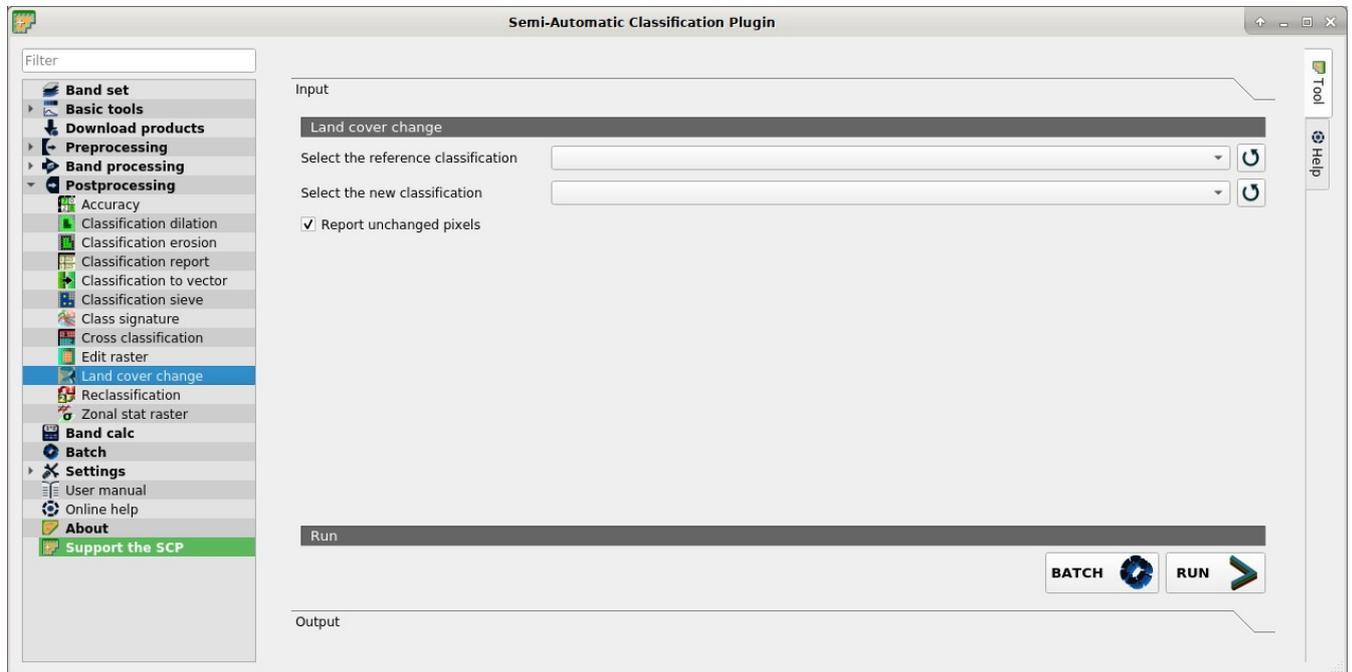
Land cover change

- *Input* (page 89)

Fig. 52: *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);

- *BATCH* ⬤ : add this function to the *Batch* (page 101);

- *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;

Reclassification

- *Reclassification* (page 90)

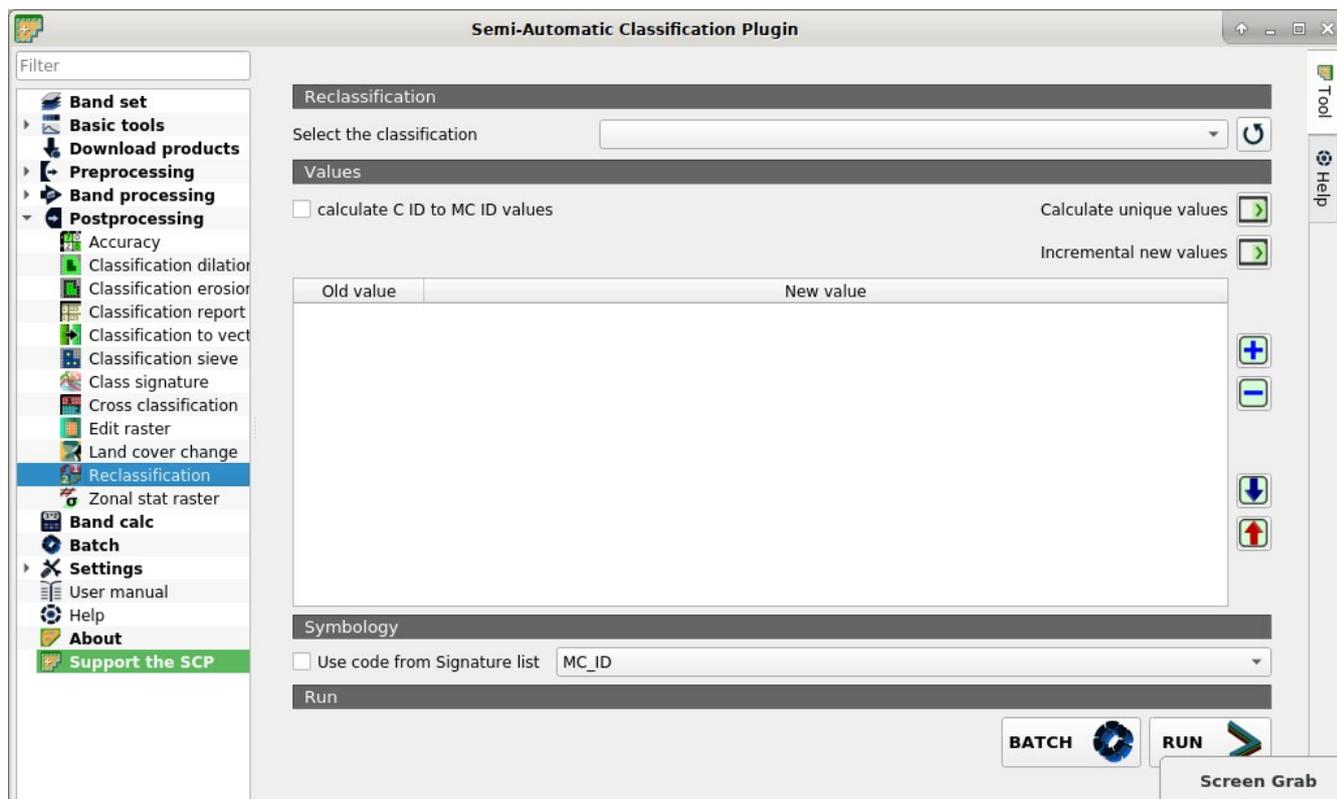- *Values* (page 91)

- *Symbology* (page 91)

Fig. 53: *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.

Reclassification

- *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 24) when *Calculate unique values* is clicked;

- *Calculate unique values* : calculate unique values in the classification and fill the reclassification table;

- *Incremental new values* : calculate a new incremental value (e.g. 1, 2, 3, . . .) for every old value 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 112)), following Python operators (e.g. `raster > 3` select all
    pixels having value > 3 ; `(raster > 5) | (raster < 2)` with parenthesis required select
    all pixels having value > 5 or < 2 ; `(raster >= 2) & (raster <= 5)` with parenthesis
    required select all pixel values between 2 and 5);

  - *New value*: set the new value for the old values defined in `Old value`; it must be an integer
    value;

- : add a row to the table;

- : remove highlighted rows from the table;

- : import rules from a text file .csv separated by comma having the following structure `Old_value,
  New_value` (where Old_value cam be also an expression and New_value is an integer value) for instance:

```
raster < 1,1
(raster > 1) & (raster < 3),2
raster < 3,3
```

- : export the reclassification table to a text file (.csv) that can be imported later;

Symbology

- *Use code from Signature list* : **if checked, color and class information are defined from** *ROI & Signature list* (

  - `MC ID`: use the ID of macroclasses;

  - `C ID`: use the ID of classes;

- *BATCH* : add this function to the *Batch* (page 101);

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

Zonal stat raster

- *Zonal stat raster* (page 92)
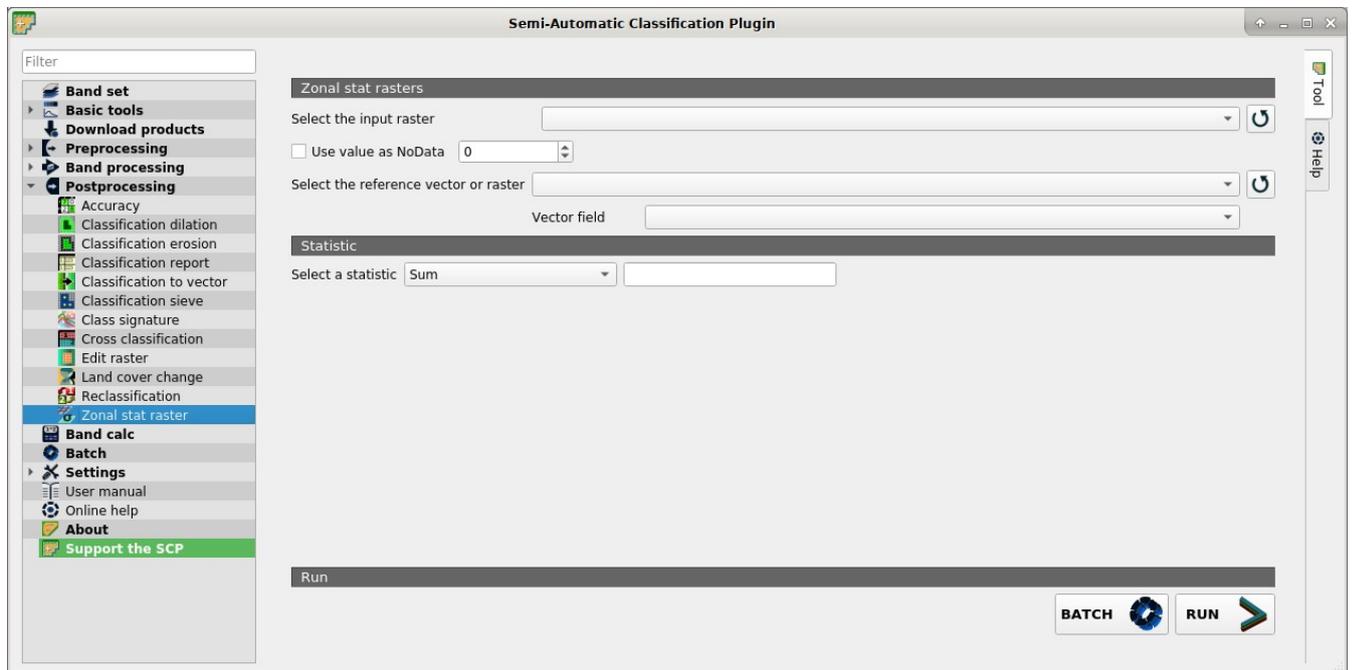
- *Statistic* (page 92)

Fig. 54: *Zonal stat raster*

This tab allows for calculating the statistics related to an input raster for every unique value of a reference vector or raster. For example, if a vector file contains a numeric field `zone`, this tool allows for calculating the mean value (for each zone) of input raster pixels.

Zonal stat raster

- *Select the input raster* [⌄]: select a raster (already loaded in QGIS);

- ↻ : refresh layer list;

- ☑ *Use value as NoData* [1⌄]: if checked, pixels having `NoData` value are excluded from the calculation;

- *Select the reference vector or raster* [⌄]: select a raster or a vector (already loaded in QGIS), used as reference layer for zones;

- ↻ : refresh layer list;

- *Vector field* [⌄]: if a vector is selected as reference, select a vector field containing numeric values;

Statistic

- *Select a statistic* [⌄] [T]: select a statistic; available options are `Sum`, `Max`, `Min`, `Count`, `Mean`, `Median`, `Percentile`, `StandardDeviation`; for `Percentile` a value can be entered;

- *BATCH* ⬤ : add this function to the *Batch* (page 101);

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

3.4.7 Band calc
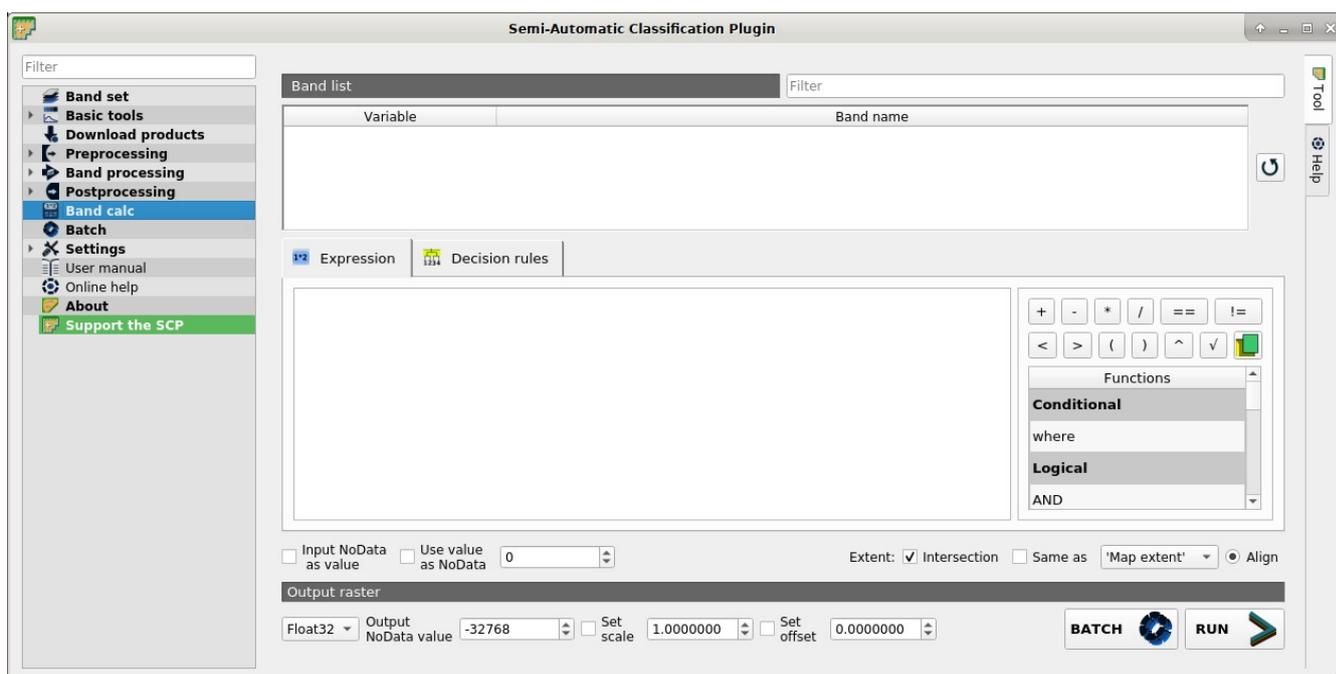
Fig. 55: *Band calc*

The `Band calc` allows for the **raster calculation for bands** (i.e. calculation of pixel values) using NumPy functions . `Band calc` can also work with multuple expression lines to perform multiple calculation at a time; several iteration functions are available for *Band sets* allowing to perform multitemporal calculations.

Raster bands must be already loaded in QGIS. Input rasters must be in the same projection.

In addition, a tool for **decision rules** is included.

Band list

- *Band list*: **table containing a list of single band rasters (already loaded in QGIS);**
    - *Filter* T : filter the list;
    - *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). Double click on any item in the *Band list* (page 94) for adding the name thereof to the expression.

If text color in the *Expression* is green, then the syntax is correct; if text color 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
```

- *Input NoData as value*: if checked, input `NoData` pixels are replaced by `NoData` value and accounted in calculation;

- *Use value as NoData* 1 : if checked, selected value is used as `NoData` during calculation;

- **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;

Input variables

The following variables related to the *Band set* (page 31) are available (please note that the character " is always required):

- *bandset#b BAND_NUMBER*: bands in the active *Band set* can be referenced directly; the following example refers to band 1 of the active *Band set*:

```
"bandset#b1"
```

- *bandset BANDSET_NUMBER* b *BAND_NUMBER*: bands in the *Band set* can be referenced directly; the following example refers to band 1 of the *Band set* 1:

```
"bandset1b1"
```

- *bandset{ BANDSET_NUMBER_LIST }b BAND_NUMBER*: list of all the bands X of all the *Band sets* matching a list between curly brackets (e.g. {1,2,3}) or range of *Band sets* separated by colon (e.g. {1:3}) or a list of ranges of *Band sets* (e.g. {1:3, 5:8}), which is equivalent to [bandset1bX, bandset2bX, ..., bandsetNbX]; this variable can be used in expressions that accept band lists such as the sum:

```
sum("bandset{1,3}b1")
```

- *bandset#b**: list of all the bands of active *Band set*, which is equivalent to [bandset#b1, bandset#b2, ..., bandset#bX]; to be used in expressions that accept band lists such as the maximum value:

```
max("bandset#b*")
```

- *bandset BANDSET_NUMBER* b*: list of all the bands of *Band set* N, which is equivalent to [bandsetNb1, bandsetNb2, ..., bandsetNbX]; to be used in expressions that accept band lists such as the minimum value:

```
min("bandset1b*")
```

- *bandset*b BAND_NUMBER*: list of all the bands X of all the *Band sets*, which is equivalent to [bandset1bX, bandset2bX, ..., bandsetNbX]; to be used in expressions that accept band lists such as the mean value:

```
mean("bandset*b1")
```

- *bandset{ DATE }b BAND_NUMBER*: list of all the bands X of all the *Band sets* matching a list of dates (format yyyy-mm-dd) between curly brackets (e.g. {2019-01-01,2019-07-31}) or range of dates separated by colon (e.g. {2019-01-01:2019-07-31}) or a list of ranges of dates (e.g. {2019-01-01:2019-01-31, 2019-04-01:2019-07-31}), which is equivalent to [bandset2bX, bandset5bX, ..., bandsetNbX]; *Band sets* dates are defined in *Band set definition* (page 32); this variable can be used in expressions that accept band lists such as the median value:

```
median("bandset{2019-01-01,2019-07-31}b1")
```

- *"#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; for example:

```
( "#NIR#" - "#RED#" ) / ( "#NIR#" + "#RED#" )
```

Output variables

Output names can be defined in the expression line entering the symbol @ followed by the name, such as the following example:

```
"raster1" * 2 @first_calculation
```

If the output name is defined in the expression, an output directory will be selected after clicking the button *RUN*.

> **WARNING**: It is recommended to avoid the use of characters # and @ in the output raster name.

It is possible to set the **output path** directly by defining the output name with this structure @path@name, such as:

```
"raster1" * 2 @/home/user@first_calculation
```

The directory will be created if it does not exist.

It is possible to create a **temporary output** (saved in the temporary directory) with @temp@ followed by output name, such as:

```
"raster1" * 2 @temp@first_calculation
```

The **output name** of calculation can be used **as input variable** for the following calculations; for example:

```
"raster1" * 2 @first_calculation
"first_calculation" + 5 @temp@second_calculation
"second_calculation" - "raster1" @/home/user@third_calculation
```

It is possible to **add the calculation result to a Band set** using the symbol % followed by the *Band set* number such as:

```
"raster1" @first_calculation%1
```

It is possible to **add the calculation result to the active Band set** using the symbol % followed by the symbol # such as:

```
"raster1" @first_calculation%#
```

Also, variables for output name are available:

- *#BANDSET#*: the name of the first band in the *Band set* (page 31);
- *#DATE#*: the current date and time (e.g. 20161110_113846527764);

Using the symbol @ followed by the variable #BANDSET# can save the raster calculation inside the **directory containing the first band** of the active band set, such as:

```
"raster1" @#BANDSET#@first_calculation
```

If the output name is defined with the extension .vrt, the output will be a **virtual raster** referencing the single .tif files calculated by parallel processing. For instance, the following expression will calculate the raster with parallel processing and the output will be a .vrt:

```
"raster1" @first_calculation.vrt
```

Virtual file is useful to reduce calculation time of parallel processing by avoiding the writing of the entire output raster.

> **WARNING**: a .vrt virtual file is a text file containing the reference to existing .tif files. Moving the .vrt virtual file or the .tif files in different directories can make the virtual file unusable.

Buttons

The following buttons are available:

- +: plus;

- -: minus;

- *: product;

- /: ratio;

- ==: equal;

- !=: not equal;

- <: less then;

- >: greater then;

- (: open parenthesis;

-): close parenthesis;

- ^: power;

- V: square-root;

- : open a text file (.txt) containing custom expressions to be listed in *Functions*; 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 *Functions*; 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
```

Functions

Conditional

- *where*: conditional expression according to the syntax `where( condition , value if true, value if false)` for example:

```
where("raster1" == 1, 2, "raster1")
```

Parenthesis are required for multiple conditions for instance to select pixel values between 1 and 3:

```
where( ("raster1" > 1) & ("raster1" < 3), 2, "raster1")
```

Nested conditions can be defined such as:

```
where( ("raster1" > 1) & ("raster1" < 3), 2, "raster1")
```

Logical

- *AND*: AND;

- *OR*: OR;

- *XOR*: XOR;

- *NOT*: NOT;

Statistics

A band list between square brackets or *Input variables* (page 94) are required arguments.

- *max*: maximum; for instance:

```
max(["raster1", "raster2", "raster3"])
```

- *min*: minimum; for instance:

```
min(["bandset#b*"])
```

- *mean*: mean; for instance:

```
mean("bandset*b1")
```

- *median*: median; for instance:

```
median("bandset{2019-01-01,2019-07-31}b1")
```

- *percentile*: percentile calculation; the expression must have this structure `percentile([band_list],` `percentile_value)`; for instance, the following expression calculates the 10th percentile of active band set:

```
percentile("bandset#b*", 10)
```

- *std*: standard deviation; for instance:

```
std("bandset{1,3}b1")
```

- *sum*: sum; for instance:

```
sum("bandset{1:5}b1")
```

Operations

- *sin*: sine; for instance:

```
sin("raster1")
```

- *cos*: cosine;
- *tan*: tangent;
- *asin*: inverse sine;
- *acos*: inverse cosine;
- *atan*: inverse tangent;
- *exp*: natural exponential;
- *ln*: natural logarithm;
- *log*: base 10 logarithm;

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
```

- *NBR*: if selected, the NBR calculation is entered in the *Expression*:

```
( "#NIR#" - "#SWIR2#" ) / ( "#NIR#" + "#SWIR2#" ) @NBR
```

Variables

- *nodata*: NoData value of raster (e.g. `nodata("raster1")`); it can be used as value in the expression:

```
where("raster1" == nodata("raster1"), 0, "raster1")
```

- *forbandsets*: it allows for the iteration over *Band sets* defined between square brackets; a range of *Band sets* separated by colon (e.g. `forbandsets[1:3]`) or a list separated by commas (e.g. `forbandsets[1, 2,3]`; `forbandsets` must be entered in the first line of expressions (not compatible with `forbsdates` or `forbandsinbandset`), for instance:

```
forbandsets[1:3]
"bandset#b1" @#BANDSET#
```

During the iteration, the *Input variables* (page 94) related to the active *Band set* are replaced by the iterator, therefore the expression:

```
forbandsets[1:3]
"bandset#b1" @#BANDSET#
```

is equivalent to:

```
"bandset1b1" @calc1
"bandset2b1" @calc2
"bandset3b1" @calc3
```

It is possible to enter a string (or a list of strings separated by comma `,`) after the square bracket `]` to filter *Band sets* by the name of first band in *Band set*; for instance, the following expression will iterate the first 3 *Band sets* selecting only the *Band set* whose name of the first band includes `RT`:

```
forbandsets[1,2,3]RT
```

- *forbsdates*: it allows for the iteration over *Band sets* dates (format yyyy-mm-dd, defined in *Band set definition* (page 32)) between square brackets; `forbsdates` must be entered in the first line of expressions (not compatible with `forbandsets` or `forbandsinbandset`) such as the following examples:

Iterating over a range of dates:

```
forbsdates[2020-01-01:2020-07-31]
"bandset#b1" @#BANDSET#
```

Iterating over a list of dates:

```
forbsdates[2020-02-01,2020-03-11,2020-04-21]
"bandset#b1" @#BANDSET#
```

Iterating over a list of ranges of dates:

```
forbsdates[2010-01-01:2010-06-31, 2010-08-01:2010-08-31, 2010-10-01:2010-12-31]
"bandset#b1" @#BANDSET#
```

During the iteration, the *Input variables* (page 94) related to the active *Band set* are replaced by the iterator.

It is possible to enter a string (or a list of strings separated by comma `,`) after the square bracket `]` to filter *Band sets* by the name of first band in *Band set*; for instance, the following expression will iterate the *Band sets* in the range selecting only the *Band set* whose name of the first band includes `RT`:

```
forbsdates[2020-01-01:2020-07-31]RT
```

- *forbandsinbandset*: it allows for the iteration over bands in a *Band set* or a range of *Band sets* between square brackets; `forbandsinbandset` must be entered in the first line of expressions (not compatible with `forbandsets` or `forbsdates`); the variable #BAND# must be used to refer to the iterated band such as the following examples:

Iterating over the bands of the first *Band set* (note the `"` in the expression):

```
forbandsinbandset[1]
where("#BAND#" > 1, 1, 2) @#BAND#)
```

Iterating over all the bands of *Band sets* from 1 to 3:

```
forbandsinbandset[1:3]
where("#BAND#" > 1, 1, 2) @#BAND#)
```

- *#BAND#*:
- *!function!*: it allows for using a *Batch* (page 102) function inside Band calc; !function! must be followed by a Batch command to execute a function using raster names (also using *Output variables* (page 95)) in the command; the special variable `!directory!` can be used in the Batch command to refer to the output directory (defined after clicking the button *RUN*); the special variable `!file!` can be used in the Batch command to refer to the relative output file name (defined with @ after the command) respectively ; it is required to use the section character `$` instead of apostrophe `'` and `!!` instead of `;` for functions; for instance:

```
!function! add_raster!!input_raster_name : $#NIR#$!!band_set : 1

!function! stack_raster_bands!!band_set : 1!!output_raster_path : $!directory!$
```

- *#BANDSET#*: the name of the first band in the *Band set* (page 31);
- *#DATE#*: the current date and time (e.g. 20161110_113846527764);
- @: charcter @;

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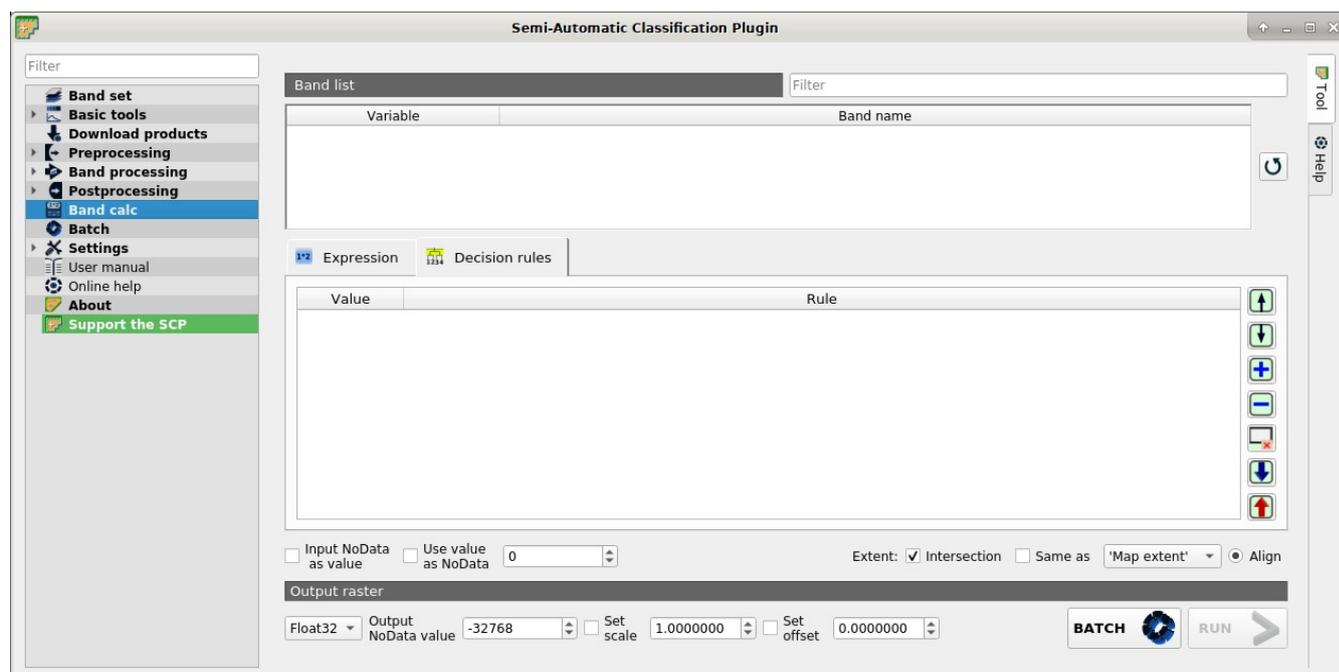
Decision rules allows for the calculation of an output raster based on rules. Rules are conditional statements based on other rasters; if the *Rule* is true, the corresponding *Value* is assigned to the output pixel.

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;

- : import rules from a text file;

- : export the rules to a text file that can be imported later;

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.

> **WARNING**: if multiple lines are entered in Expression or output name are defined in line, a directory selection instead of a file selection is prompted for output.

- *Float32* : option to select output raster type as Float32 (default), Int32, Int16, UInt32, UInt16, Byte;

- *Output NoData* : set the value of `NoData` pixels in output raster;

- *Set scale* : if checked, set a scale in output raster (and output values are divided by scale);

- *Set offset* : if checked, set an offset in output raster (and offset is subtracted to output values);

- *BATCH* : add this function to the *Batch* (page 101);

- *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

    - *Band set* (page 103)

    - *Band calculation* (page 103)

    - *Preprocessing* (page 104)

    - *Band processing* (page 105)

    - *Post processing* (page 106)

    - *Variables* (page 107)

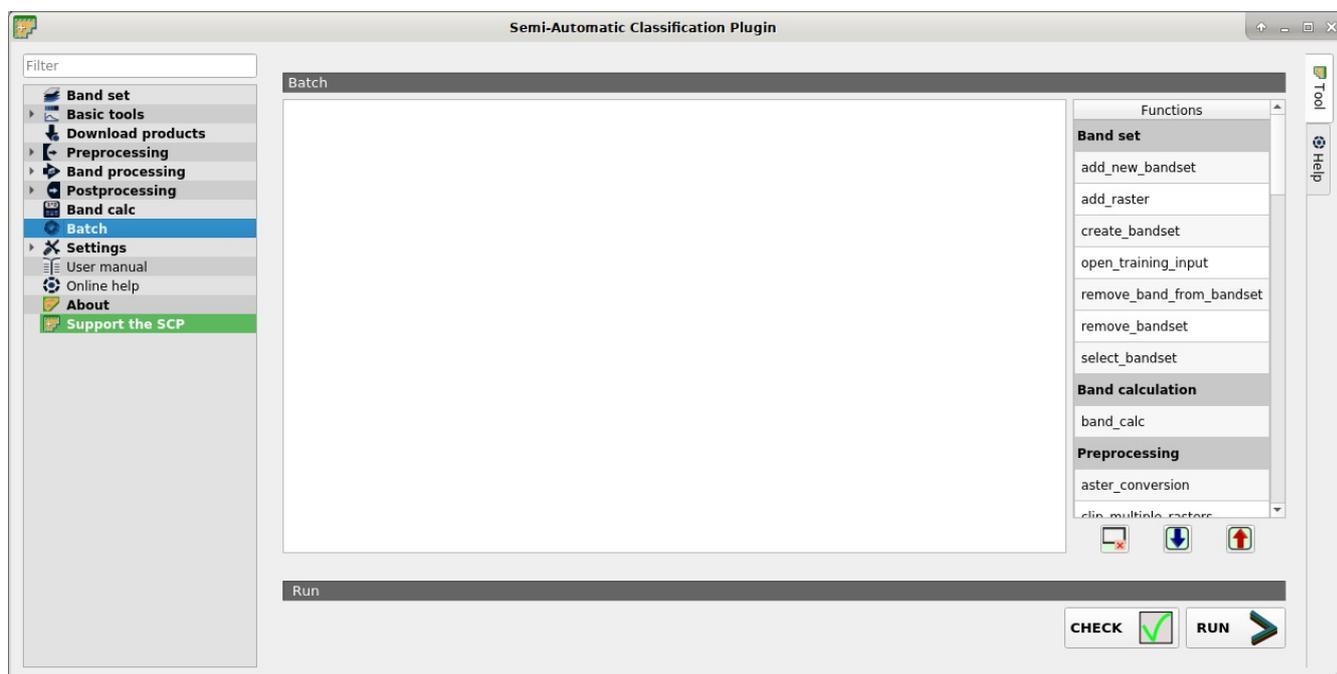   - *QGIS Processing* (page 109)

    - *Run* (page 110)

Fig. 56: *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 `,` .

- : clear the expression;

- : export the batch expression to a file;

- : import a previously saved batch expression from file;

A panel *Functions* is displayed at the right side; double click to insert a function in the expression; the following functions are available with the corresponding options:

Band set

- *add_new_bandset*: add a new empty band set; optionally it is possible to specify the position of the added band set (e.g. band_set : 1):

```
add_new_bandset;band_set : 1
```

- *add_raster*: add a raster to QGIS, and optionally to an existing band set defining the wavelength:

```
add_raster;input_raster_path : '';input_raster_name : '';band_set : 1;center_
↪wavelength : 1
```

- *create_bandset*: create a *Band set* assigning bands; it is possible to enter the satellite name as `center_wavelength` option (satellite name as displayed in *Wavelength quick settings* e.g. `center_wavelength : 'sentinel-2'` or `center_wavelength : 'landsat 8'`) to set the corresponding band wavelength center automatically for all the bands; `raster_path_list` option accepts a directory and a file name filter separated by comma (e.g. `raster_path_list : '/home/user, tif'`) to load all the raster inside the directory:

```
create_bandset;raster_path_list : '';center_wavelength : '';wavelength_unit :␣
↪1;multiplicative_factor : '';additive_factor : '';date : ''
```

- *open_training_input*: open a training input file:

```
open_training_input;training_file_path : ''
```

- *remove_band_from_bandset*: remove a list band from band set by the number thereof (e.g. `remove_band_from_bandset;band_set : 1;band_list : '1, 2'`):

```
remove_band_from_bandset;band_set : 1;band_list : ''
```

- *remove_bandset*: remove a band set by the number thereof:

```
remove_bandset;band_set : 1
```

- *select_bandset*: select a band set (*active band set*) by the number thereof:

```
select_bandset;band_set : 1
```

Band calculation

- *Band calc* (page 93): band calculation:

```
band_calc;expression : '';output_raster_path : '';extent_same_as_raster_name :
↪'';align : 1;extent_intersection : 1;input_nodata_as_value : 0;use_value_
↪nodata : 0;output_nodata_value : -32768;data_type : 'Float32';scale_value :
↪1;offset_value : 0;band_set : 1
```

Preprocessing

- *ASTER* (page 50): 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_set
↪: 1
```

- *Clip multiple rasters* (page 62): clip multiple rasters:

```
clip_multiple_rasters;band_set : 1;output_dir : '';use_vector : 0;vector_path
↪: '';use_vector_field : 0;vector_field : '';ul_x : '';ul_y : '';lr_x : '';lr_
↪y : '';nodata_value : 0;output_name_prefix : 'clip'
```

- *Cloud masking* (page 63): 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 : ''
```

- *GOES* (page 52): GOES conversion:

```
goes_conversion;input_dir : '';use_nodata : 1;nodata_value : 0;create_bandset
↪: 1;output_dir : '';band_set : 1
```

- *Landsat* (page 53): 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 : '';band_set : 1
```

- *MODIS* (page 55): MODIS conversion:

```
modis_conversion;input_raster_path : '';reproject_wgs84 : 1;use_nodata : 1;
↪nodata_value : -999;create_bandset : 1;output_dir : '';band_set : 1
```

- *Mosaic band sets* (page 65): mosaic band sets:

```
mosaic_bandsets;band_set_list : '';output_dir : '';output_name_prefix : 'mosaic
↪'
```

- *Neighbor pixels* (page 65): neighbor pixels:

```
neighbor_pixels;band_set : 1;matrix_size : 1;matrix_file_path : '';output_name_
↪prefix : 'neighbor';statistic : 'sum';stat_value : 50;output_dir : ''
```

- *Reproject raster bands* (page 67): reproject raster bands:

```
reproject_raster_bands;band_set : 1;output_dir : '';align_raster_path : '';
↪same_extent_reference : 0;epsg : '';x_resolution : '';y_resolution : '';
↪resample_pixel_factor : '';resampling_method : 'near';output_nodata_value : -
↪32768;data_type : 'auto';output_name_prefix : 'reproj'
```

- *Sentinel-1* (page 57): Sentinel-1 conversion:

```
sentinel1_conversion;input_raster_path : '';xml_file_path : '';vh : 1;vv : 1;
↪raster_project : 0;raster_projections_band_set : 1;convert_to_db : 1;use_
↪nodata : 1;nodata_value : 0;create_bandset : 1;output_dir : '';band_set : 1
```

- *Sentinel-2* (page 59): Sentinel-2 conversion:

```
sentinel2_conversion;input_dir : '';mtd_safl1c_file_path : '';apply_dos1 : 0;
↪preprocess_bands_1_9_10 : 0;use_nodata : 1;nodata_value : 0;create_bandset :␣
↪1;output_dir : '';band_set : 1
```

- *Sentinel-3* (page 60): Sentinel-3 conversion:

```
sentinel3_conversion;input_dir : '';apply_dos1 : 0;use_nodata : 1;nodata_value␣
↪: 0;create_bandset : 1;output_dir : '';band_set : 1
```

- *Vector to raster* (page 70): 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 : ''
```

- *Split raster bands* (page 68): split raster to single bands:

```
split_raster_bands;input_raster_path : '';output_dir : '';output_name_prefix :
↪'split'
```

- *Stack raster bands* (page 69): stack rasters into a single file:

```
stack_raster_bands;band_set : 1;output_raster_path : ''
```

Band processing

- *Band combination* (page 71): band combination:

```
band_combination;band_set : 1;output_raster_path : ''
```

- *Classification* (page 72): perform classification:

```
classification;band_set : 1;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 : ''
```

- *Clustering* (page 75): 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 : ''
```

- *PCA* (page 76): Principal Component Analysis:

```
pca;band_set : 1;use_number_of_components : 0;number_of_components : 2;use_
↪nodata : 1;nodata_value : 0;output_dir : ''
```

- *Random Forest* (page 77): Random Forest classification:

```
random_forest;band_set : 1;use_macroclass : 1;number_training_samples : 5000;
↪number_trees : 10;evaluate_classifier : 0;evaluate_feature_power_set : 0;min_
↪power : 2;max_power : 7;save_classifier : 0;classifier_file_path : '';output_
↪classification_path : ''
```

- *Spectral distance* (page 78): 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_raster_path : ''
```

Post processing

- *Accuracy* (page 79): calculate accuracy:

```
accuracy;classification_file_path : '';reference_file_path : '';vector_field_
↪name : '';output_raster_path : '';use_value_nodata : 0
```

- *Class signature* (page 85): class signature:

```
class_signature;input_raster_path : '';band_set : 1;save_signatures : 1;output_
↪text_path : ''
```

- *Classification dilation* (page 80): dilation of a classification:

```
classification_dilation;input_raster_path : '';class_values : '';size_in_
↪pixels : 1;pixel_connection : 4;output_raster_path : ''
```

- *Classification erosion* (page 81): erosion of a classification:

```
classification_erosion;input_raster_path : '';class_values : '';size_in_pixels␣
↪: 1;pixel_connection : 4;output_raster_path : ''
```

- *Classification report* (page 82): 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 83): convert classification to vector:

```
classification_to_vector;input_raster_path : '';use_signature_list_code : 0;
↪code_field : 'C_ID';dissolve_output : 0;output_vector_path : ''
```

- *Cross classification* (page 86): cross classification:

```
cross_classification;classification_file_path : '';use_nodata : 0;nodata_value␣
↪: 0;reference_file_path : '';vector_field_name : '';output_raster_path : ''
```

- *Edit raster* (page 87): edit raster values using a vector:

```
edit_raster_using_vector;input_raster_path : '';input_vector_path : '';vector_
↪field_name : '';constant_value : 0;expression :  'where(raster == 1, 2,␣
↪raster)'
```

- *Land cover change* (page 89): calculate land cover change:

```
land_cover_change;reference_raster_path : '';new_raster_path : '';output_
↪raster_path : ''
```

- *Reclassification* (page 90): raster reclassification:

```
reclassification;input_raster_path : '';value_list : 'oldVal_newVal,oldVal_
↪newVal';use_signature_list_code : 1;code_field : 'MC_ID';output_raster_path␣
↪: ''
```

- *Zonal stat raster* (page 91): calculate zonal statistics related to an input raster:

```
zonal_stat_raster;input_raster_path : '';reference_file_path : '';use_nodata :␣
↪0;nodata_value : 0;vector_field_name : '';statistic : 'sum';stat_value : 50;
↪output_raster_path : ''
```

Variables

Working directory

- *!working_dir!*: 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';input_nodata_as_value : 1;use_value_nodata : 0
band_calc;expression : '"raster1.tif" * "calc1.tif"';output_raster_path : '!
↪working_dir!/calc2.tif';extent_intersection : 0
```

Iterate directories

- *!for_directory_in!*: function to iterate commands for all the directories in a directory path (e.g. `!for_directory_in!;'directoryPath'`):

```
!for_directory_in!;''
```

The variables !directory_name! can be used to reference the current directory name and !directory! for the current directory path.

The iterated commands must terminate with a line `!end_for_directory!`; for instance the following script performs Sentinel-2 conversion of all the subdirectories of `/home/user/`:

```
!for_directory_in!;'/home/user/'
sentinel2_conversion;input_dir : '!directory!';create_bandset : 1;output_dir : '!
↪directory!_converted'
!end_for_directory!
```

Optionally a filter (i.e. only directories matching the filter will be processed) can be defined for the subdirectory level; the following examples stop the iteration at level 2:

```
!for_directory_in!;'/home/user/';2
```

A name filter can be set; for instance the following script creates a band set for every subdirectory having `rt` in the name:

```
!for_directory_in!;'/home/user/';'rt'
add_new_bandset;
```

(continues on next page)

```
create_bandset;raster_path_list : '!directory!, tif';center_wavelength : 'landsat 8
↪';
!end_for_directory!
```

Multiple name filters can be set separated by character | such as:

```
!for_directory_in!;'/home/user/';3;'name1|name2')
```

It is possible to filter by date if the directory name ends with a date (format yyyy-mm-dd) using a range separated by colon:

```
!for_directory_in!;'/home/user/';2020-01-01:2020-03-31
sentinel2_conversion;input_dir : '!directory!';create_bandset : 1;output_dir : '!
↪directory!_converted'
!end_for_directory!
```

- *!directory!*: variable to be used with `!for_directory_in!` to reference current directory path:

    ```
    !directory!
    ```

- *!directory_name!*: variable to be used with `!for_directory_in!` to reference current directory name:

    ```
    !directory_name!
    ```

- *!end_for_directory!*: ending line to be used with `!for_directory_in!` to close the iterative commands:

    ```
    !end_for_directory!
    ```

Iterate files

- *!for_file_in!*: function to iterate commands for all the files in a directory path (e.g. `!for_file_in!; 'directoryPath'`):

    ```
    !for_file_in!;''
    ```

The variable !file! can be used to reference the current file path.

The iterated commands must terminate with a line `!end_for_file!`, for instance:

```
!for_file_in!;'/home/user/'
create_bandset;raster_path_list : '!file!';
!end_for_file!
```

Optionally a filter (i.e. only directories matching the filter will be processed) can be defined for the subdirectory level; the following examples stop the iteration at level 0:

```
!for_file_in!;'/home/user/';0
```

Also, a file name filter can be defined:

```
!for_file_in!;'/home/user/';0;'tif'
```

Multiple name filters can be set separated by character | such as:

```
!for_file_in!;'/home/user/';0;'jp2|tif'
```

It is possible to filter by date if the file name ends with a date (format yyyy-mm-dd) using a range:

```
!for_file_in!;'/home/user/';2020-01-01:2020-03-31
```

Also !file_directory! can be used to refer to the parent directory of the file.

- *!file!*: variable to be used with `!for_file_in!` to reference current file path:

```
!file!
```

- *!file_directory!*: variable to be used with `!for_file_in!` to reference the directory containing current file path:

```
!file_directory!
```

- *!end_for_file!*: ending line to be used with `!for_file_in!` to close the iterative commands:

```
!end_for_file!
```

Iterate band sets

- *!for_band_set!*: function to iterate commands for all the band sets in a range (e.g. `!for_band_set!;` `bandsetNumbers`):

```
!for_band_set!;''
```

It is possible to enter a list of numbers (separated by commas), a range separated by colon, or a list of ranges, for instance:

```
!start_for_band_set!;'2:3'
add_new_bandset;band_set : !bandset_number!
!end_for_band_set!
```

- *!bandset_number!*: variable to be used with `!for_band_set!` to reference band set number;

- *!end_for_band_set!*: ending line to be used with `!for_band_set!`;

Custom variables

- *!customVariableName!*:   it is possible to create custom variables entering a line such as `!customVariableName! = value` (value can be either number or text), that will be replaced in the following parts of the batch script (the variable name cannot be any of the program Batch variables); for instance:

```
!number! = 20
!path_to_file! = /home/file.tif
add_new_bandset;band_set : !number!
band_combination;band_set : 1;output_raster_path : '!path_to_file!'
```

Temporary output

- *!temp_raster_1!*: create a temporary raster path (saved in the temporary directory) to be used with other functions:

```
!temp_raster_1!
```

`!temp_raster_1!` can be used as temporary output for other functions such as:

```
band_calc;expression : '"raster1"';output_raster_path : '!temp_raster_1!'
```

Additional temporary output can be entered manually, replacing `1` with any number or string (e.g. !temp_raster_2! or !temp_raster_calculation!). The actual raster name will be the string between ! , for instance temp_raster_1 is the raster name of variable `!temp_raster_1!`.

QGIS Processing

- *qgis_processing*: use a QGIS Processing algorithm entering a command (algorithm name) and parameters (without brackets) as described in the QGIS console

---

```
qgis_processing;command : '';parameters : '';load_results : 1
```

For instance the following command executes GRASS vector dissolve:

```
qgis_processing;command : 'grass7:v.dissolve';parameters : 'input': '/home/user/
↪vector.shp','column':'DN','output':'/home/user/output_vector.shp','GRASS_OUTPUT_
↪TYPE_PARAMETER':0
```

It is possible to use the Batch *Variables* (page 107) for setting input or output paths.

Run

- *CHECK* ✅ : check if expression syntax is correct; if expression is correct then the text color is green, red otherwise; in case of error, a label is displayed with a brief description of the error;

- *RUN* ⫸ : check if expression syntax is correct and start the batch processes;

3.4.9 Settings

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

Debug

- *Log file* (page 111)

- *Test* (page 111)
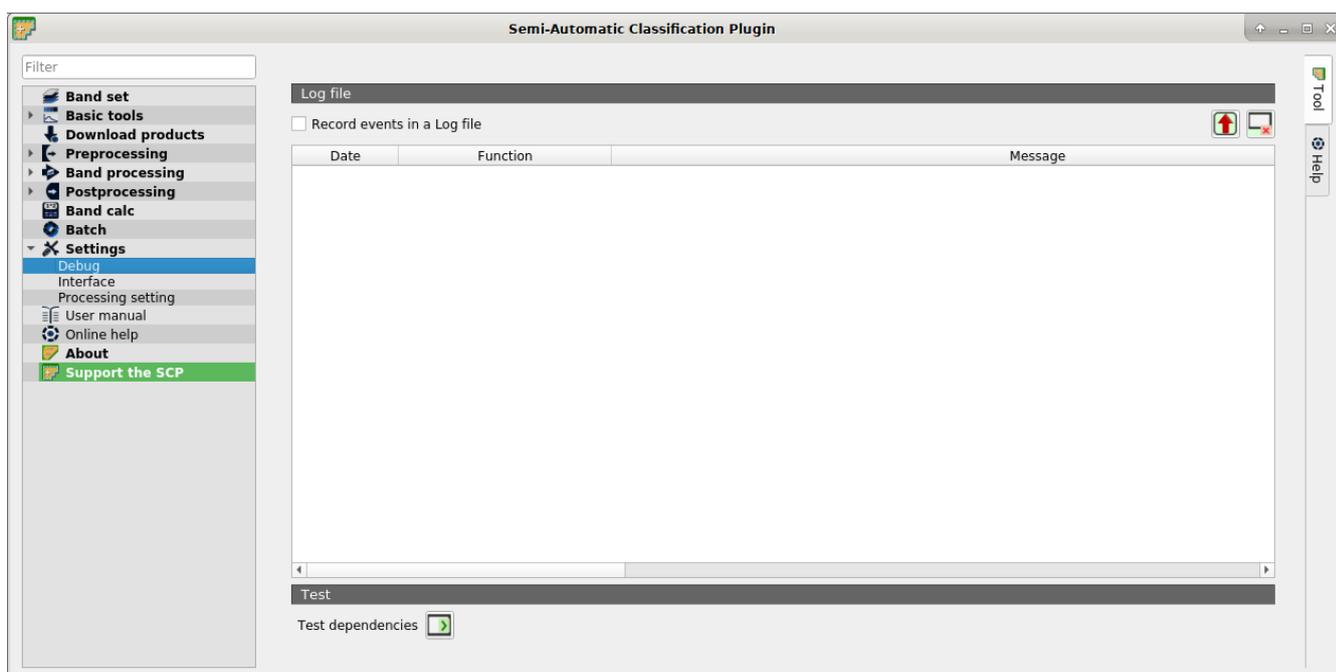
Fig. 57: *Debug*

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 214) .

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;

Test

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

Interface

Customization of the interface.

Field names of training input

Set the names of fields in the *Training input* (page 23) . Changing field names should usually be avoided.

- *MC ID field* T 🟢 : name of the Macroclass ID field (default is MC_ID);

- *MC Name field* T 🟢 : name of the Macroclass Name field (default is MC_info);

- *C ID field* T 🟢 : name of the Class ID field (default is C_ID);

- *C Name field* T 🟢 : name of the Class Name field (default is C_info);

- ❌: reset field names to default;
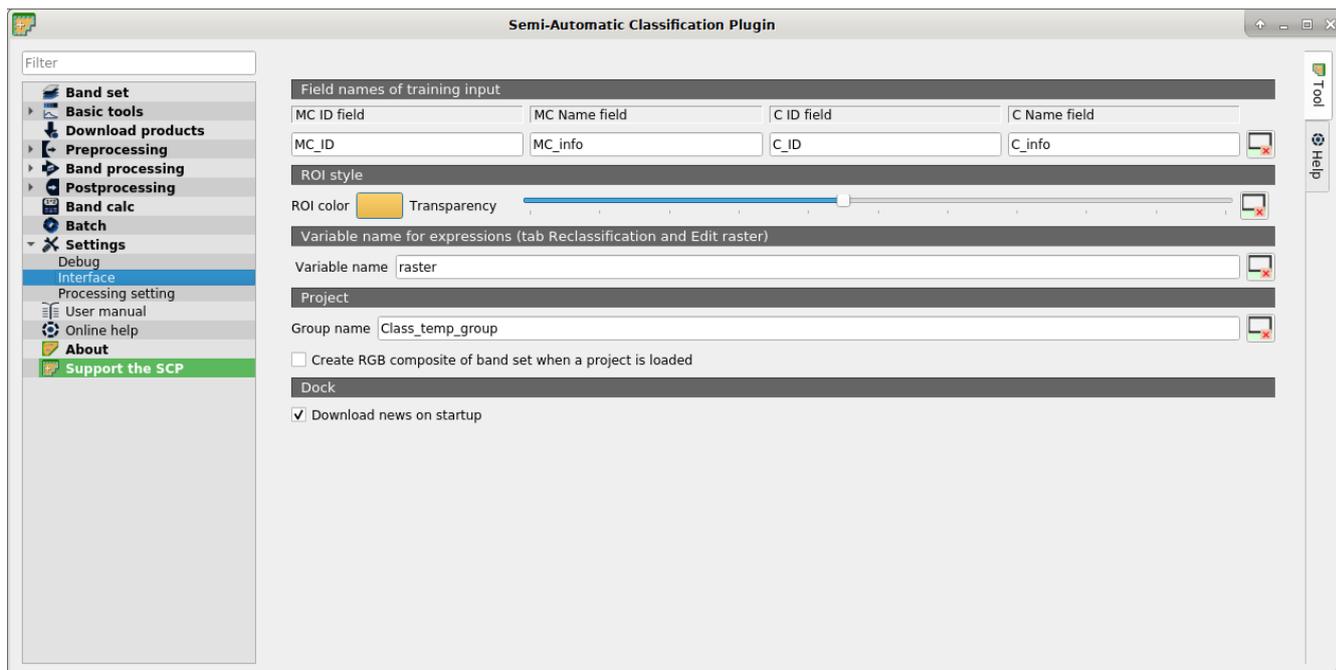
Fig. 58: *Interface*

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 90) and *Edit raster* (page 87) .

- *Variable name* T ● : 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* T ● : set group name (default is `Class_temp_group`);

- : reset group name to default;

- *Create RGB composite of band set when a project is loaded* ● : if checked, a RGB composite of active band set is added to the map when a project is loaded;

Dock

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

Processing

- *System* (page 113)
- *Classification process* (page 114)
- *SMTP process notification* (page 114)
- *External programs* (page 114)
- *Temporary directory* (page 114)
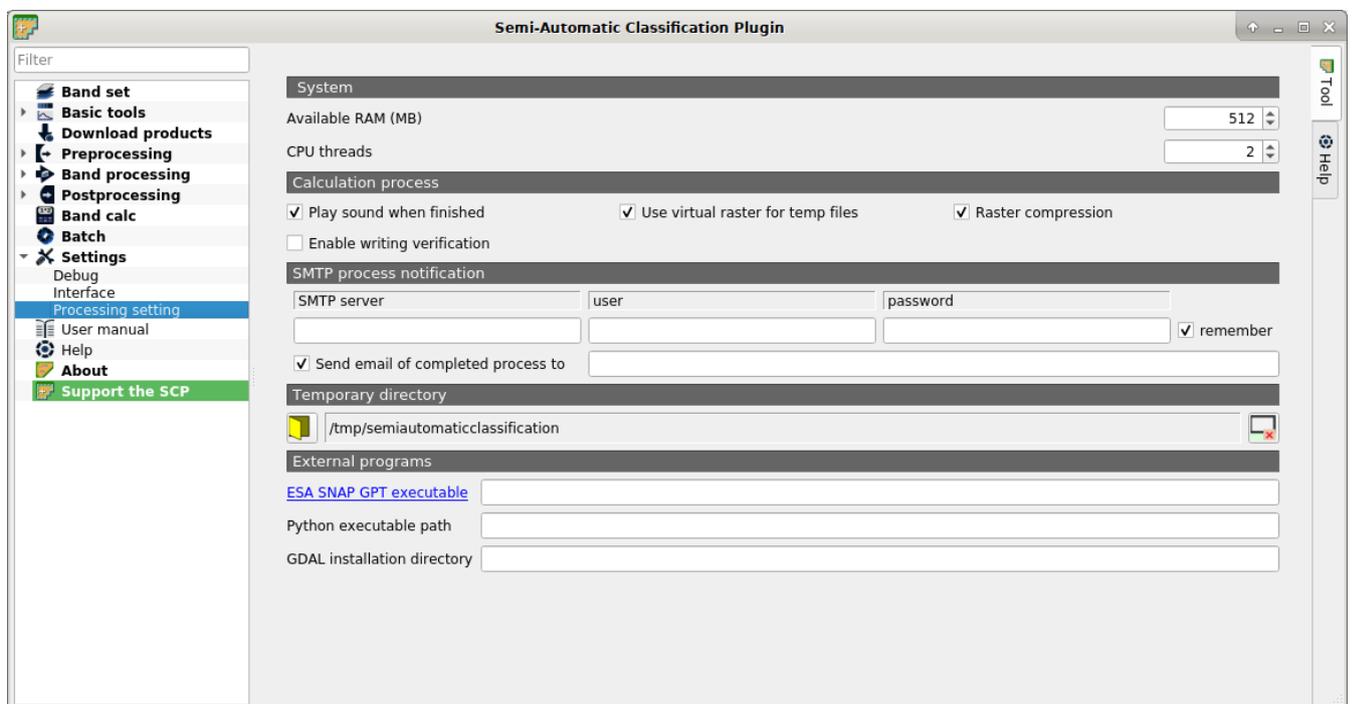
Fig. 59: *Processing*

System

- *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;

- *CPU threads* 🔢 🟢 : set the number of threads available for processing; it is recommended to set a value lower than the maximum number of system threads (e.g. if the system has 4 available threads set value 3);

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

3.4. Main Interface Window

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;

- *Enable writing verification* : if checked, the output raster is compared to output calculation in order to avoid writing errors; it can slow the process;

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;

External programs

Some SCP tools require external programs to perform the processing.

- *ESA SNAP GPT executable* : enter the path to the SNAP gpt executable; usually `C:/snap/bin/gpt.exe` for Windows, `/Applications/snap/bin/gpt` for Mac, and `/usr/local/snap/bin/gpt` for Linux; for the installation of ESA SNAP, please visit this page http://step.esa.int/main/download/snap-download/ ;

- *Python executable path* : enter the path to the Python 3 executable (e.g. `/usr/local/bin/python3`); should be used only in case of issues with multiprocessing;

- *GDAL installation directory* : enter the path to the GDAL directory containing tools such as gdal_translate and gdalwarp (e.g. `/usr/bin`); should be used only in case of issues with GDAL processing;

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;

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 31)). Signatures can be added to the `Spectral Signature Plot` through the *SCP dock* (page 20).

The window *Spectral Signature Plot* includes also some functions useful for the definition of value ranges used by the *Land Cover Signature Classification* (page 141) (see *LCS threshold* (page 39)).

Overlapping signatures (belonging to different classes or macroclasses) are highlighted in orange in the table *Plot Signature list* (page 115); the overlapping check is performed considering *MC ID* or *C ID* according to the setting *Use* *MC ID* *C ID* in *Algorithm* (page 73). Overlapping signatures sharing the same *ID* are not highlighted.
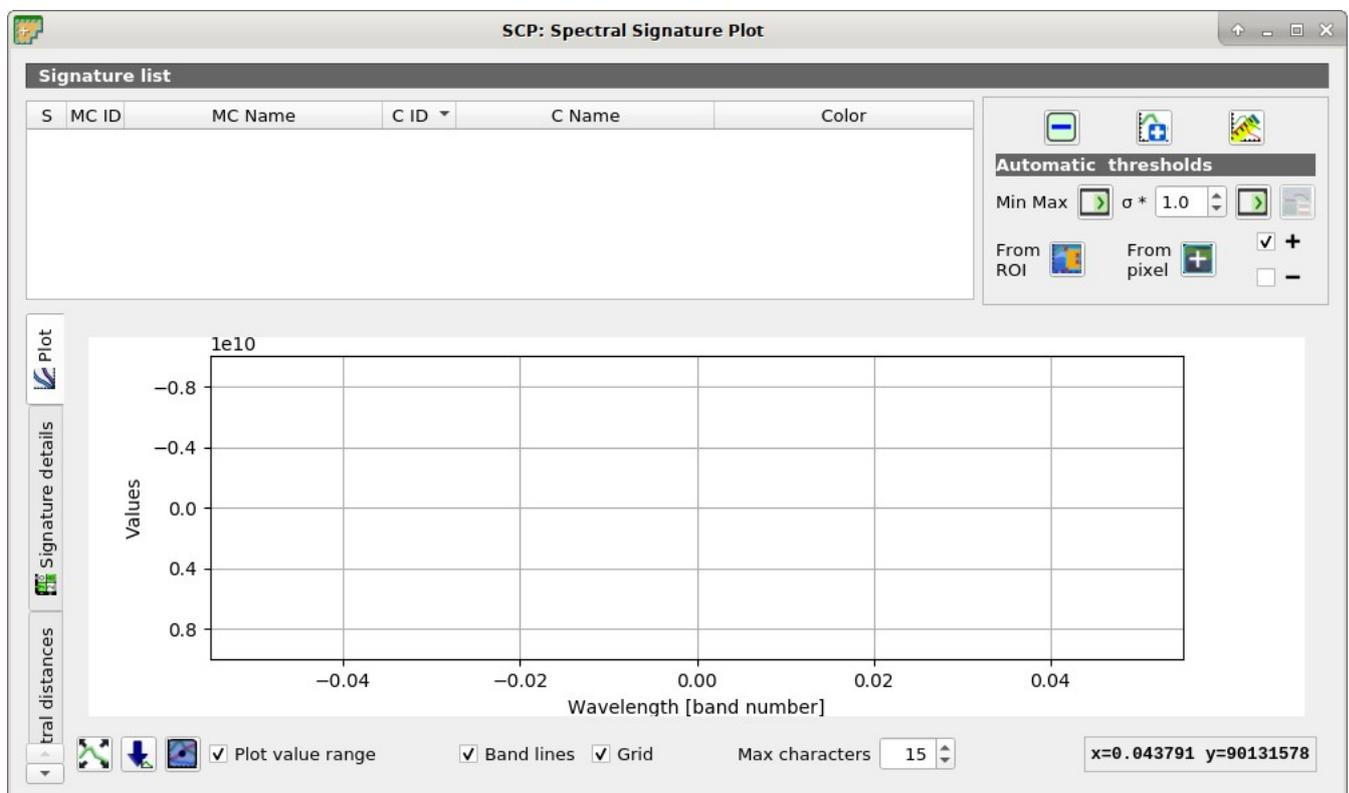
Fig. 60: *Spectral Signature Plot*

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;

    – *MC Name*: signature Macroclass Name;

    – *C ID*: signature Class ID;

> – *C Name*: signature Class Name;
>
> – *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 141));
>
> – *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 24);

- : calculate the spectral distances of spectral signatures displayed in the plot; distances are reported in the tab *Spectral distances* (page 117);

Automatic thresholds

Set thresholds automatically for highlighted signatures in the table *Plot Signature list* (page 115); 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;

- σ * : set an automatic threshold calculated as (band value + (σ * v)), where σ 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;
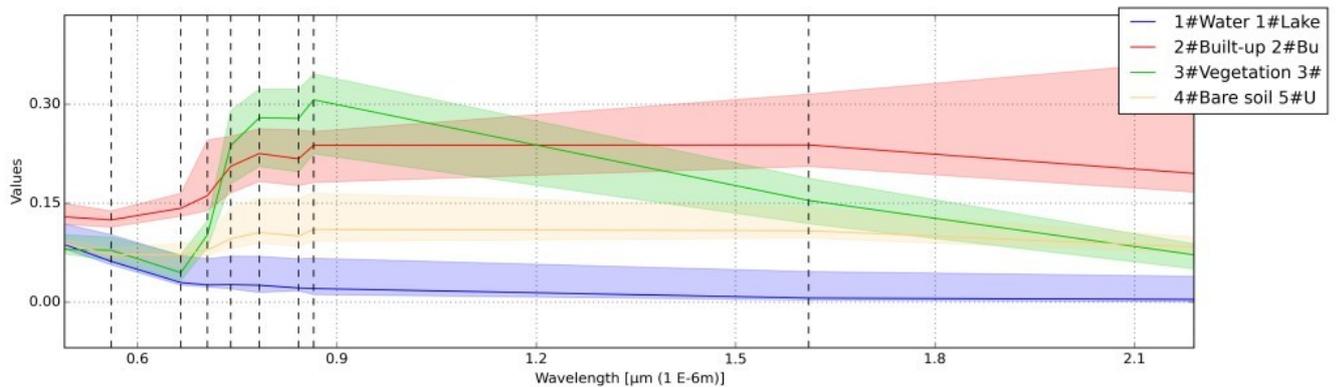
Fig. 61: *Spectral Signature: Example of spectral signature plot*

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 115)), which are useful for assessing ROI separability (see *Spectral Distance* (page 143)).

The following spectral distances are calculated :

- *Jeffries-Matusita Distance* (page 143): range [0 = identical, 2 = different]; useful in particular for *Maximum Likelihood* (page 138) classifications;

- *Spectral Angle* (page 144): range [0 = identical, 90 = different]; useful in particular for *Spectral Angle Mapping* (page 139) classifications;

- *Euclidean Distance* (page 144): useful in particular for *Minimum Distance* (page 137) classifications;

- *Bray-Curtis Similarity* (page 144): range [0 = different, 100 = identical]; useful in general;

Values are displayed in red if signatures are particularly similar.
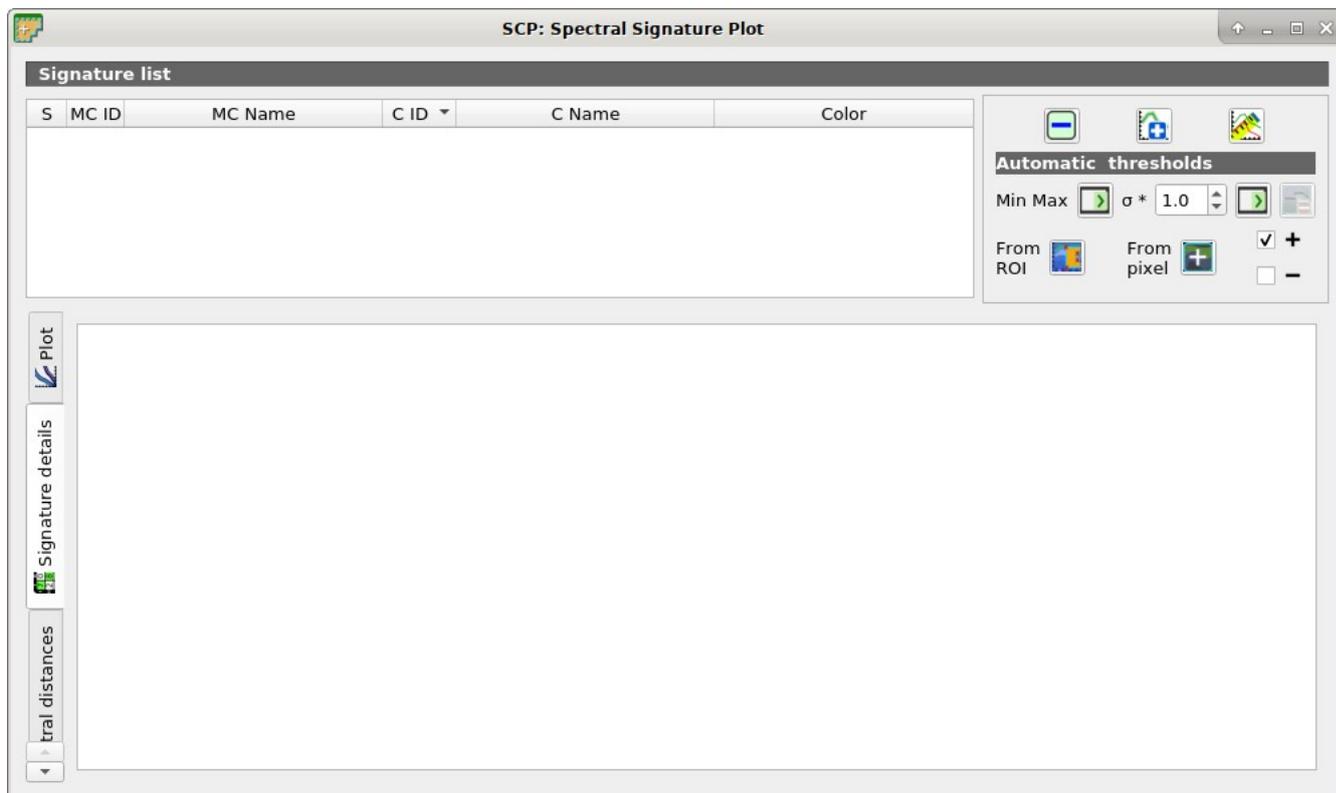
Fig. 62: *Spectral Signature: Signature details*

Fig. 63: *Spectral Signature: Example of signature details*
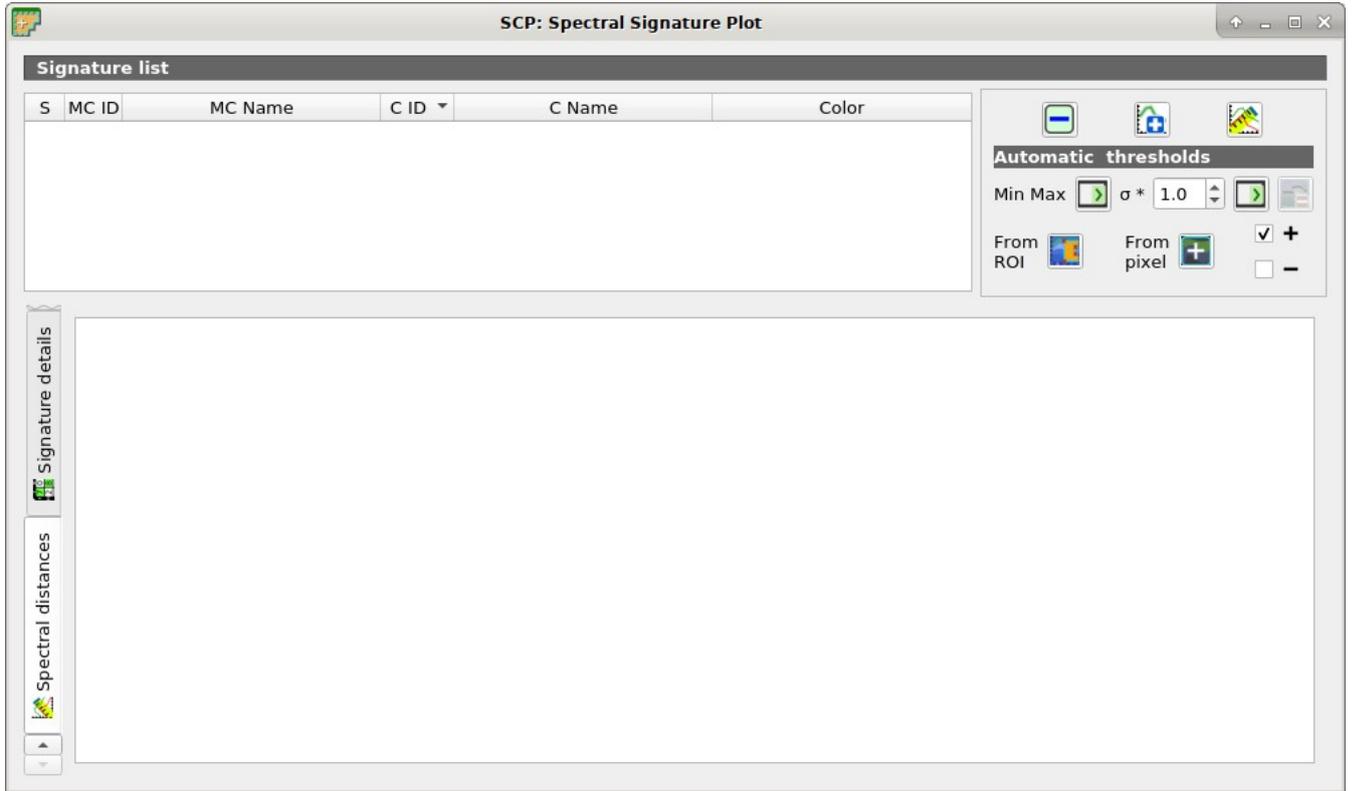
Fig. 64: *Spectral Signature: Spectral distances*

Fig. 65: *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.
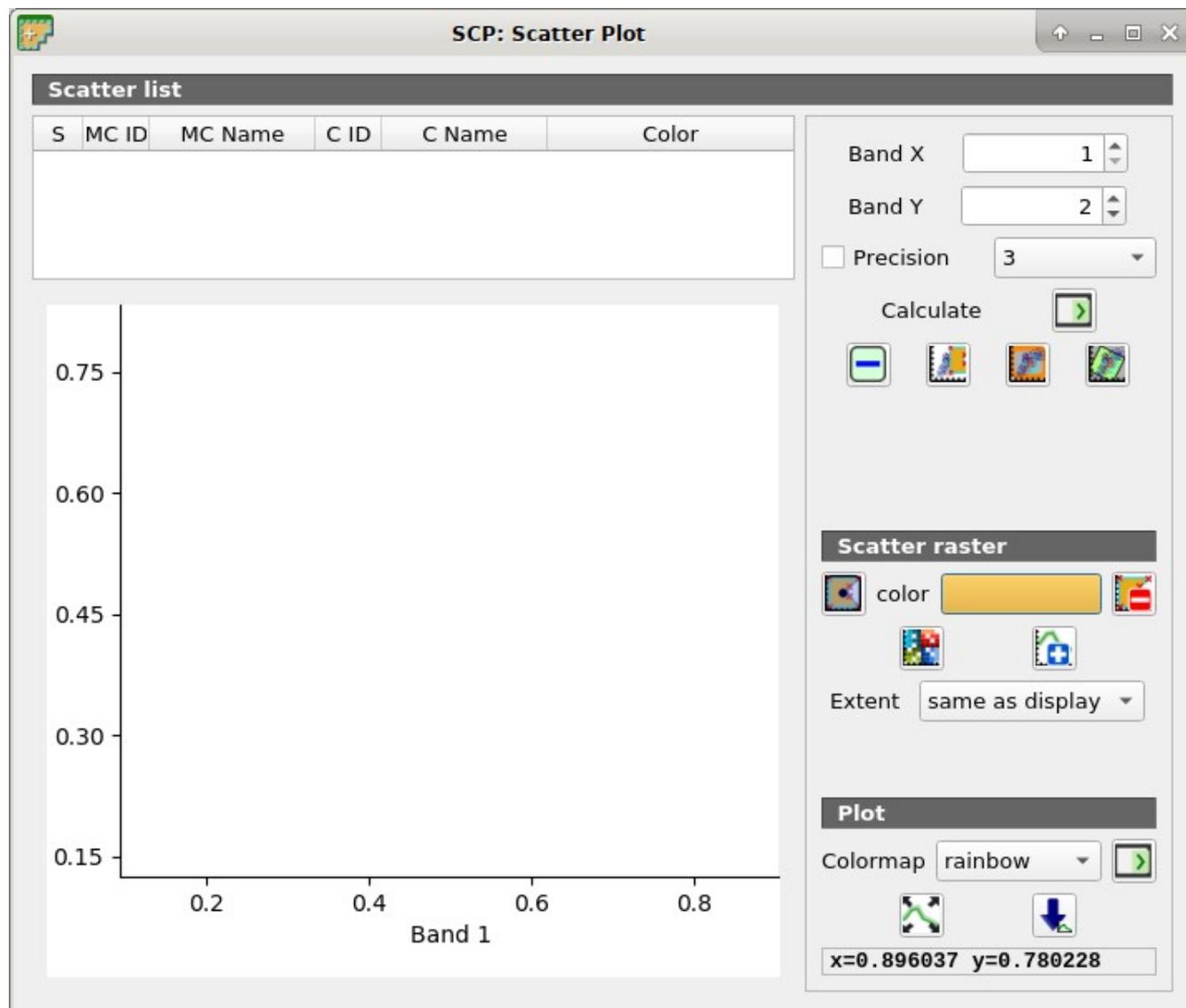

Fig. 66: *Scatter Plot*

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 Name*: signature Macroclass Name;

    - *C ID*: signature Class ID;

    - *C Name*: signature Class Name;

- *Color*: color field; double click to select a color for the plot;

- *Band X* 1◇ : X band of the plot;

- *Band Y* 1◇ : 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 Name = tempScatter`) and start the plot calculation of the last temporary ROI (see *Working toolbar* (page 29));

- : add a temporary scatter plot to the list (as `MC Name = tempScatter`) and start the plot calculation of pixels in current display extent;

- : add a temporary scatter plot to the list (as `MC Name = 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 112)) 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 24);

- *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);

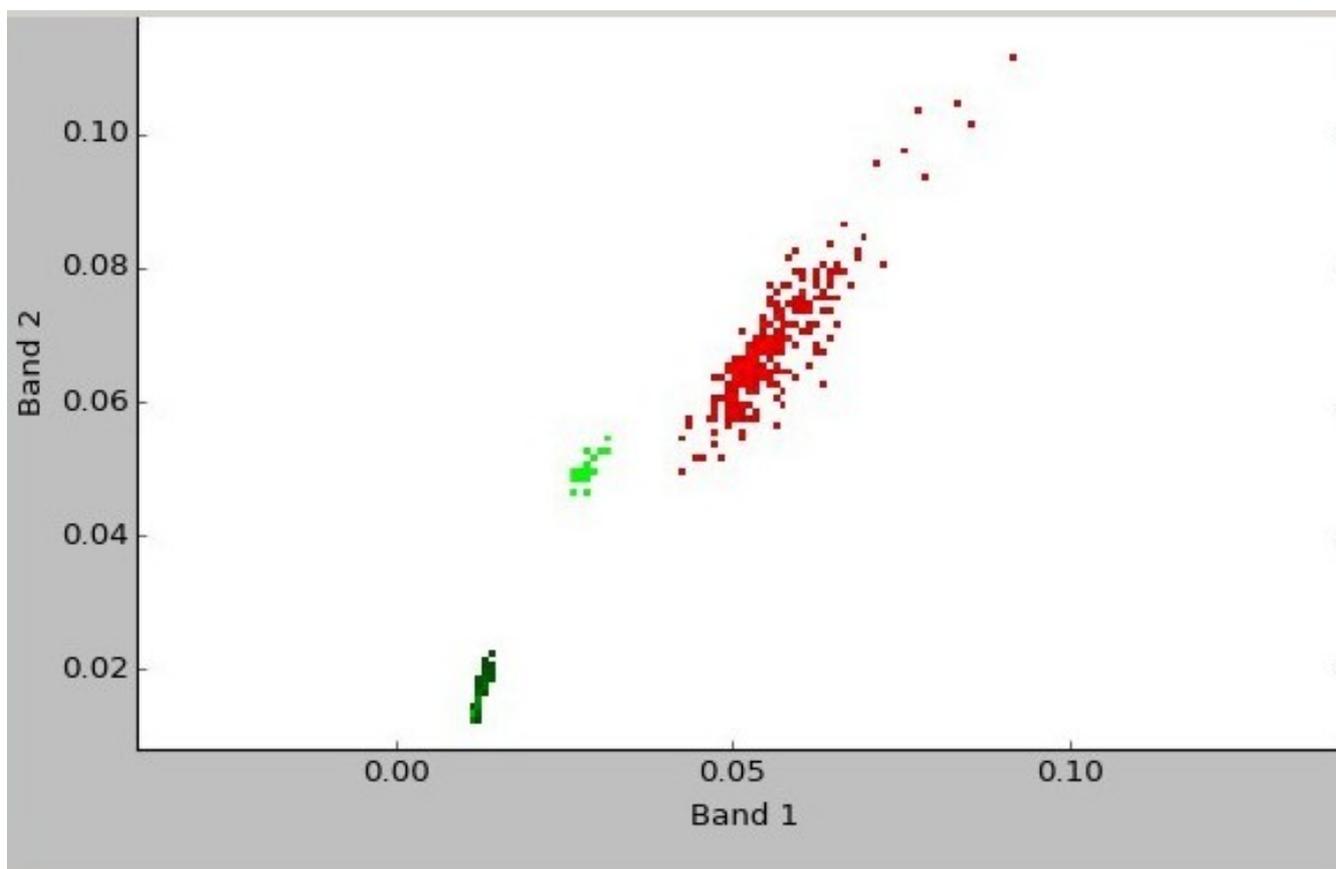- *x y*: display x y coordinates of mouse cursor inside the plot;


Fig. 67: *Example Scatter Plot*

3.7 SCP Edit Toolbar

Fig. 68: *SCP Tools*

The *SCP Edit Toolbar* allows for the direct editing of pixel values in the input raster defined in *Edit raster* (page 87) 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);
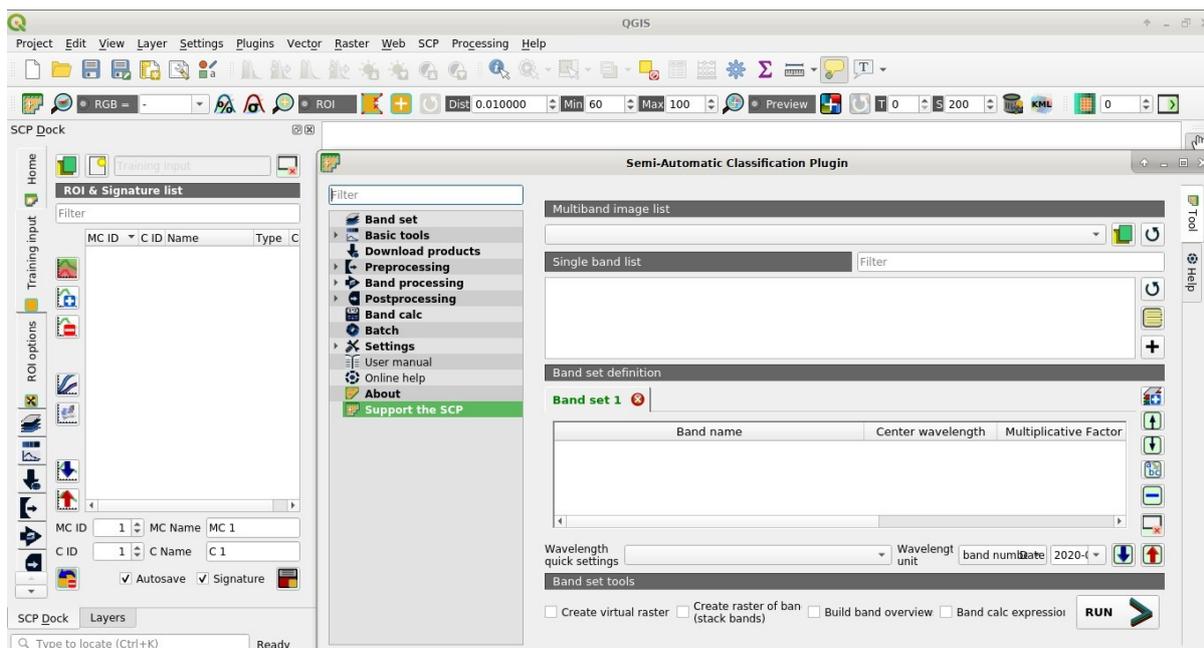
The functions described in the following paragraphs use these conventions:

 = Input date

 = Input text

 = List

 = Input number

 = Optional

 = Configuration stored in the active project of QGIS

 = Configuration stored in QGIS registry

 = Slider

 = Table

Brief Introduction to Remote Sensing

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 217).

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 ore 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 127)).
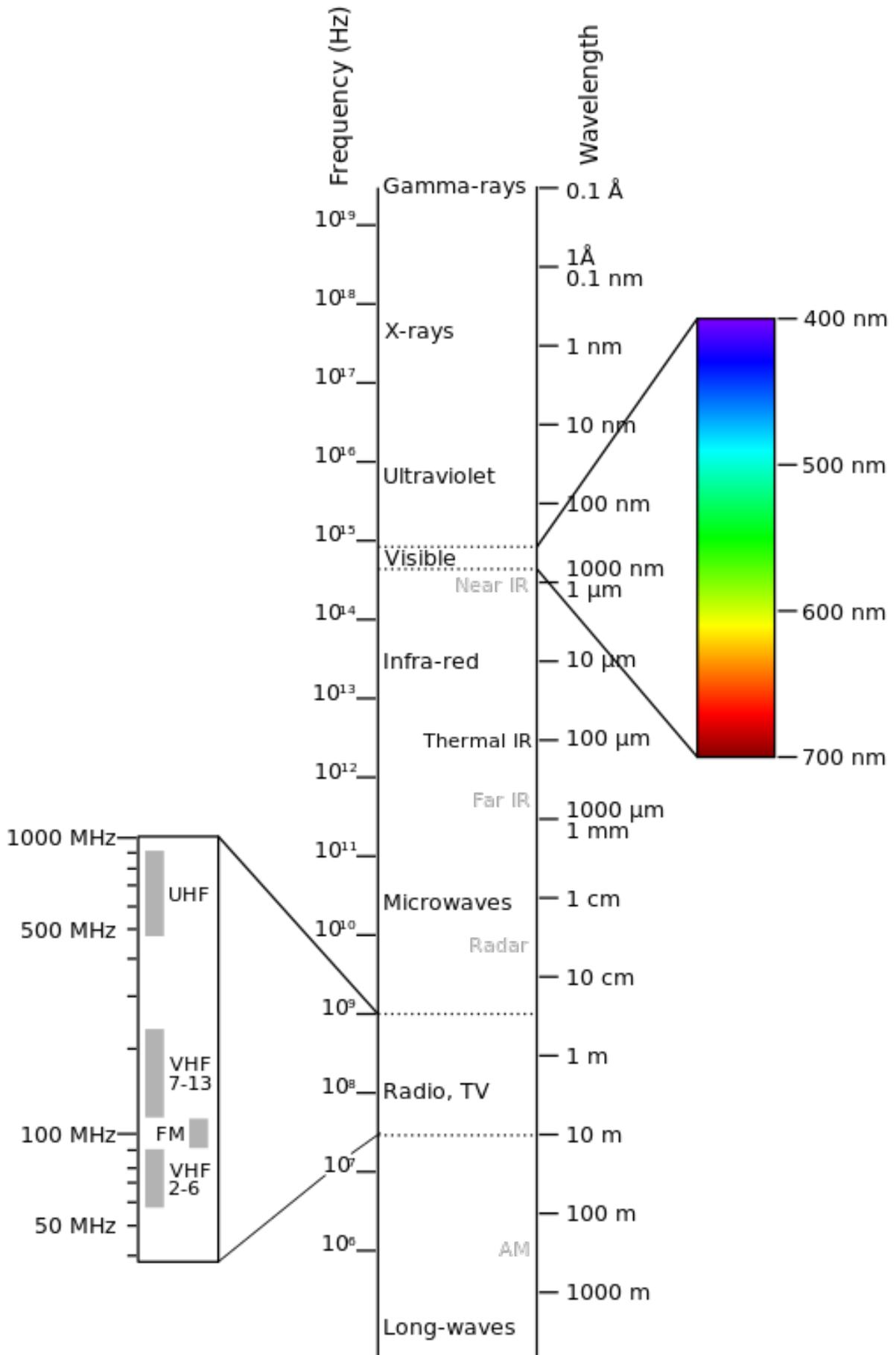
Fig. 1: *Electromagnetic-Spectrum*

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.

- **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 129)); 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.
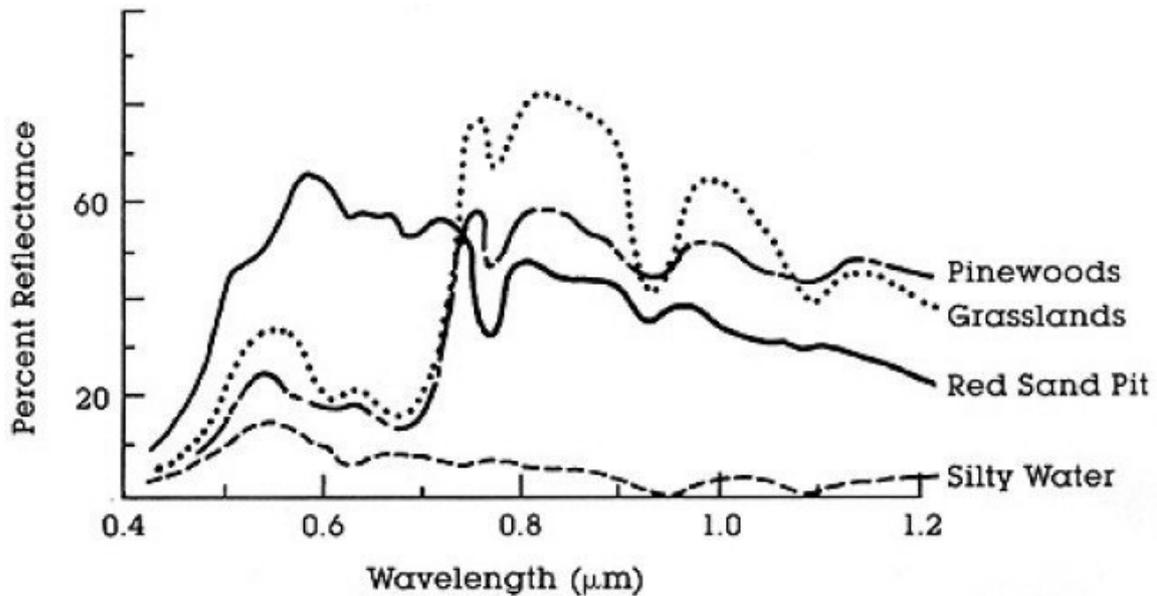
Fig. 2: *Spectral Reflectance Curves of Four Different Targets*
(from NASA, 2013)

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 continously growing with recent images.

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); 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); 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); 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 μm 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).

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) 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);

4.2.6 GOES Products

The **Geostationary Operational Environmental Satellite-R Series** (**GOES-R**) are geostationary satellites developed for weather monitoring by the National Oceanic and Atmospheric Administration (NOAA) and the NASA (NOAA, 2020).

GOES constellation is composed of **GOES-R** satellite (also known as GOES-16 that replaced GOES-13 on December 2017), and **GOES-S** satellite (also known as GOES-17, operational since February 2019). Other satellites (GOES-T and GOES-U) are planned to be launched in the future. For more information please visit https://www.goes-r.gov/mission/mission.html .

GOES geostationary satellites monitor continuously the same area, a very large portion of Earth surface with three geographic coverage regions: Full Disk, Continental United States (CONUS), and Mesoscale. In particular, Full Disk products have hemispheric coverage of 83° local zenith angle, and images are acquired every 5-15 minutes. GOES-16 monitors from 75.2 degrees west longitude, including America, the Atlantic Ocean, and the west coast of Africa. GOES-17 monitors from 137.2 degrees west longitude, including the Pacific Ocean.

GOES sensors include several spectral bands; the following table describes the bands downloaded using *SCP*.

GOES Bands

GOES Bands	Central Wavelength [micrometers]	Resolution [meters]
Band 1 - Blue	0.47	1000
Band 2 - Red	0.64	500
Band 3 - Near Infrared (NIR)	0.87	1000
Band 4 - SWIR - Cirrus	1.38	2000
Band 5 - SWIR	1.61	1000
Band 6 - SWIR	2.25	2000

4.3 SAR satellites

Synthetic Aperture Radar (SAR) is a technique of active remote sensing that is the sensor platform emits microwaves in order to acquire images of the ground (Richards and Jia, 2006). In fact, the sensor platform emits the radiation (at a specific wavelength) and measures the magnitude and the phase of radiation that bounces back from the ground to the sensor.

Unlike passive sensors, SAR systems can work day and night and can penetrate clouds allowing for the monitoring of surface also with adverse meteorological conditions; depending on the microwave wavelength, the radiation can penetrate different types of materials allowing for different applications (NASA, 2020).

The main SAR systems can be divided according to the wavelength as illustrated in the following table (NASA, 2020):

Main SAR Bands

Band	Wavelength [centimeters]	Application
X	3.8 – 2.4	High Resolution SAR, urban monitoring, ice and snow, little penetration into vegetation cover
C	7.5 – 3.8	global mapping, change detection, ice, low penetration into vegetation cover
S	15 – 7.5	global mapping, agriculture monitoring, medium penetration into vegetation cover
L	30 – 15	Medium resolution SAR, biomass and vegetation mapping, high penetration into vegetation cover

Usually, SAR sensors can emit and measure different polarizations (i.e. orientation of the microwaves of the electric field), for instance vertical (i.e. polarization oriented in the vertical direction in antenna coordinates) and horizontal (i.e. polarization oriented in the horizontal direction in antenna coordinates) (ESA, 2020).

SAR systems can acquire in both ascending and descending orbits, however the acquired images are affected by the different acquisition geometries, which should be considered when mixing ascending and descending images.

Acquisitions are called `swaths` and usually they are composed of sub-swaths. With particular acquisition modes, the resolution of pixels along track (the side parallel to the flight direction) can be different than slant-range (the side perpendicular to the flight direction).

SAR phase information is used to perform interferometry (also InSAR) to measure the distance from the sensor to the target (NASA, 2020).

For more information, please read the ESA introduction to SAR and the NASA definition of SAR .

4.3.1 Sentinel-1 Satellites

Sentinel-1 is a Copernicus mission of satellites that operate at C-band to provide SAR imagery at medium resolution (about 10m).

The Sentinel-1 constellation provides high revisit time (about 5 days), a wide swath (250 km), and acquires images in different operational modes. The primary operation mode on land is the Interferometric Wide swath (IW), which is data is acquired in three swaths using the Terrain Observation with Progressive Scanning SAR (TOPSAR) imaging technique (ESA, 2020b).

The Level-1 products systematically delivered by Copernicus are Single Look Complex (SLC, data comprising complex imagery with amplitude and phase) and **Ground Range Detected** (GRD, Level-1 data with multi-looked intensity only).

Sentinel-1 supports dual polarization, which are horizontal (H) or vertical (V); VV and VH polarimetric channels are available to classify and analyze land cover such as built-up areas or vegetation.

Sentinel-1 preprocessing

SCP preprocesses Sentinel-1 GRD images performing basically the same methodology applied for the images included in Google Earth Engine .

The preprocessing comprises the following phases:

- Application of the orbit file;
- Removal of GRD border noise for low intensity and invalid data;
- Removal of thermal noise to reduce discontinuities between sub-swaths;
- Calculation of backscatter intensity using radiometric calibration;
- Orthorectification (terrain correction) using the SRTM 30 meter DEM;
- Conversion of backscatter coefficient to dB.

These processes are performed through the SNAP Graph Processing Tool (GPT) and a graph file .xml . Therefore, SCP requires ESA SNAP to perform the preprocessing. For the installation of ESA SNAP, please visit this page http://step.esa.int/main/download/snap-download/ .

The path to the SNAP gpt executable must be entered in settings *Processing* (page 113). Usually `C:/snap/bin/gpt.exe` for Windows, `/Applications/snap/bin/gpt` for Mac, and `/usr/local/snap/bin/gpt` for Linux.

It is also possible to use custom graph files and select to project the raster to the same coordinate reference system as a band set (default WGS 84).

4.4 Land Cover Classification

This chapter provides basic definitions about land cover classifications.

4.4.1 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.

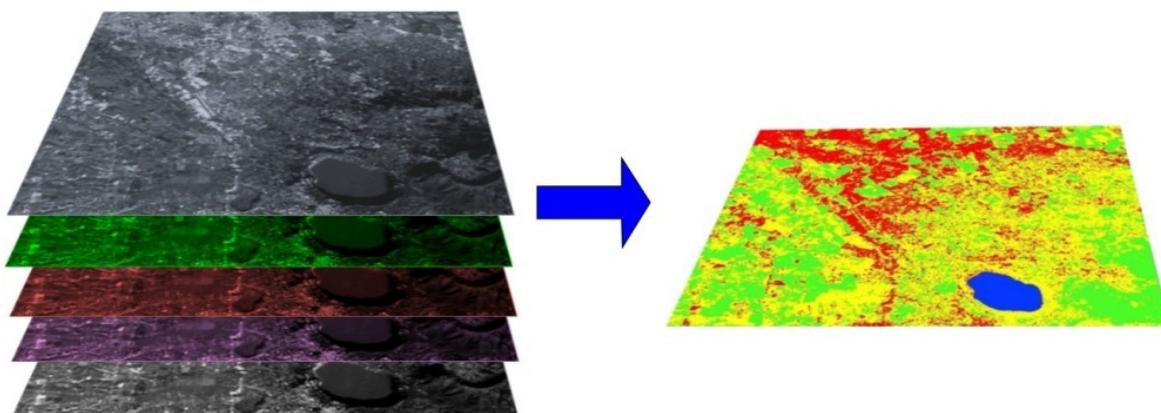Image processing and GIS spatial analyses require specific software such as the Semi-Automatic Classification Plugin for QGIS.

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

4.4.2 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:

"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 136) 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).

4.4.3 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
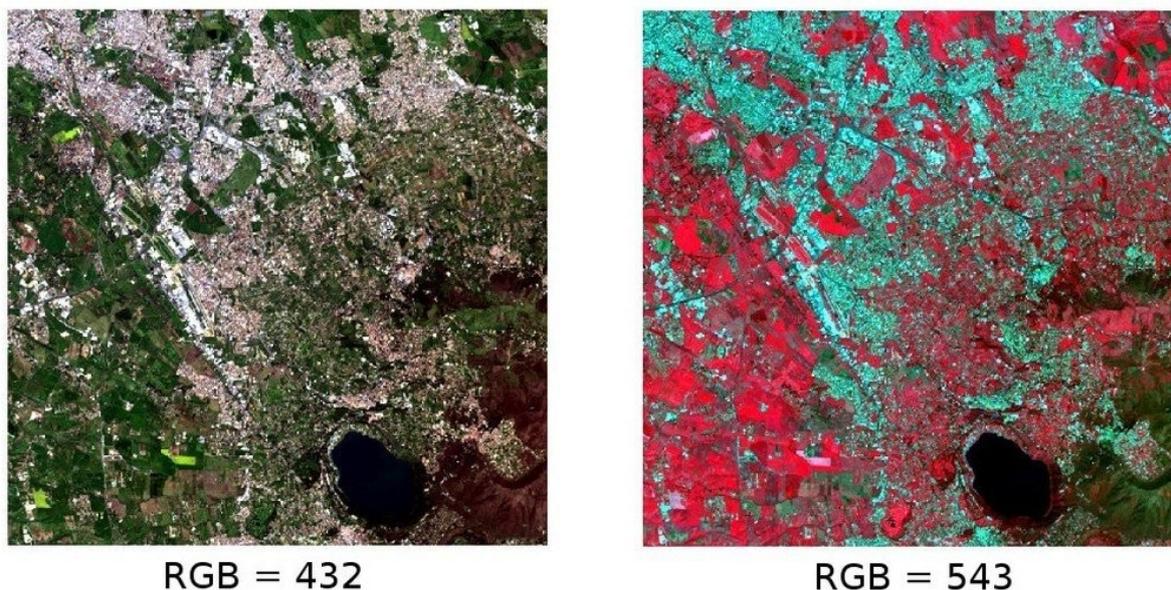
RGB = 432   RGB = 543

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

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.

In figure *Region growing example* (page 137) 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).

4.4.4 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.
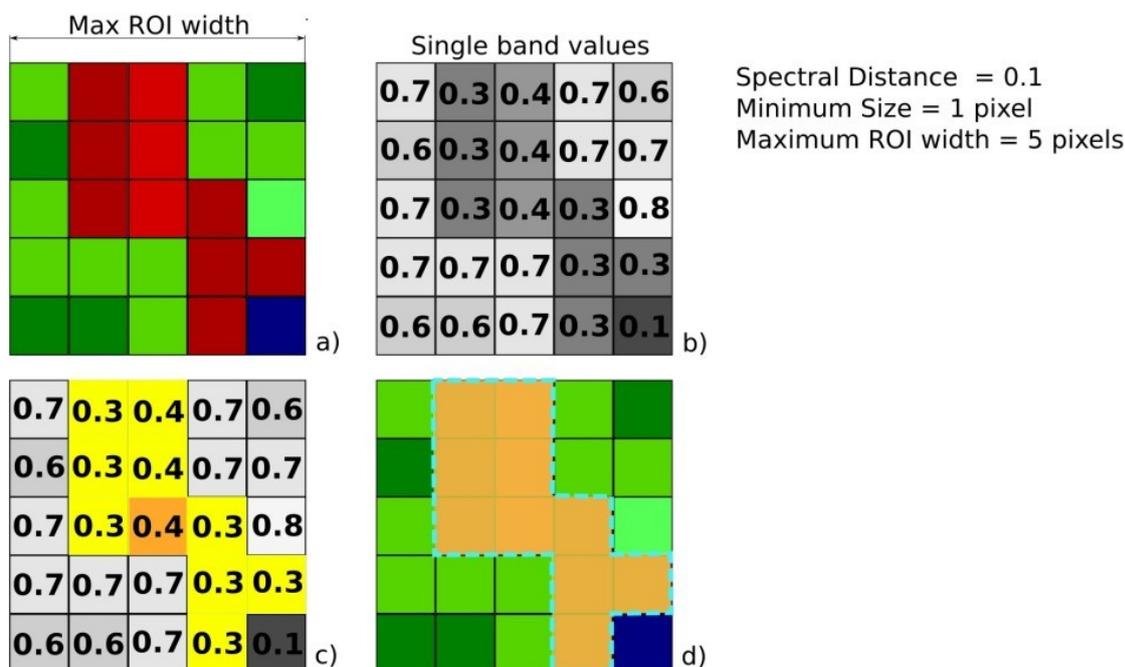
Example of Macroclasses

Fig. 5: *Region growing example*

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 138).

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.

4.4.5 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.

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;
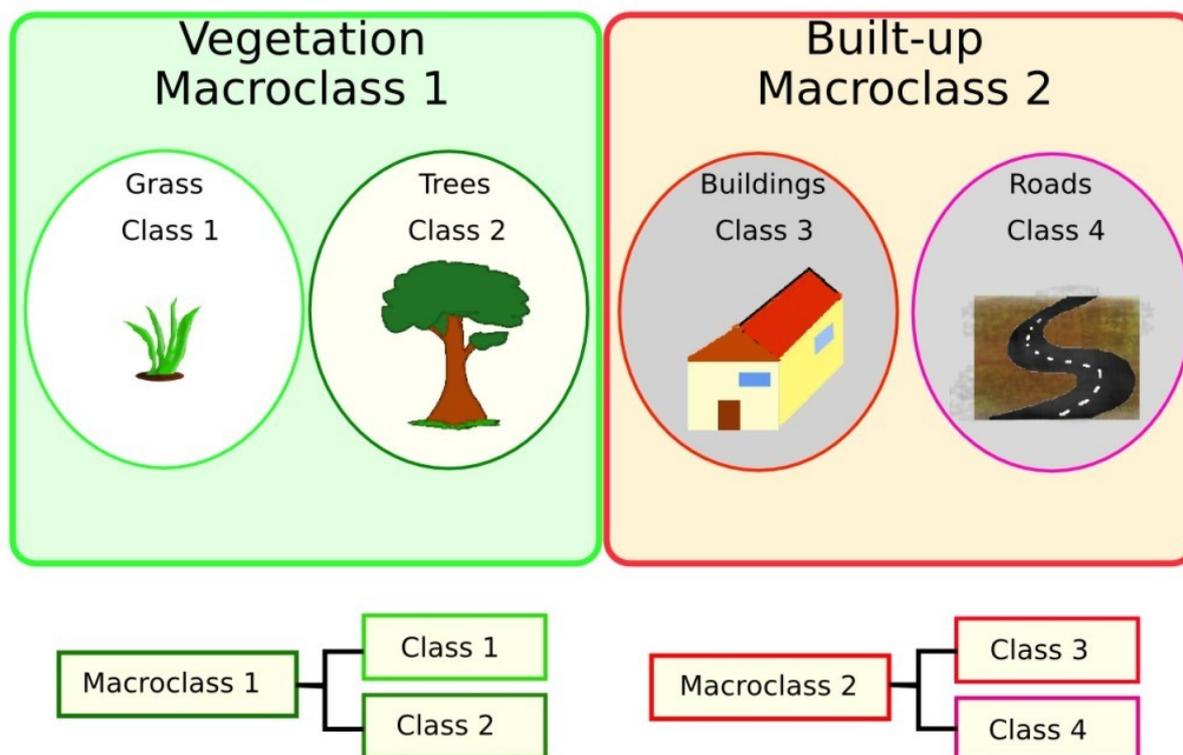
Fig. 6: *Macroclass example*

- 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;
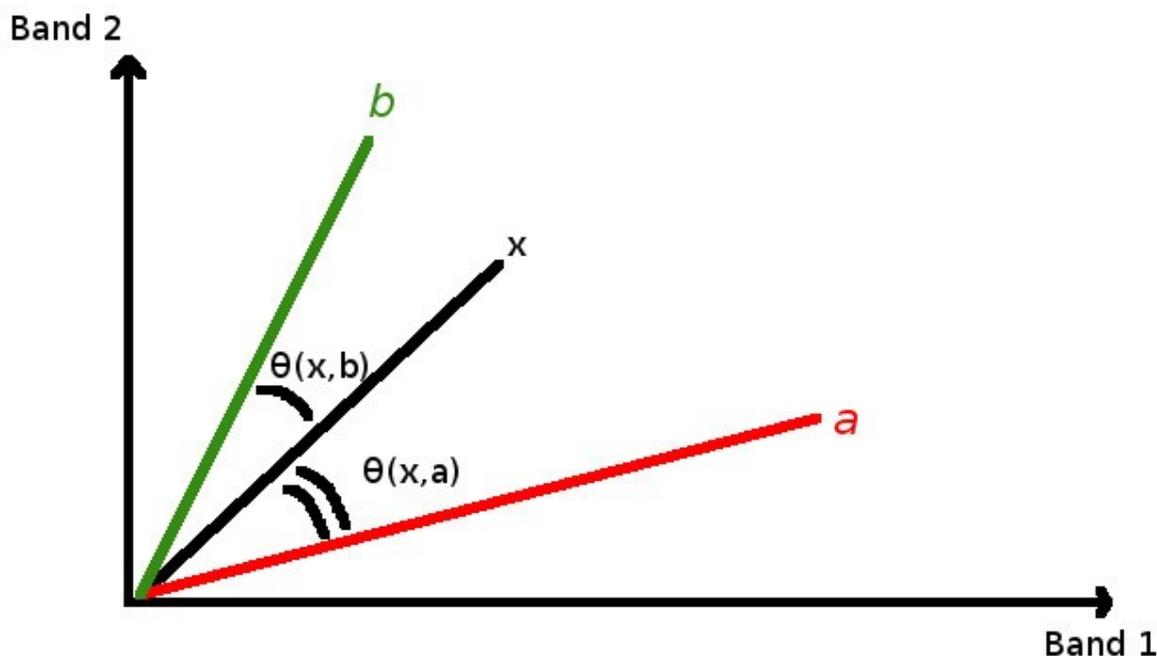
- y_j = spectral signature of class j.

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

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

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;
- Σ_k^{-1} = inverse of the covariance matrix;
- y_k = spectral signature vector of class k.

Therefore:

$$x \in C_k \iff g_k(x) > g_j(x) \forall k \neq j$$
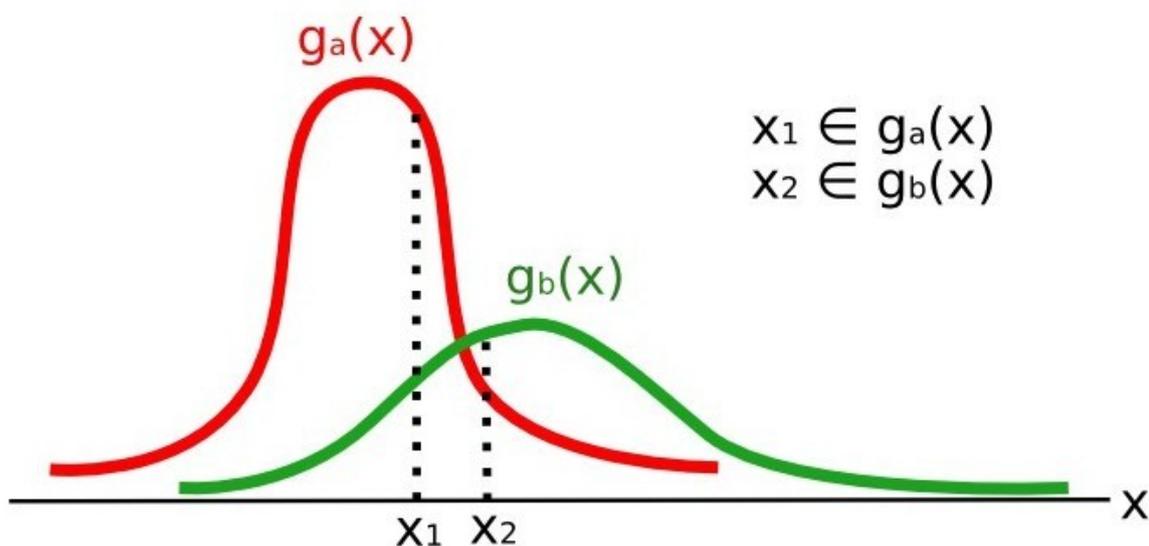
Fig. 7: *Maximum Likelihood example*

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 137).

Spectral Angle Mapping

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

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

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 74)). 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 137), *Maximum Likelihood* (page 138), *Spectral Angle Mapping* (page 139)) 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 .
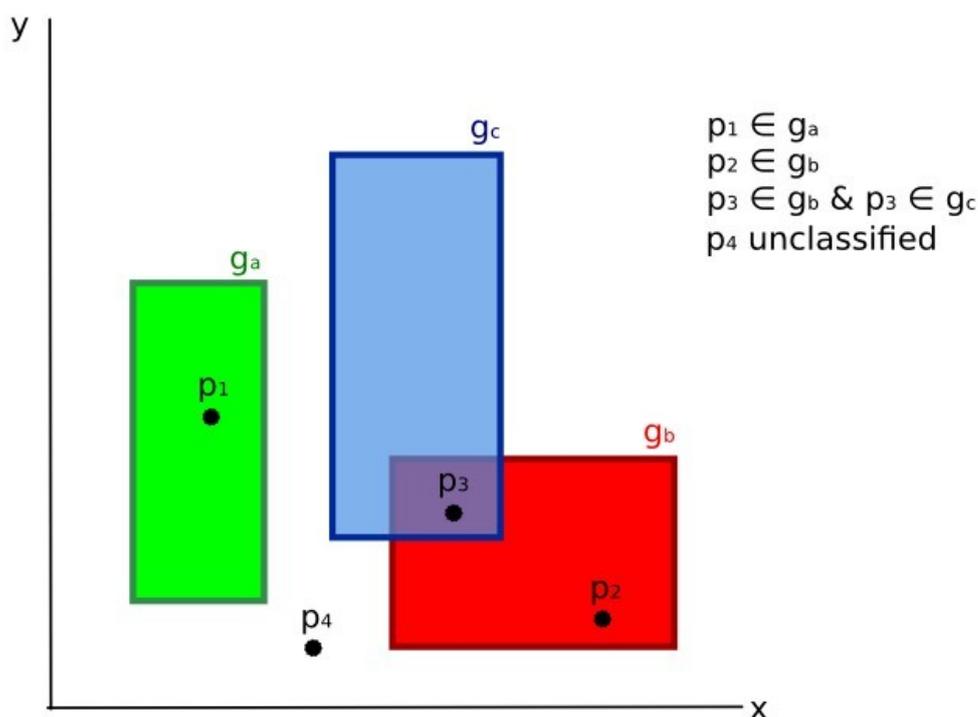
Fig. 9: *Land cover signature classification*

This is similar to *Parallelepiped Classification* (page 140), 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 142) 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
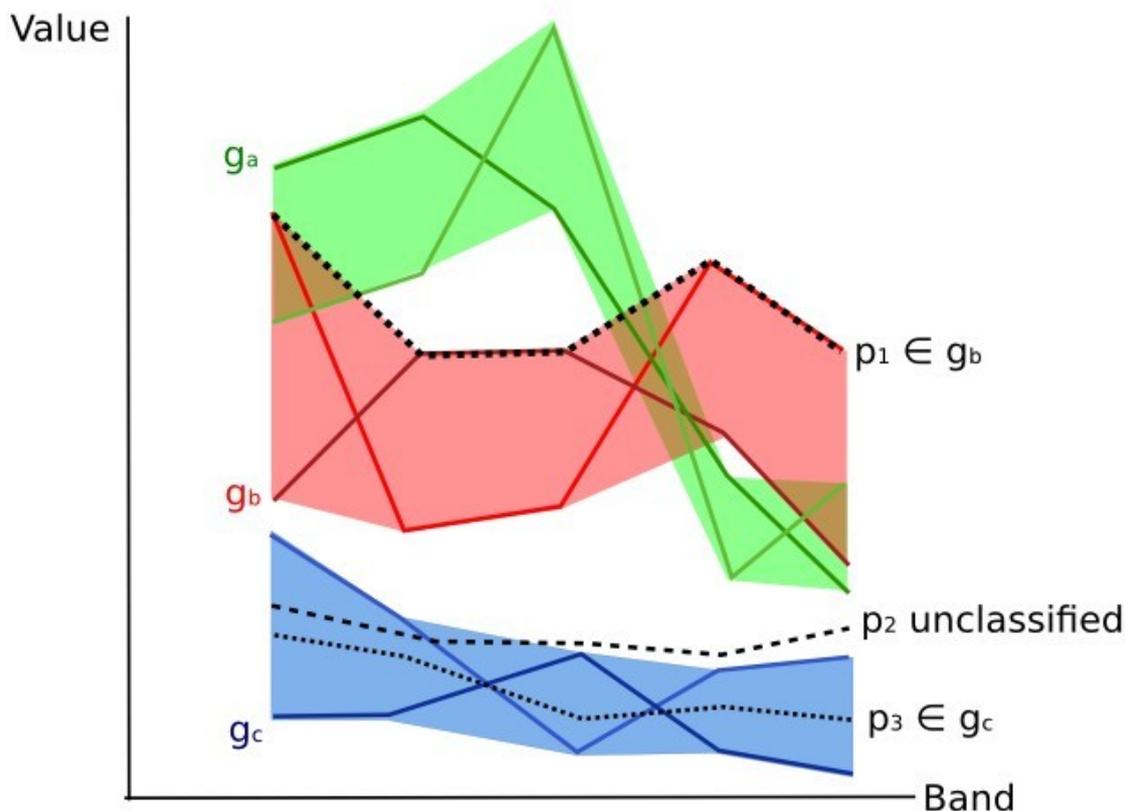
4.4. Land Cover Classification

Fig. 10: *Plot of spectral ranges*

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 142) could not exist).

One of the main benefit of the *Land Cover Signature Classification* is that it is possible to select pixels and 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.

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 137) or *Spectral Angle Mapping* (page 139) (or highest in case of *Maximum Likelihood* (page 138)).

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 30)).

4.4.6 Machine Learning

Machine Learning is a broad set of classification techniques that aim to build mathematical models based on training data.

In general, Machine Learning algorithms split the data in (ESA, 2019):

- Training Dataset: the sample data used to fit the model;

- Validation Dataset: the sample data used to tune the model parameters to fit on the training dataset;

- Test Dataset: the sample data used to provide an evaluation of the final model;

Usually, the training and model evaluation are performed iteratively.

Random Forest

Random Forest is a particular machine learning technique, based on the iterative and random creation of decision trees (i.e. a set of rules and conditions that define a class).

First, the input features should be defined, which can be spectral bands or ancillary rasters. *Training Areas* (page 135) should be created to define the classes used for training the model.

Random Forest calculates several random decision trees, based on the following parameters:

- number of training samples: is the number of training data (pixels) randomly used to train the model; it should be set lower than total training input pixels;

- number of trees: is the number of decision trees; the more the number of trees, the more is the model accuracy, but it also increases the calculation time.

For instance, a decision tree could be defined as:

- class 1 = band 1 > 0.1 –> band 2 < 0.3 –> band 3 > 0.4

- class 2 = band 1 > 0.4 –> band 2 > 0.6 –> band 3 < 0.1

- class 3 = band 1 < 0.7 –> band 2 > 0.1 –> band 3 < 0.5

Random Forest creates several decision trees randomly. Usually, the Gini coefficient is calculated to split the trees. Therefore, a model based on the decision trees is created and used to classify all the pixels.

A pixel is classified according to the majority vote of decision trees, for example a pixel is classified as class 1 if most decision trees evaluated it as class 1. Also, a confidence layer is produced, which measures the uncertainty of the model based on training data.

Random Forest can be used to evaluate the importance of input features, according to the contribution thereof to the model.

4.4.7 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 138) classifications.

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

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

where:

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

where:

- x = first spectral signature vector;

- y = second spectral signature vector;

- Σ_x = covariance matrix of sample x;

- Σ_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 139) algorithm. The spectral angle θ is defined as (Kruse et al., 1993):

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

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 137) 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.

4.4.8 Classification Result

The result of the classification process is a raster (see an example of Landsat classification in Figure *Landsat classification* (page 145)), where pixel values correspond to class IDs and each color represent a land cover class.
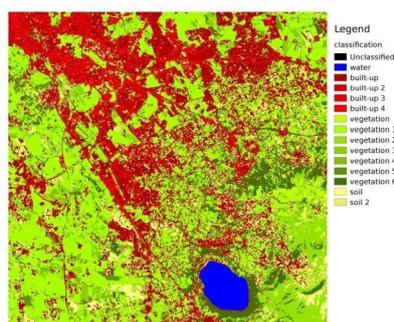
Fig. 11: *Landsat classification*
Data available from the U.S. Geological Survey

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.

4.4.9 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 (aii) 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
Class 1	a_{11}	a_{12}	...	a_{1k}	a_{1+}
Class 2	a_{21}	a_{22}	...	a_{2k}	a_{2+}
...	...	...	...	...	...
Class k	a_{k1}	a_{k2}	...	a_{kk}	a_{k+}
Total	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.

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 Data Users Handbook.

4.5 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.

4.5.1 Principal Component Analysis

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

Th 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 135) for highlighting *Land Cover* (page 128) classes, or used as input for *Supervised Classification* (page 135).

4.5.2 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:

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

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

4.5.3 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:

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

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).

4.5.4 Clustering

Clustering is the grouping of pixels based on spectral similarity (e.g. *Euclidean Distance* (page 144) or *Spectral Angle* (page 144)) 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 135) produces a classification whit 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 144) or *Spectral Angle* (page 144) 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

- σ_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 144) 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

- σ_{ij} = standard deviation of cluster i in band j

- σmax_i = maximum standard deviation of cluster i (i.e. $max(\sigma_{ij})$)

- k_i = band where σmax_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 $P <= C$ then try to split clusters. For each cluster i:

- If $\sigma max_i > \sigma_t$:

    - If $((AVERAGEDIST_i > AVERAGEDISTANCE)$ AND $(N_i > (2 * N_{min} + 2)))$ 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 $Sk_{p+1} = Sk_i$ - σmax_i

        * $P = P + 1$

        * start a new iteration

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

- For each combination xy of spectrals signatures calculate D_{xy} = *Euclidean Distance* (page 144) 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.

4.6 Image conversion to reflectance

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

4.6.1 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_λ, measured in [watts/(meter squared * ster * μm)]) is given by (https://www.usgs.gov/core-science-systems/nli/landsat/using-usgs-landsat-level-1-data-product):

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

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 150), scaled prior to output (ESA, 2015).

4.6.2 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 (ρ_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_λ = 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)

- $ESUN_\lambda$ = Mean solar exo-atmospheric irradiances

- θ_s = Solar zenith angle in degrees, which is equal to θ_s = 90° - θ_e where θ_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).

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.

4.6.3 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** (ρ) 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 ρ (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).

4.6.4 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 /(m2 * μm)] values for Landsat sensors are provided in the following table.

ESUN values for Landsat bands

Band	Landsat 1 MSS*	Landsat 2 MSS*	Landsat 3 MSS*	Landsat 4 TM*	Landsat 5 TM*	Landsat 7 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

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 /(m2 * 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 [W /(m2 * μm)] 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 to 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 153).
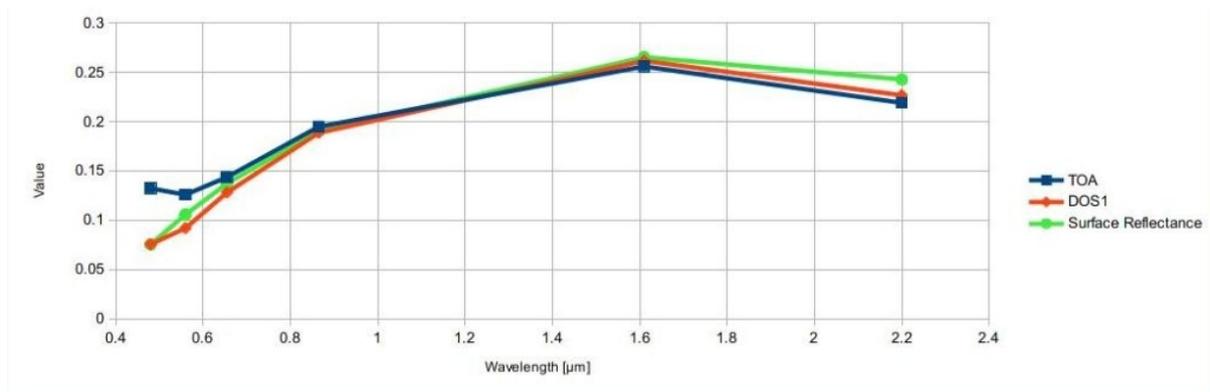
Fig. 13: *Spectral signatures of a built-up pixel*
Comparison of TOA reflectance, DOS1 corrected reflectance and Landsat Surface
Reflectance High Level Data Products

4.7 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**.

4.7.1 Conversion to At-Satellite Brightness Temperature

For thermal bands, the conversion of DN to At-Satellite Brightness Temperature is given by (from https://www.usgs.gov/core-science-systems/nli/landsat/using-usgs-landsat-level-1-data-product):

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

where:

- K_1 = Band-specific thermal conversion constant (in watts/meter squared * ster * μm)

- K_2 = Band-specific thermal conversion constant (in kelvin)

and L_λ is the Spectral Radiance at the sensor's aperture, measured in watts/(meter squared * ster * μm).

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 = $1.191 * 10^{-16} W m^2 sr^{-1}$

- c_2 = second radiation constant = $1.4388 * 10^{-2} mK$

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	$1.733 * 10^3$	$1.663 * 10^3$	$1.581 * 10^3$	$1.357 * 10^3$	$1.273 * 10^3$

4.7.2 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:

- λ = 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 = $2.998 * 10^8$ m/s

The values of λ for the thermal bands of Landsat and ASTER satellites can be calculated from the tables in *Landsat Satellites* (page 129) and *ASTER Satellite* (page 131).

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

4.8 References

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Basic Tutorials

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.

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 125) before this tutorial.

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

1. Water;

2. Built-up;

3. Vegetation;

4. Soil.

The study area of this tutorial is Matera (Basilicata, Italy) which is a city in the Southern Italy. Matera is the site of a Center of the Italian Space Agency (ASI) specialized in remote sensing, which has several purposes, in particular to acquire, process and store remote sensing data.

Following the video of this tutorial.

http://www.youtube.com/watch?v=Ceyhm3DlZNY

Download the Data

We are going to download a *Sentinel-2 Satellite* (page 130) image (Copernicus land monitoring services) and use the bands illustrated in the following table.

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

TIP : In case of slow internet connection you can download an image subset from this archive (about 30 MB, © Copernicus Sentinel data 2020 downloaded from https://scihub.copernicus.eu/), unzip the downloaded file, and skip to *Preprocess the data* (page 162).

Start QGIS and the *SCP*. Open the tab *Download products* (page 45) clicking the button in the *Home* (page 21), or in the *SCP menu* (page 19),

In the tab *Download products* (page 45) click the button to display the OpenStreetMap tiles (© Open-StreetMap contributors) in the QGIS map, licensed as CC BY-SA (Tile Usage Policy).

We are searching a specific image acquired on 8 July 2020 because it is cloud free (however you can use any other Sentinel-2 image). In *Search parameters* (page 47) enter the point coordinates:

- *UL*: 16.5 / 40.7

- *LR*: 16.7 / 40.6

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 *Sentinel-2* from the *Products* and set:

- *Date from*: 2020-07-08

- *to*: 2020-07-08

Now click the button *Find* and after a few seconds the image will be listed in the *Product list* (page 49). Click the ProductID `L2A_T33TXF_A026345_20200708T094035` 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.
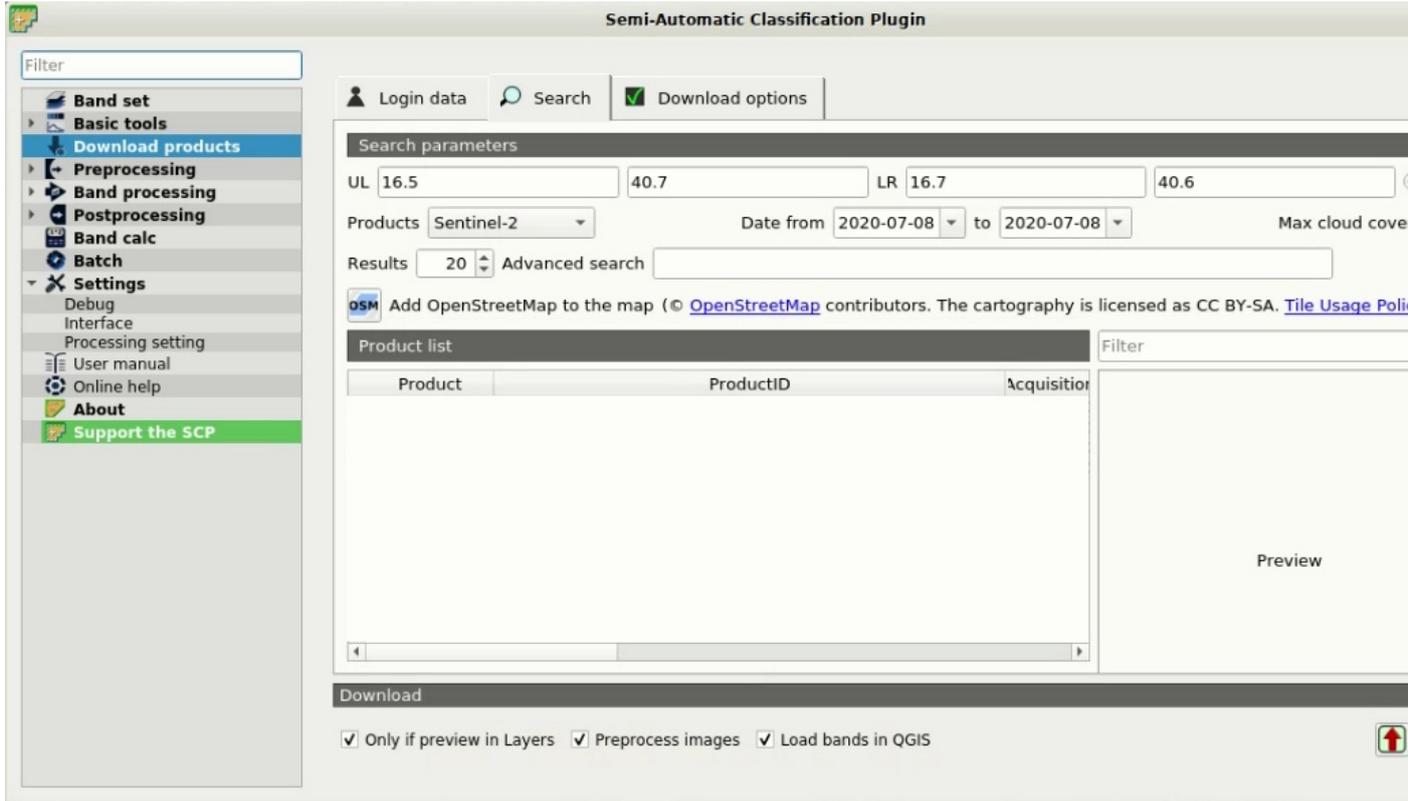
Fig. 1: *Search products*
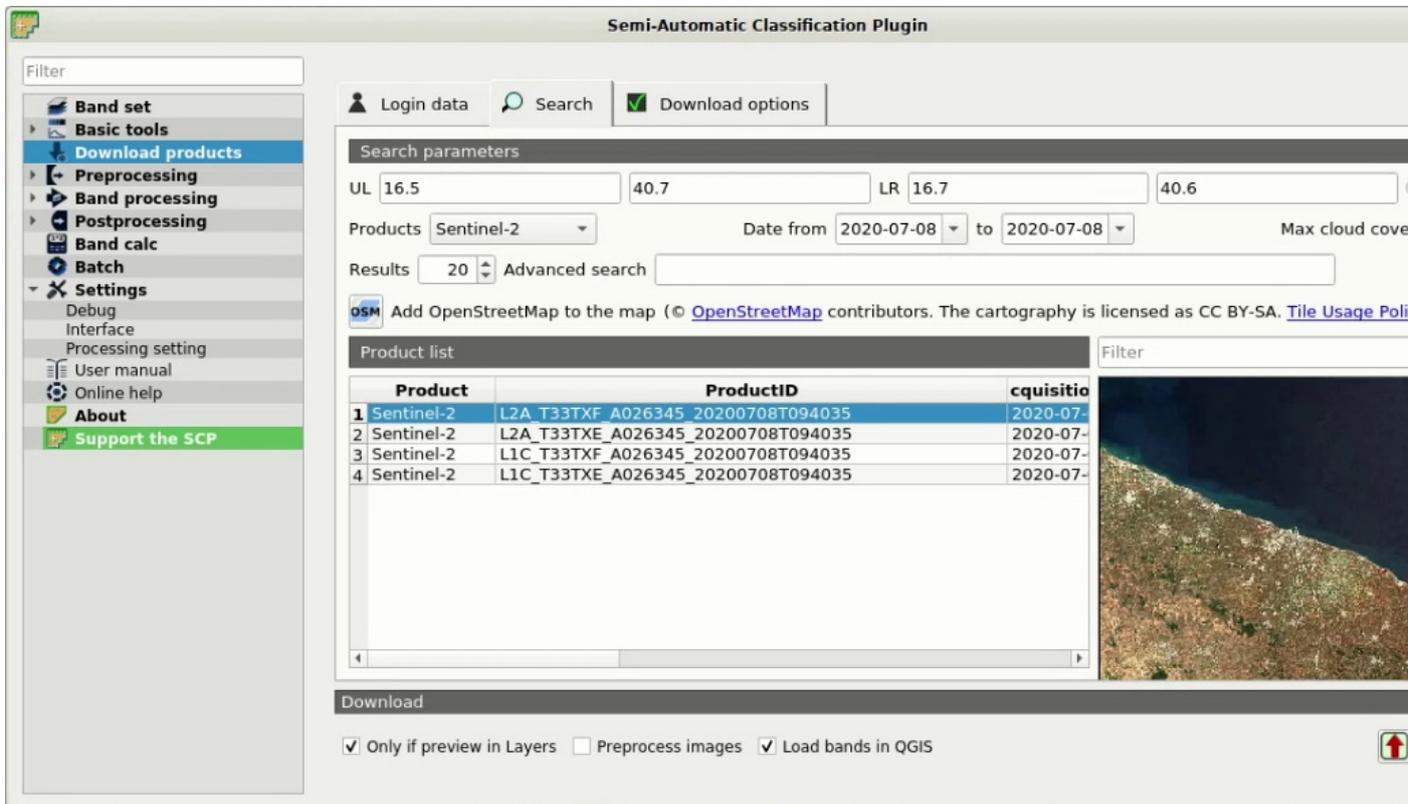
Fig. 2: *Search result*
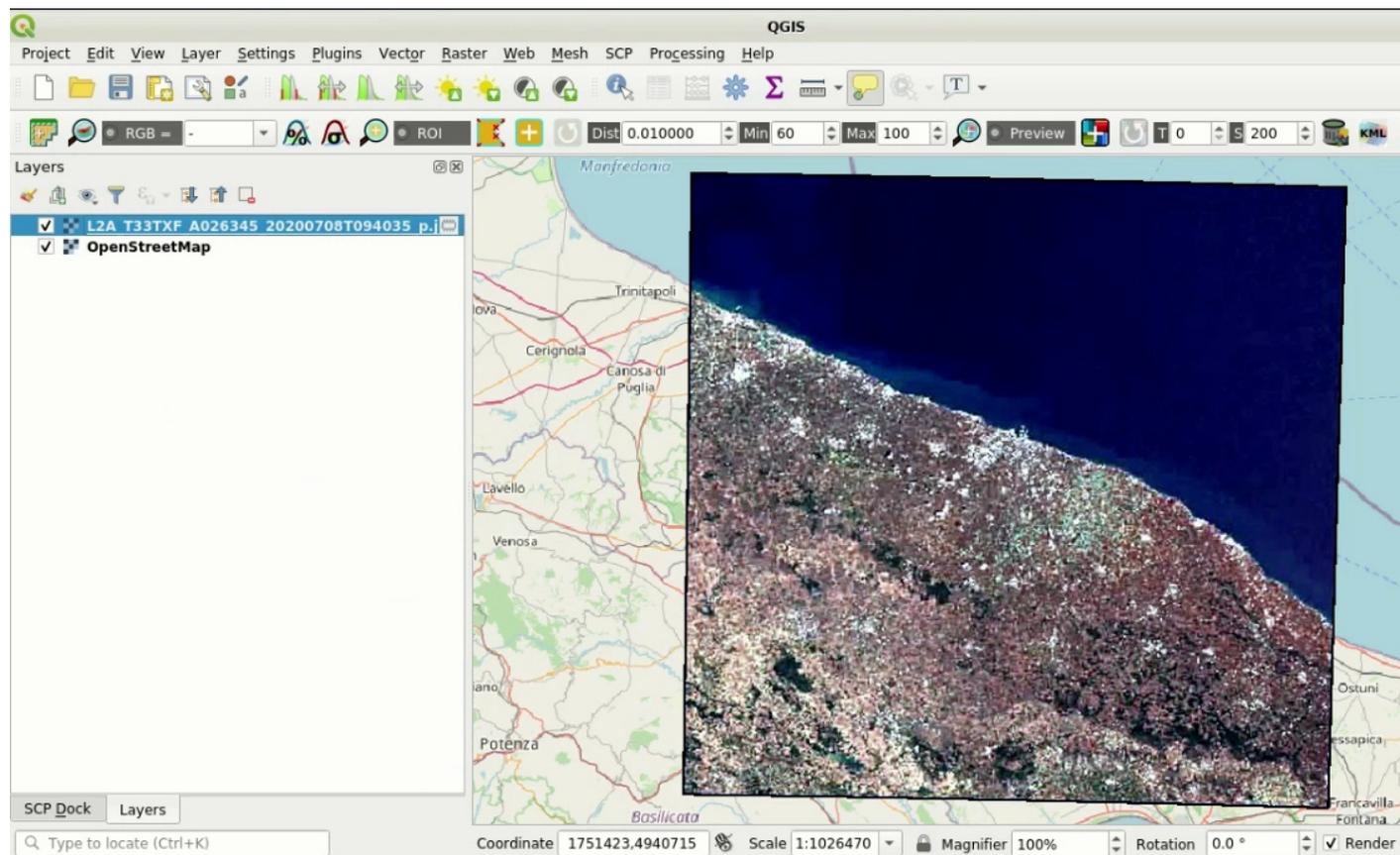
Fig. 3: *Image preview*

We can also select which bands to be downloaded according to our purpose. In particular, select the tab *Download options* (page 50) and check only the Sentinel-2 bands (that will be used in this tutorial): 2, 3, 4, 5, 6, 7, 8, 8A, 11, 12 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 *Preprocess the data* (page 162). To start the image download, click the button *RUN* ⧸ 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 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. Several tools in SCP use the *Band sets*, which are numbered sets of raster bands and related information (such as center wavelength and acquisition date).

Open the tab *Band set* (page 31) clicking the button ⬙ in the *SCP menu* (page 19) or the *SCP dock* (page 20).

Click the button ↻ to refresh the layer list, and select the bands: 2, 3, 4, 5, 6, 7, 8, 8A, 11, and 12; then click
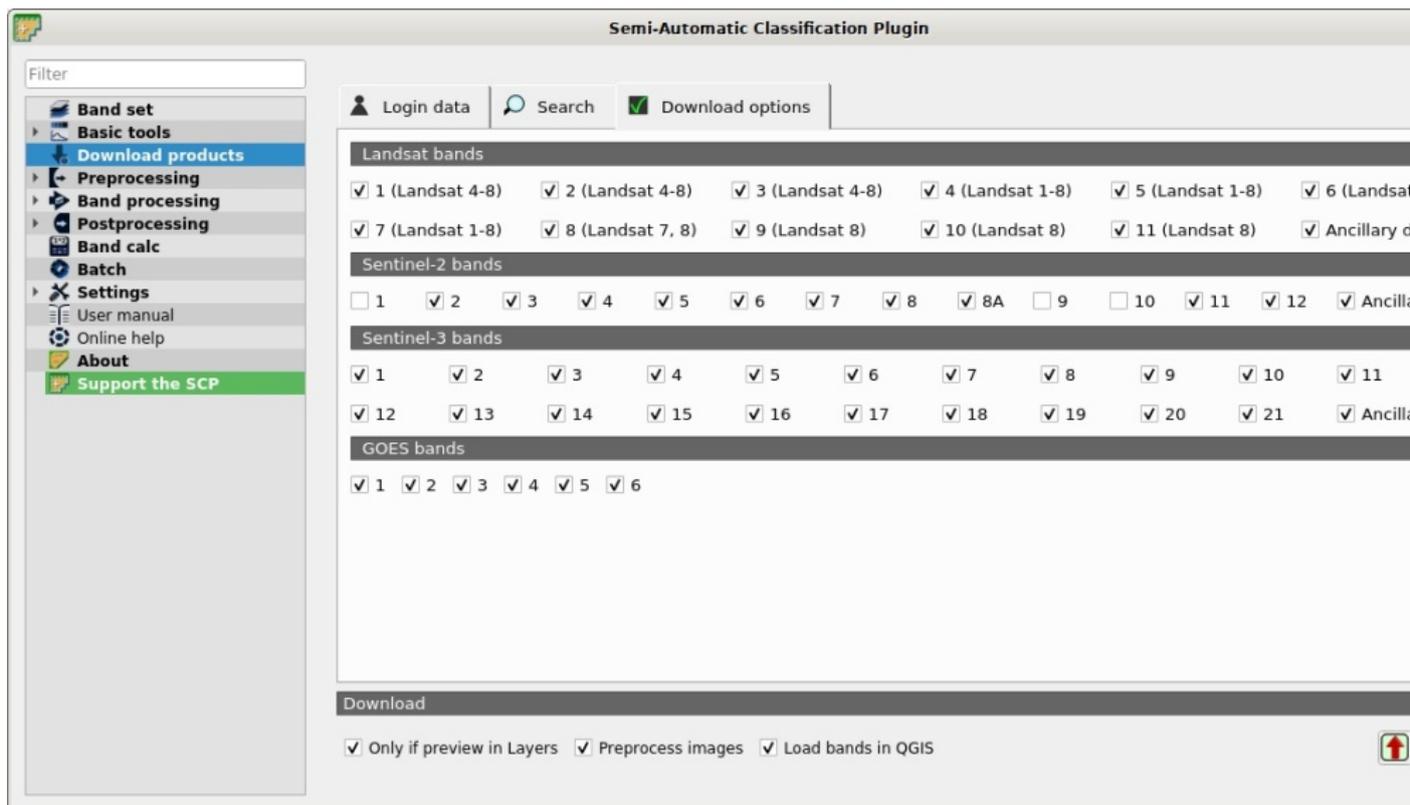
Fig. 4: *Download options*
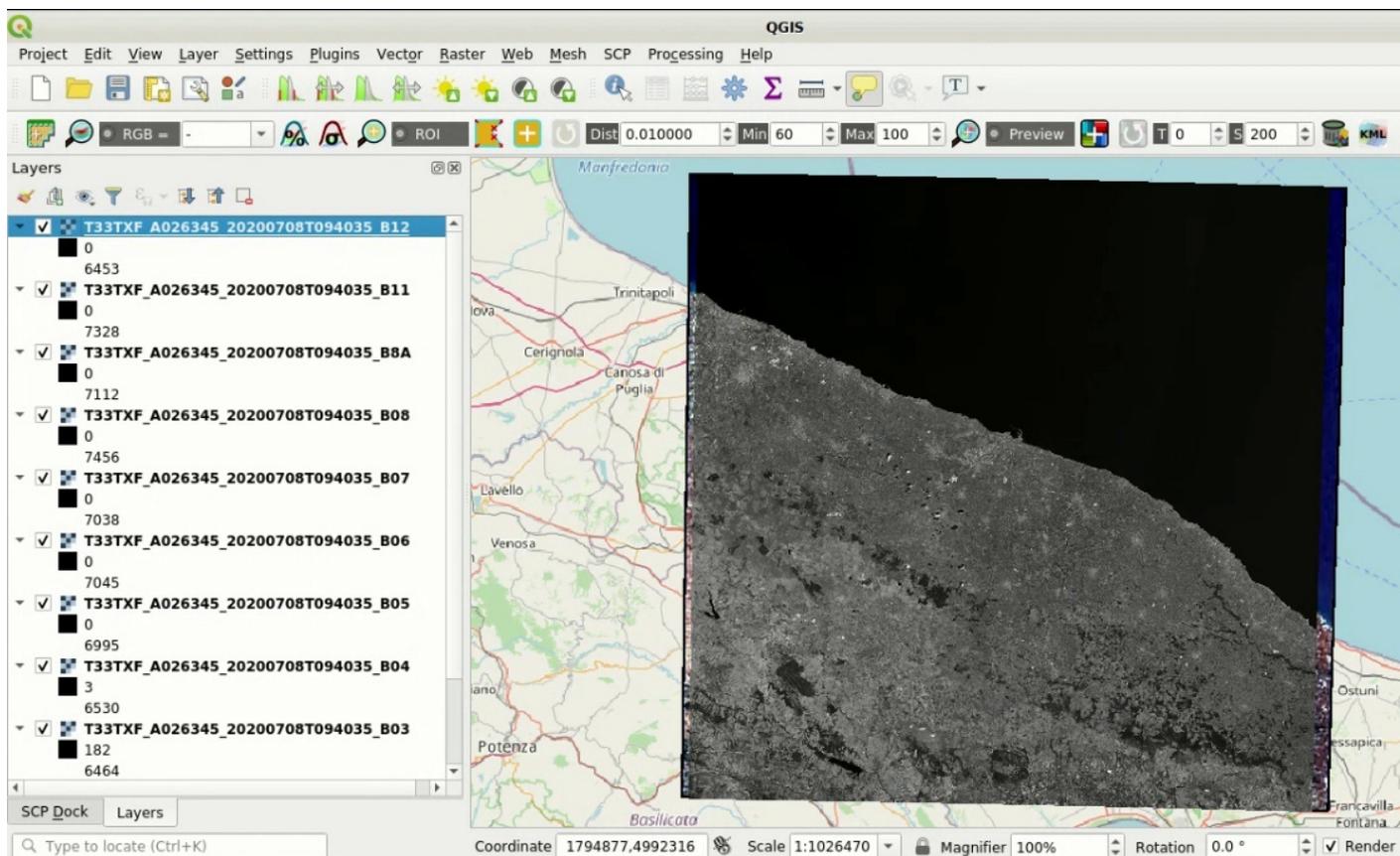
Fig. 5: *Download of Sentinel-2 bands*

✚ to add selected rasters to the *Band set 1*.
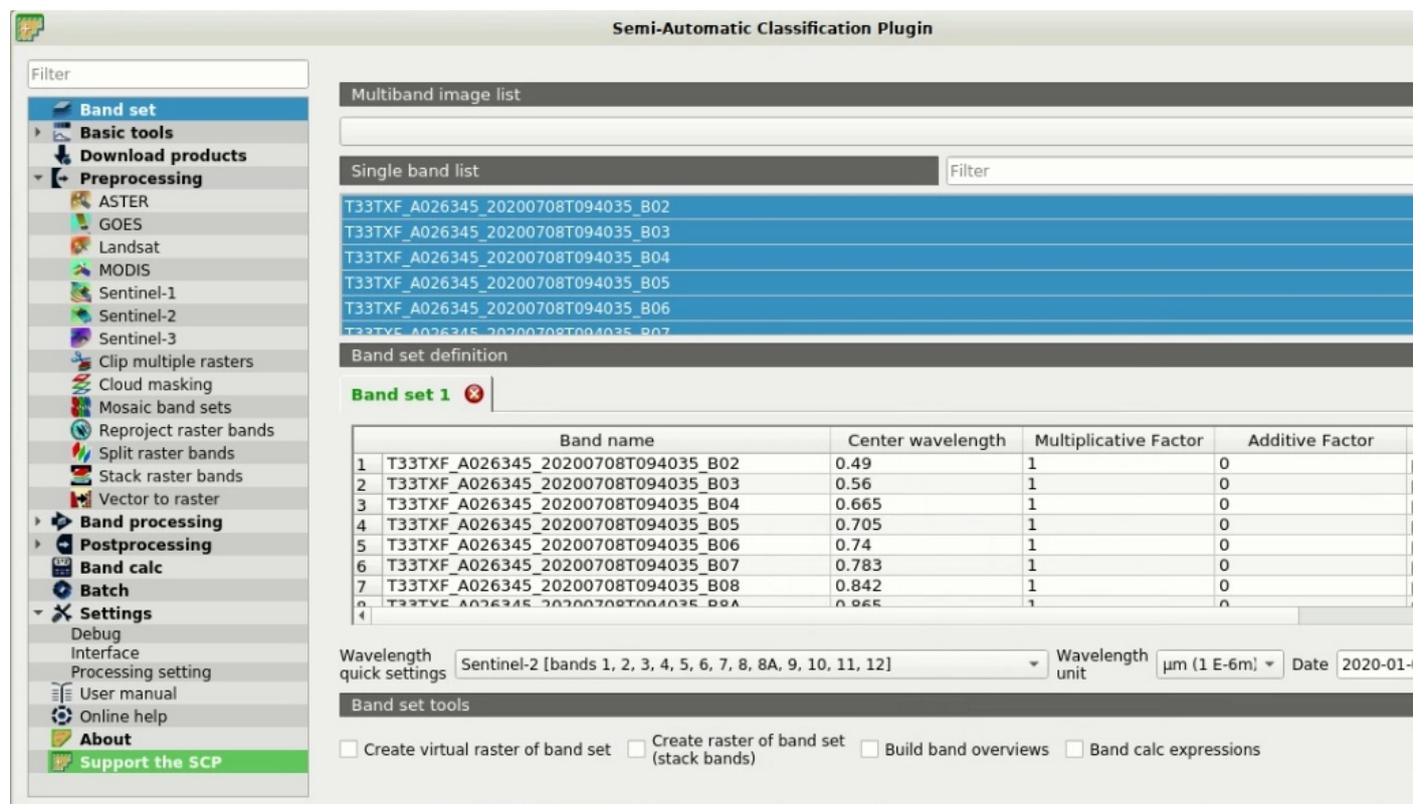
Fig. 6: *Band set for clipping*

In *Preprocessing* (page 50) open the tab *Clip multiple rasters* (page 62). We are going to clip the *Band set 1* which contains Sentinel-2 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*: 623830 / 4505410

- *LR*: 645330 / 4494350

Click the button *RUN* ⟫ 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.

Preprocess the data

The downloaded product is a Sentinel-2 Level 2A image, which is already atmospherically corrected (Level 1C images require atmospherical correction as described in *Image conversion to reflectance* (page 150)). Nevertheless, preprocessing is required to convert pixel values to a decimal value of reflectance.

Conversion to reflectance (see *Radiance and Reflectance* (page 128)) 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.

In order to convert bands to reflectance, open the *Preprocessing* (page 50) clicking the button ➦ in the *SCP menu* (page 19) or the *SCP dock* (page 20), and select the tab *Sentinel-2* (page 59).
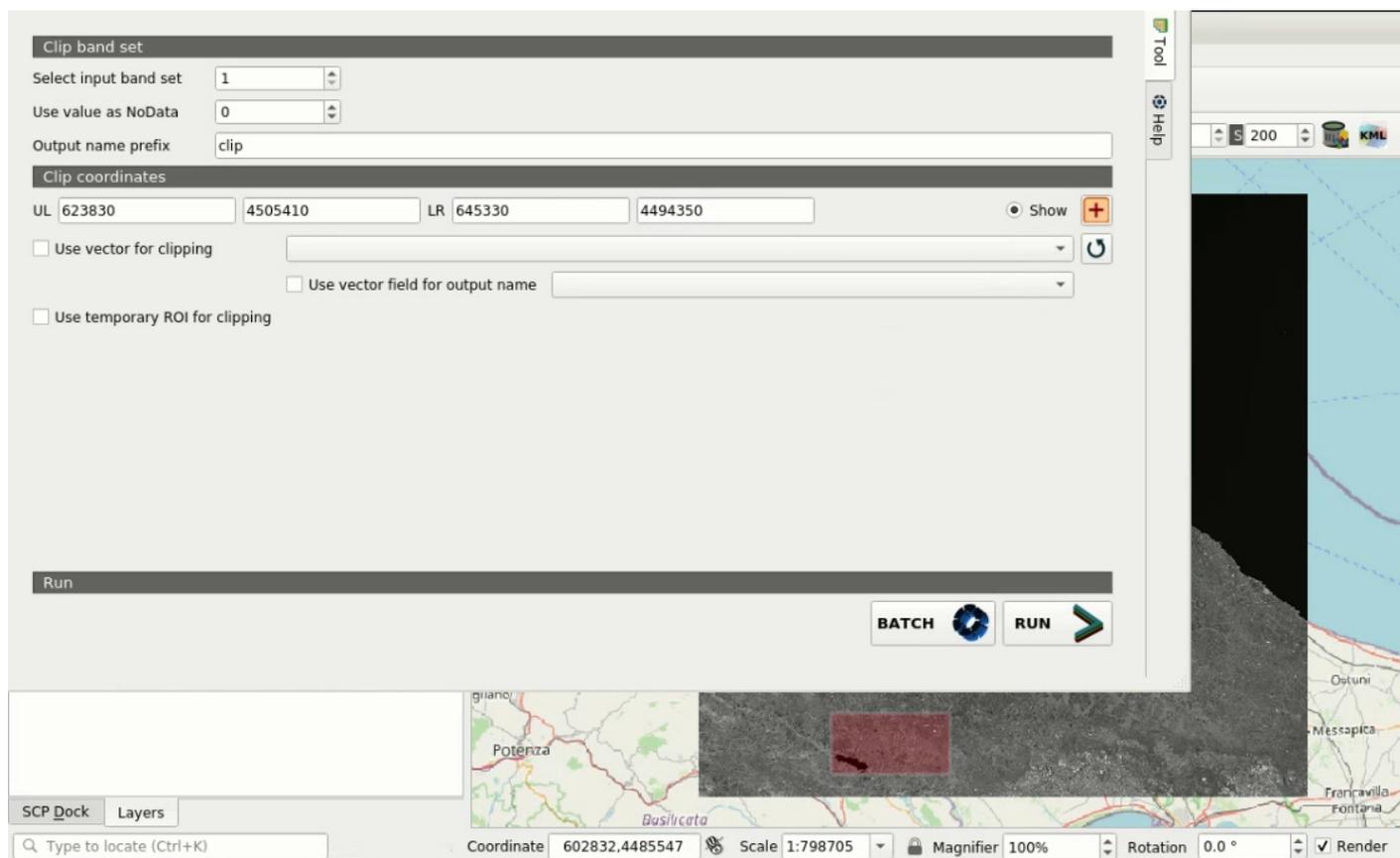
Fig. 7: *Clip area*

Click the button *Directory containing Sentinel-2 bands* and select the directory of clipped Sentinel-2 bands. The list of bands is automatically loaded in the table *Metadata* (page 60).

You can ignore *Select metadata file* because this conversion doesn't require additional information.

Sentinel-2 Level 2A images don't require the *DOS1 Correction* (page 151); if it was a Level 1C image we should 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 165).

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 114) 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_.
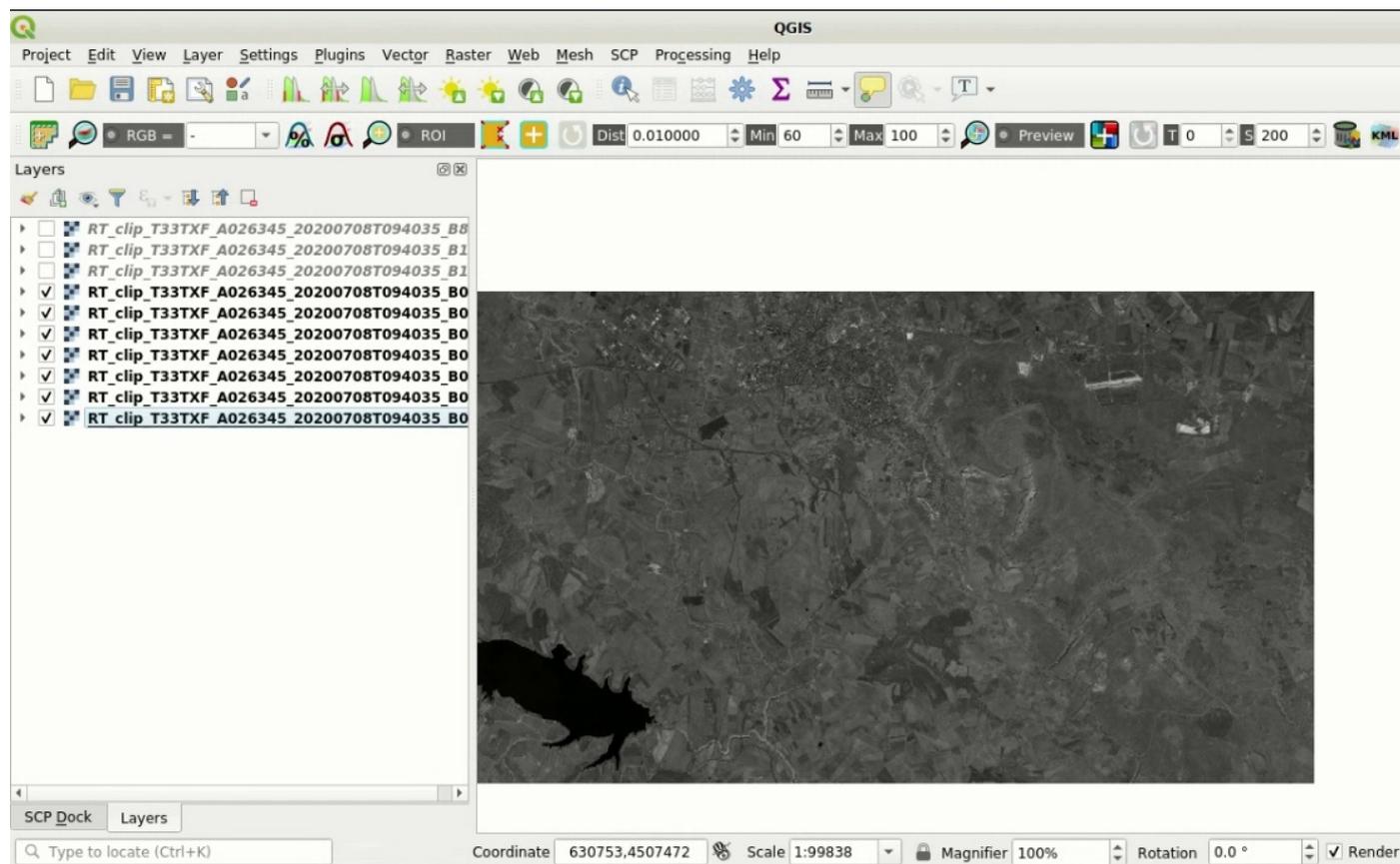
Fig. 8: *Clipped bands*
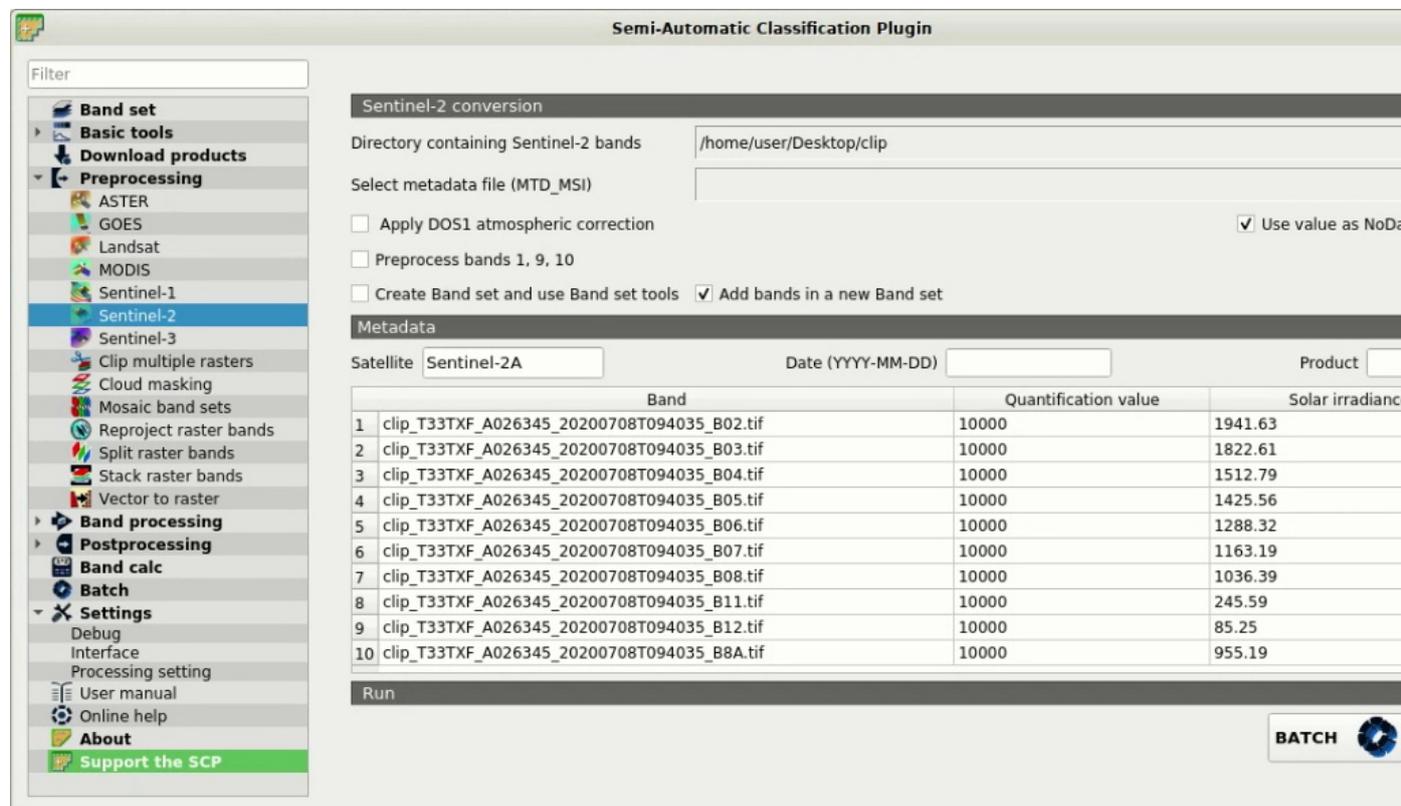
Fig. 9: *Sentinel-2 conversion to reflectance*
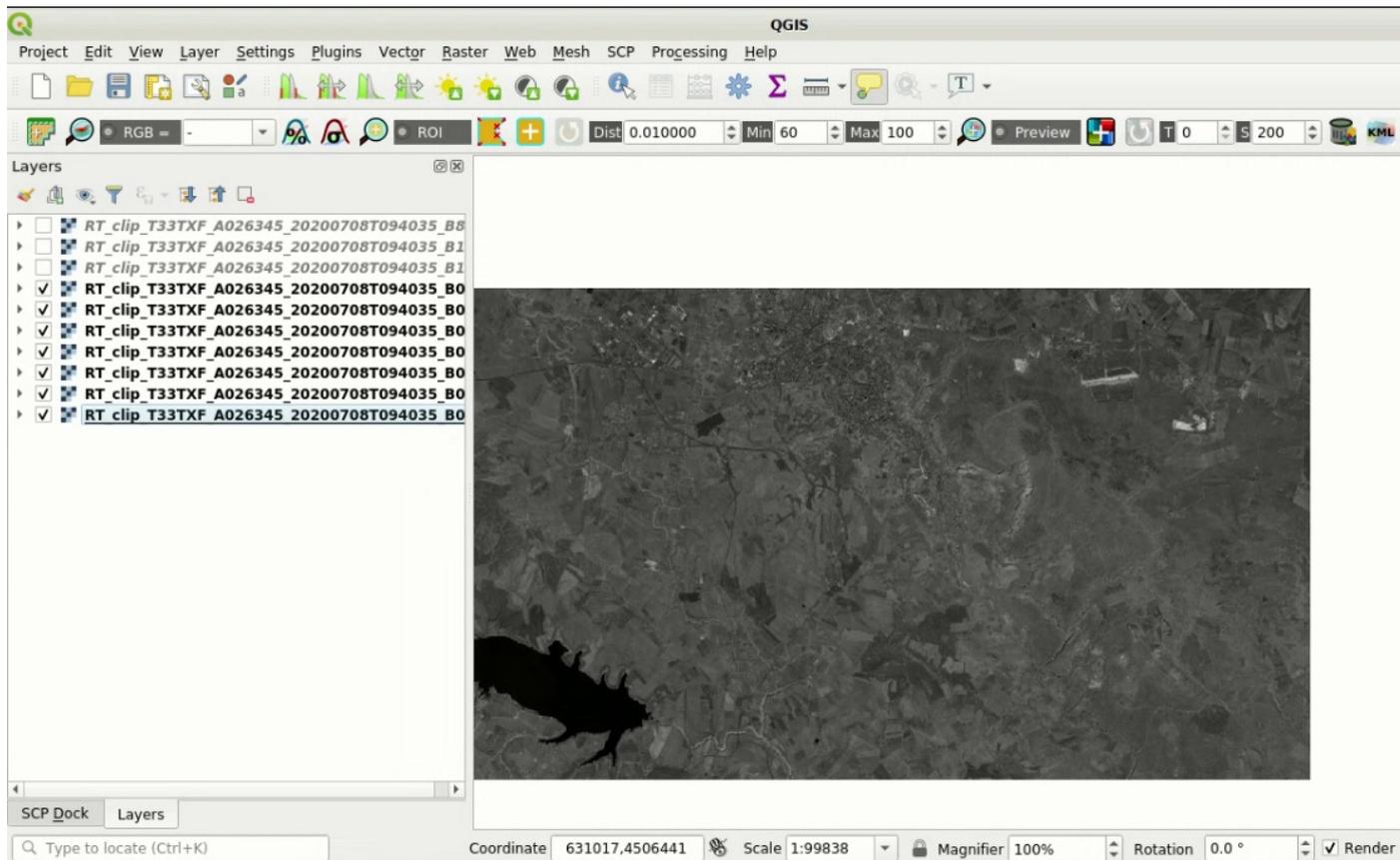
Fig. 10: *Converted Sentinel-2 bands*

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* classification. Open the tab *Band set* (page 31) clicking the button ![layers button] in the *SCP menu* (page 19) or the *SCP dock* (page 20).

In *Band set definition* click the button ![clear button] to clear all the bands from *active band set* created during the previous steps.

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

In the table *Band set definition* order the band names in ascending order (click ![sort button] to sort bands by name automatically). Finally, select *Sentinel-2* from the list *Wavelength quick 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 135) of bands: Near-Infrared, Red, and Green: in the *Working toolbar* (page 29), click the list *RGB=* and select the item `7-3-2` (corresponding to the band numbers in *Band set* (page 31)). 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 31) is defined, a temporary virtual raster (named `Virtual Band Set 1`) is created automatically, which allows for the display of *Color Composite* (page 135). 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 23) in order to collect *Training Areas* (page 135) (ROIs) and calculate the *Spectral Signature* (page 128) thereof (which are used in classification).
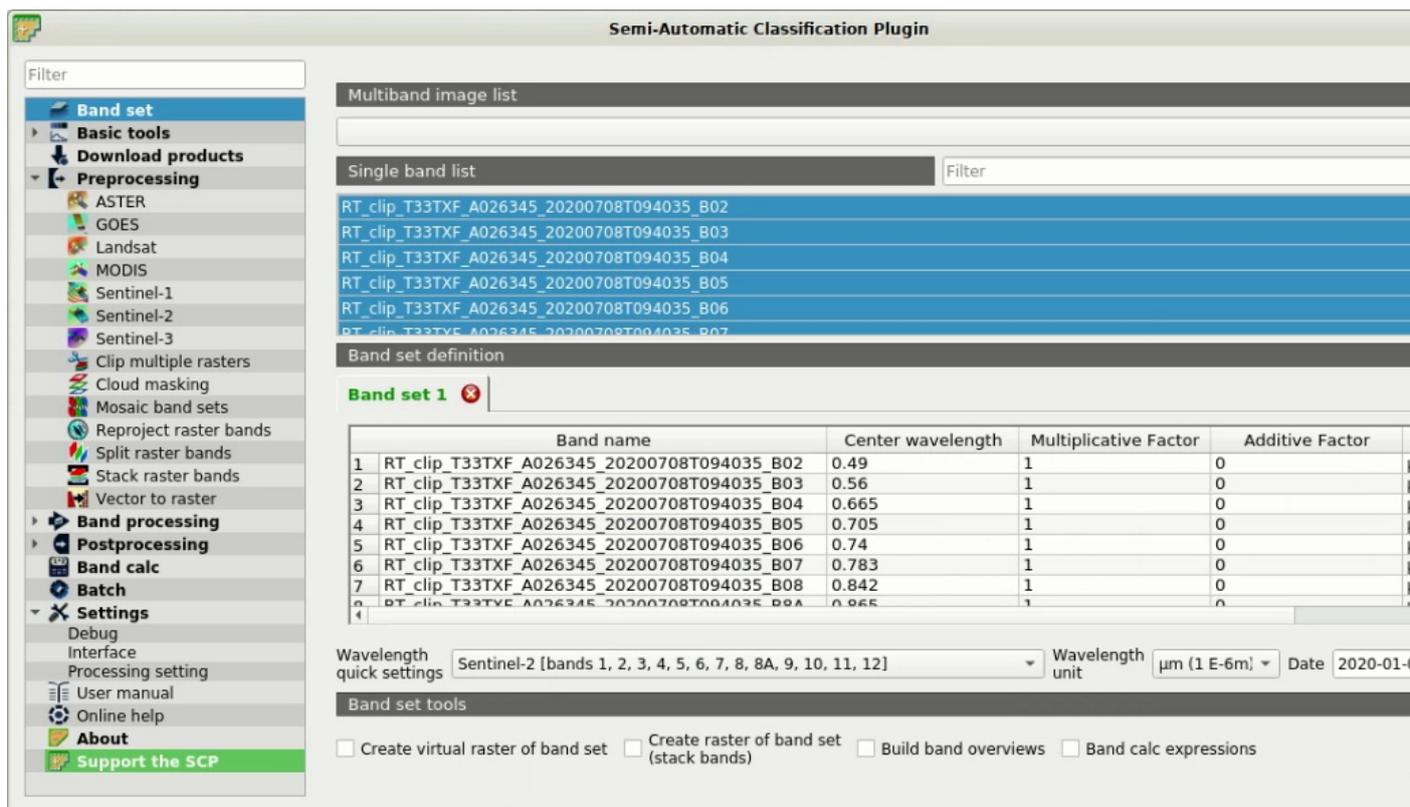
Fig. 11: *Definition of a band set*
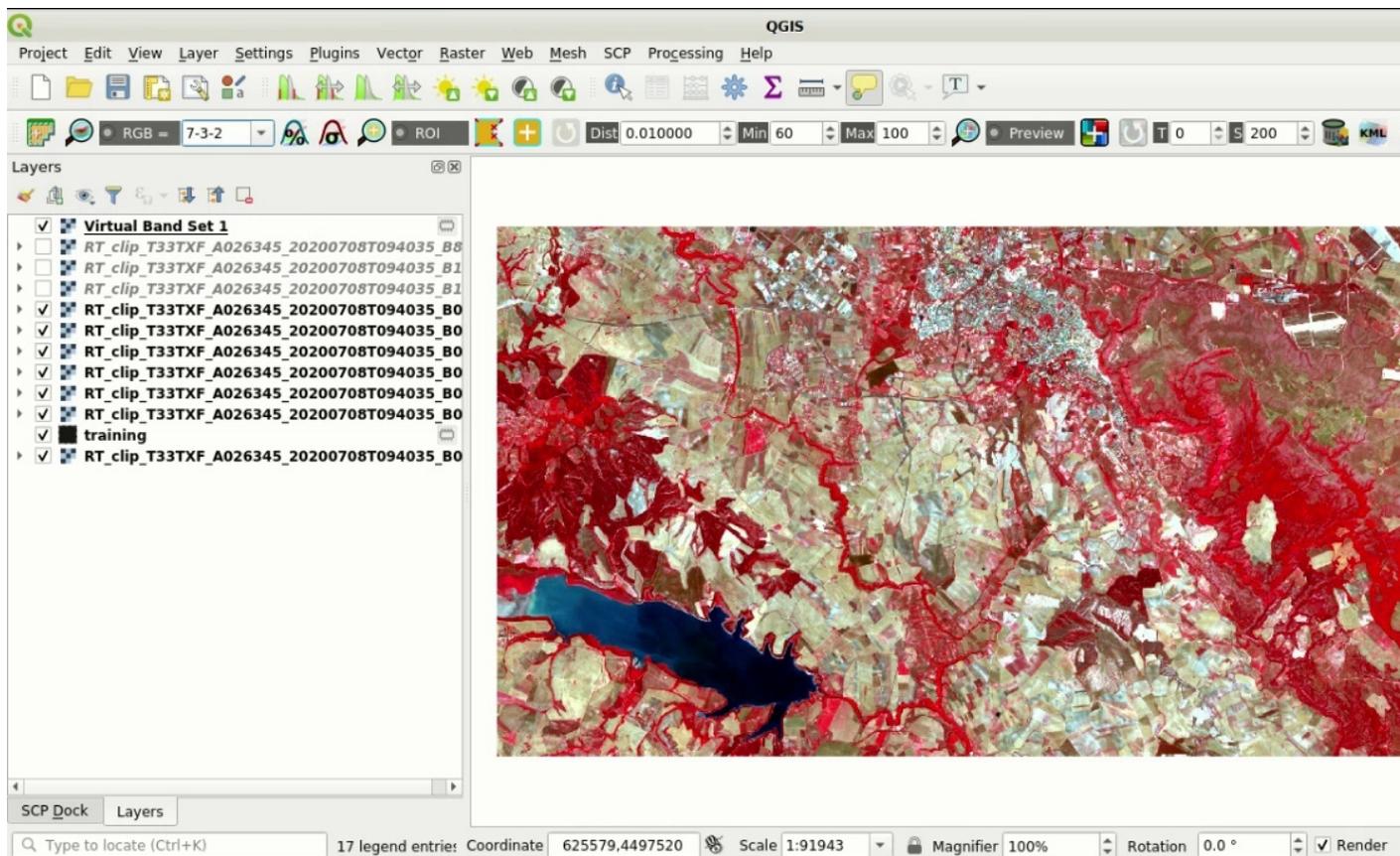
Fig. 12: *Color composite RGB=7-3-2*

In the *SCP dock* (page 20) select the tab *Training input* (page 23) and click the button [image] 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).

Create the ROIs

We are going to create ROIs defining the *Classes and Macroclasses* (page 136). 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 used the Macroclass IDs defined in the following table.

Macroclasses

Macroclass name	Macroclass ID
Water	1
Built-up	2
Vegetation	3
Soil	4

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

In the map zoom over the dark blue area in the lower left corner of the image which is a water body. To manually create a ROI inside the dark area, click the button [image] in the *Working toolbar* (page 29). 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.

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

Open the *Training input* (page 23) to define the *Classes and Macroclasses* (page 136) . In the *ROI & Signature list* (page 24) set *MC ID* = 1 and *MC Name* = `Water`; also set *C ID* = 1 and *C Name* = `Lake`. Now click [image] to save the ROI in the *Training input*.

After a few seconds, the ROI is listed in the *ROI & Signature list* (page 24) and the spectral signature is calculated (because [image] *Signature* is checked).

As you can see, the *C ID* in *ROI & Signature list* (page 24) 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 24) you can notice that the *Type* is *RS*, meaning that the ROI spectral signature was calculated and saved in the *Training input*.

Now we are going to create a second ROI for the built-up class using the automatic region growing algorithm. Zoom in the upper region of the image. In *Working toolbar* (page 29) set the *Dist* value to 0.05 . Click the button [image] in the *Working toolbar* (page 29) and click over the light blue 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.

Fig. 13: *Definition of Training input in SCP*
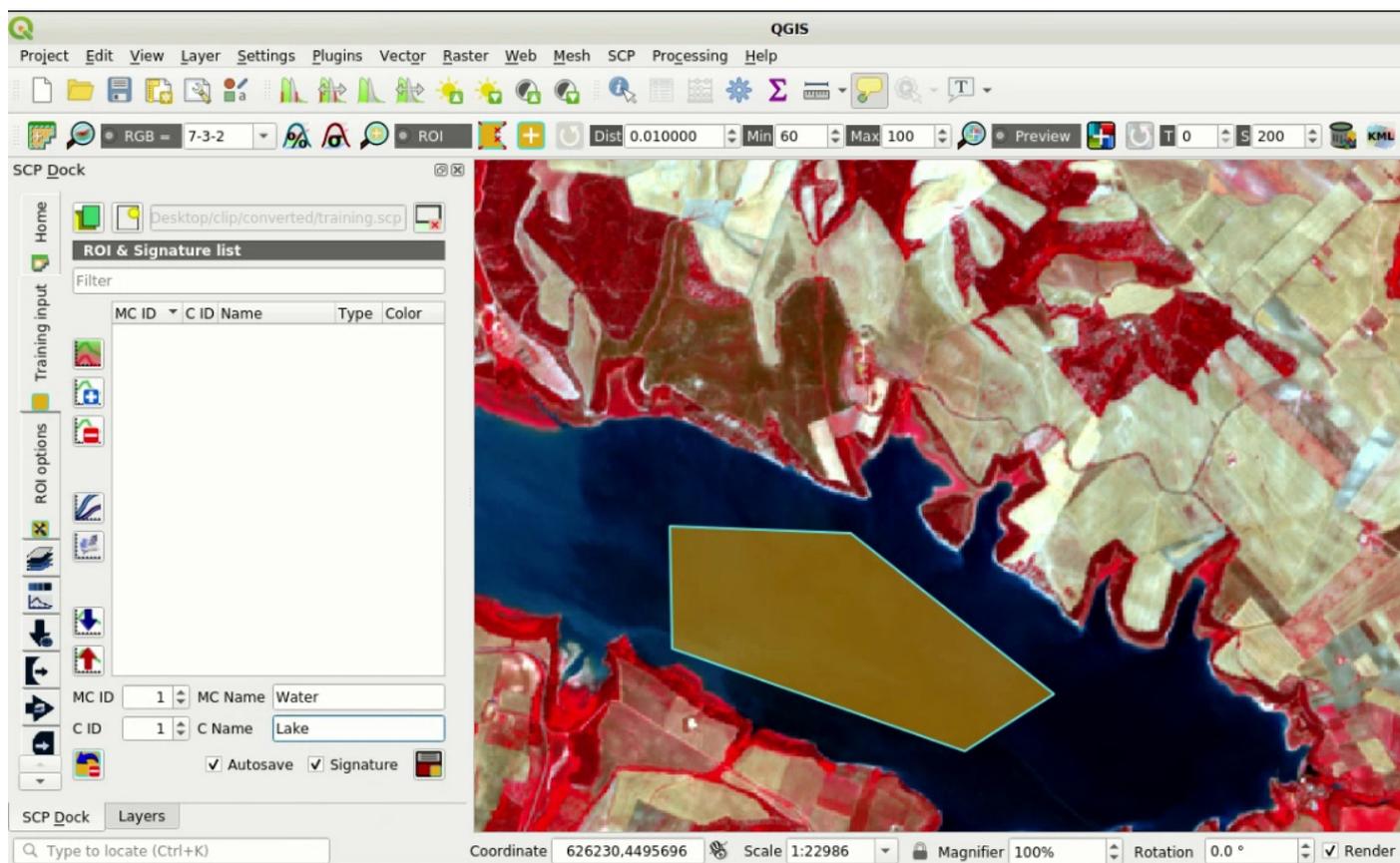
Fig. 14: *A temporary ROI created manually*

In the *ROI & Signature list* (page 24) set *MC ID* = 2 and *MC Name* = Built-up ; also set *C ID* = 2 (it should be already set) and *C Name* = Buildings.

Again, the *C ID* in *ROI & Signature list* (page 24) is automatically increased by 1.

After clicking the button ![+] in the *Working toolbar* (page 29) 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 *ROI options* (page 27)). 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.

Create a ROI for the class Vegetation (red pixels in color composite RGB=7-3-2) and a ROI for the class Soil (bare soil or low vegetation) (yellow pixels in color composite RGB=7-3-2) following the same steps described previously. The following images show a few examples of these classes identified in the map.

Assess the Spectral Signatures

Spectral signatures are used by *Classification Algorithms* (page 137) 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 143) 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.
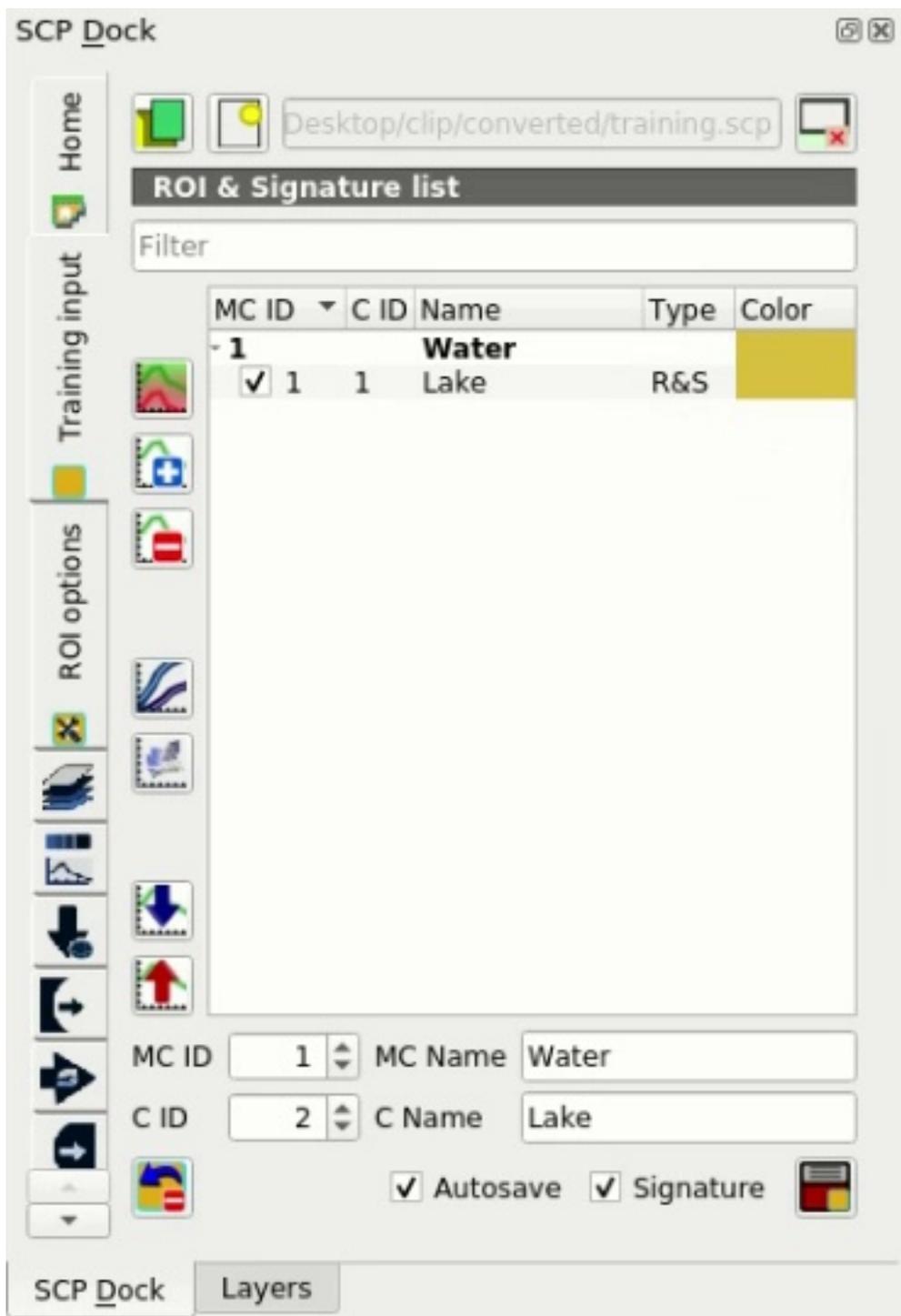
Fig. 15: *The ROI saved in the Training input*
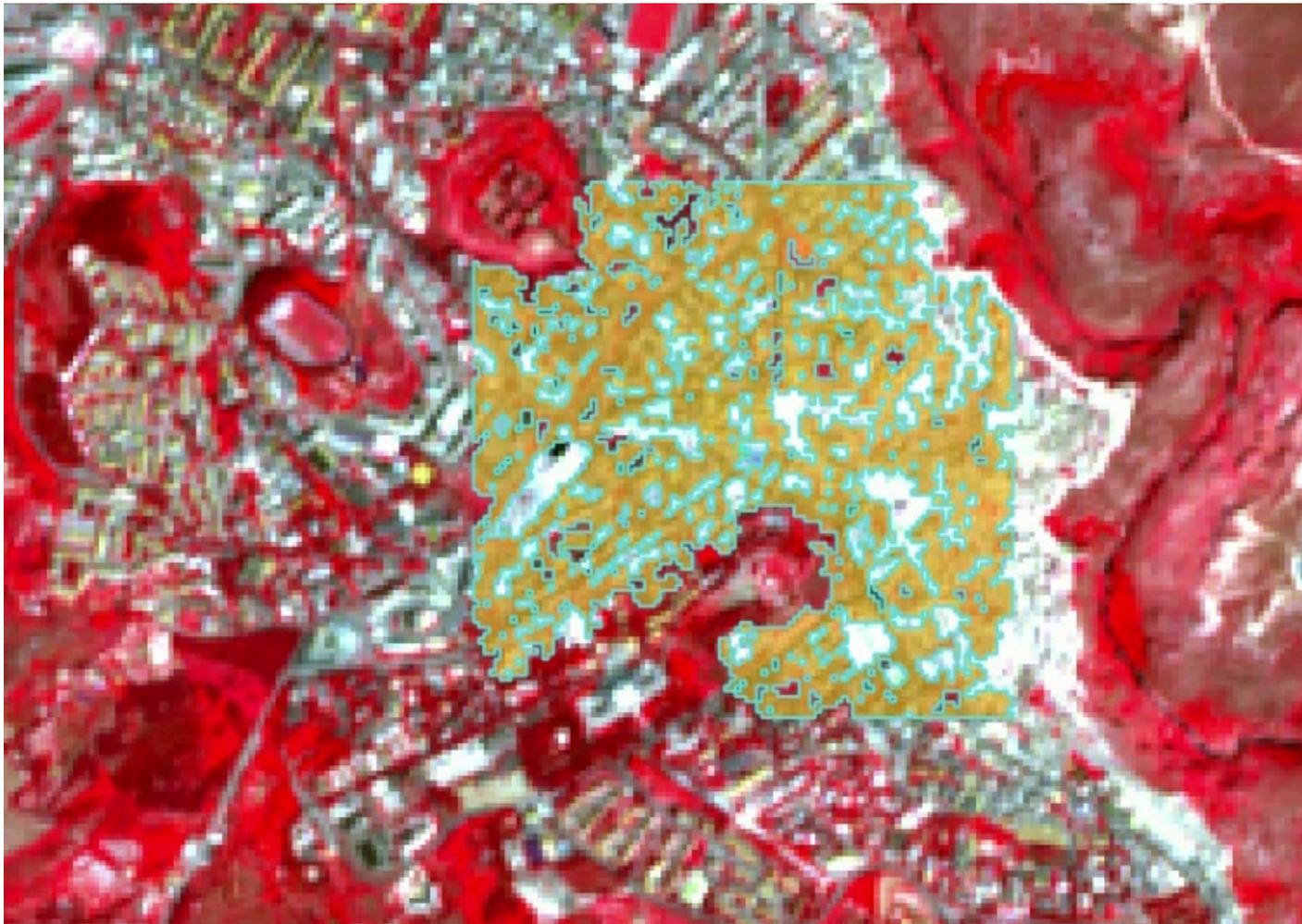
Fig. 16: *A temporary ROI created with the automatic region growing algorithm*
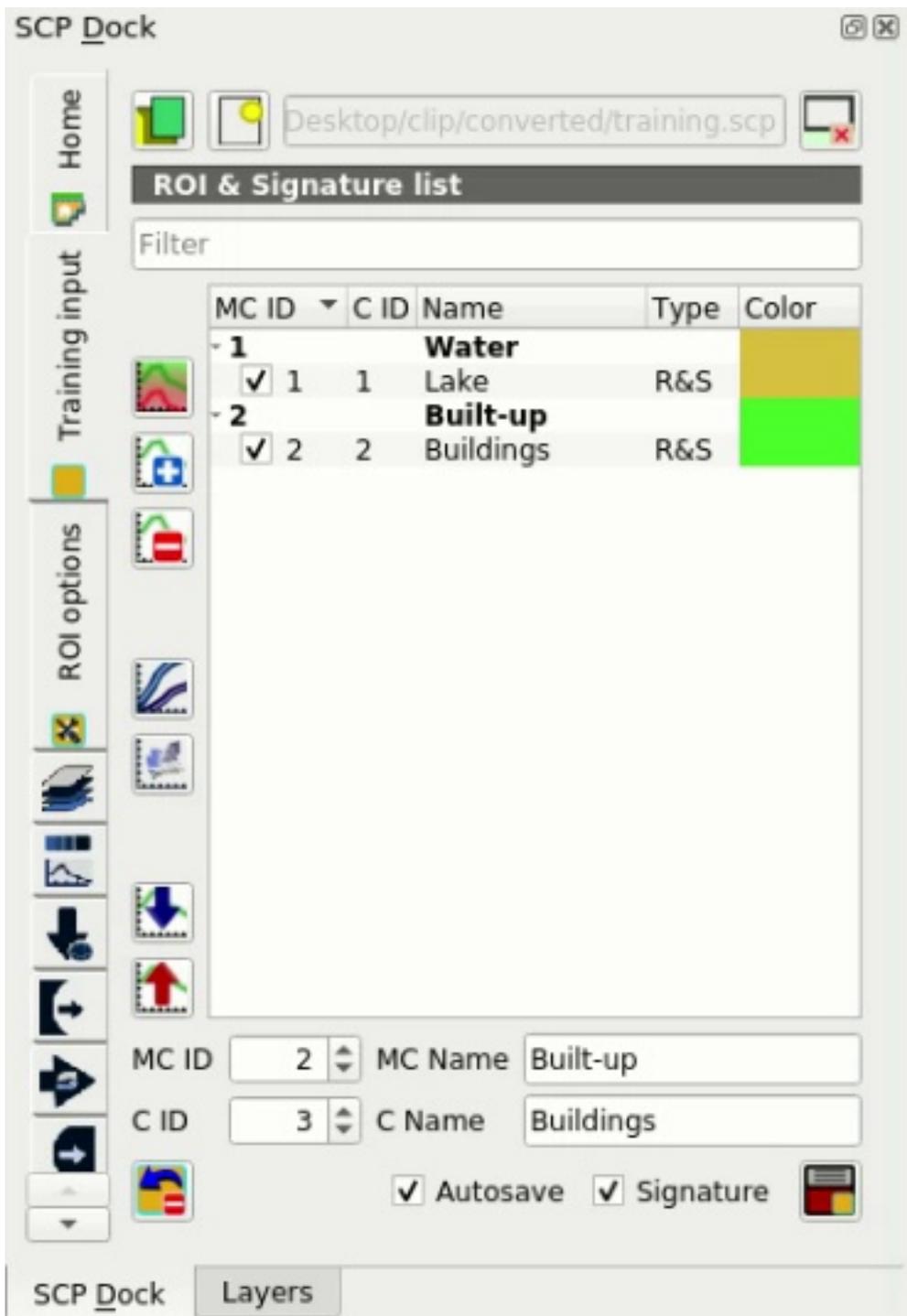
Fig. 17: *The ROI saved in the Training input*

Fig. 18: *NDVI value of vegetation pixel displayed in the map. Color composite RGB = 7-3-2*

Fig. 19: *Vegetation. Color composite RGB = 4-3-2*
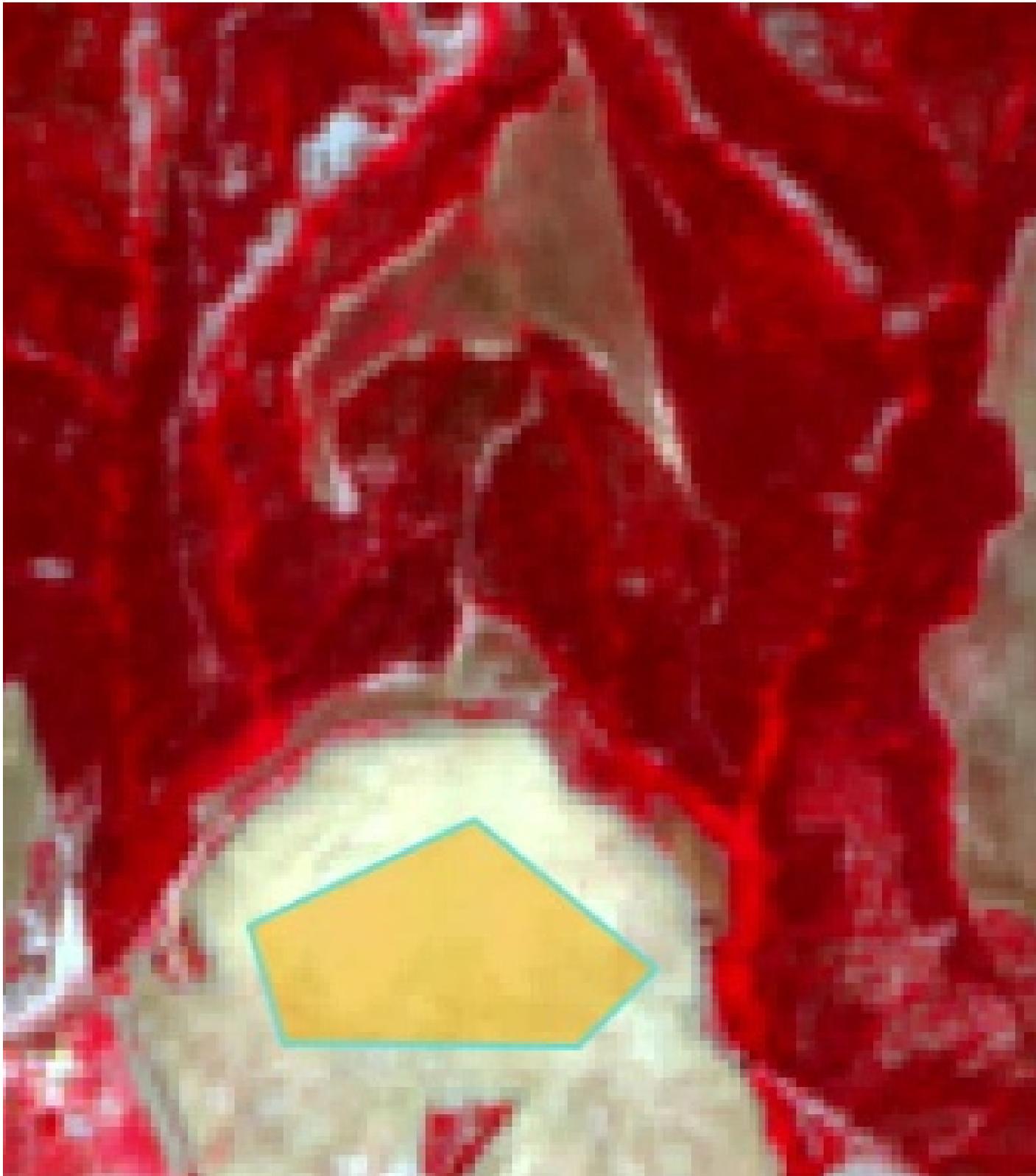
Fig. 20: *Soil. Color composite RGB = 4-3-2*

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 24) highlight two or more spectral signatures (with click in the table), then click the button ![icon]. The *Spectral Signature Plot* (page 115) is displayed in a new window. Move and zoom inside the *Plot* (page 116) to see if signatures are similar (i.e. very close). Double click the color in the *Plot Signature list* (page 115) to change the line color in the plot.

We can see in the following figure a signature plot of different materials.
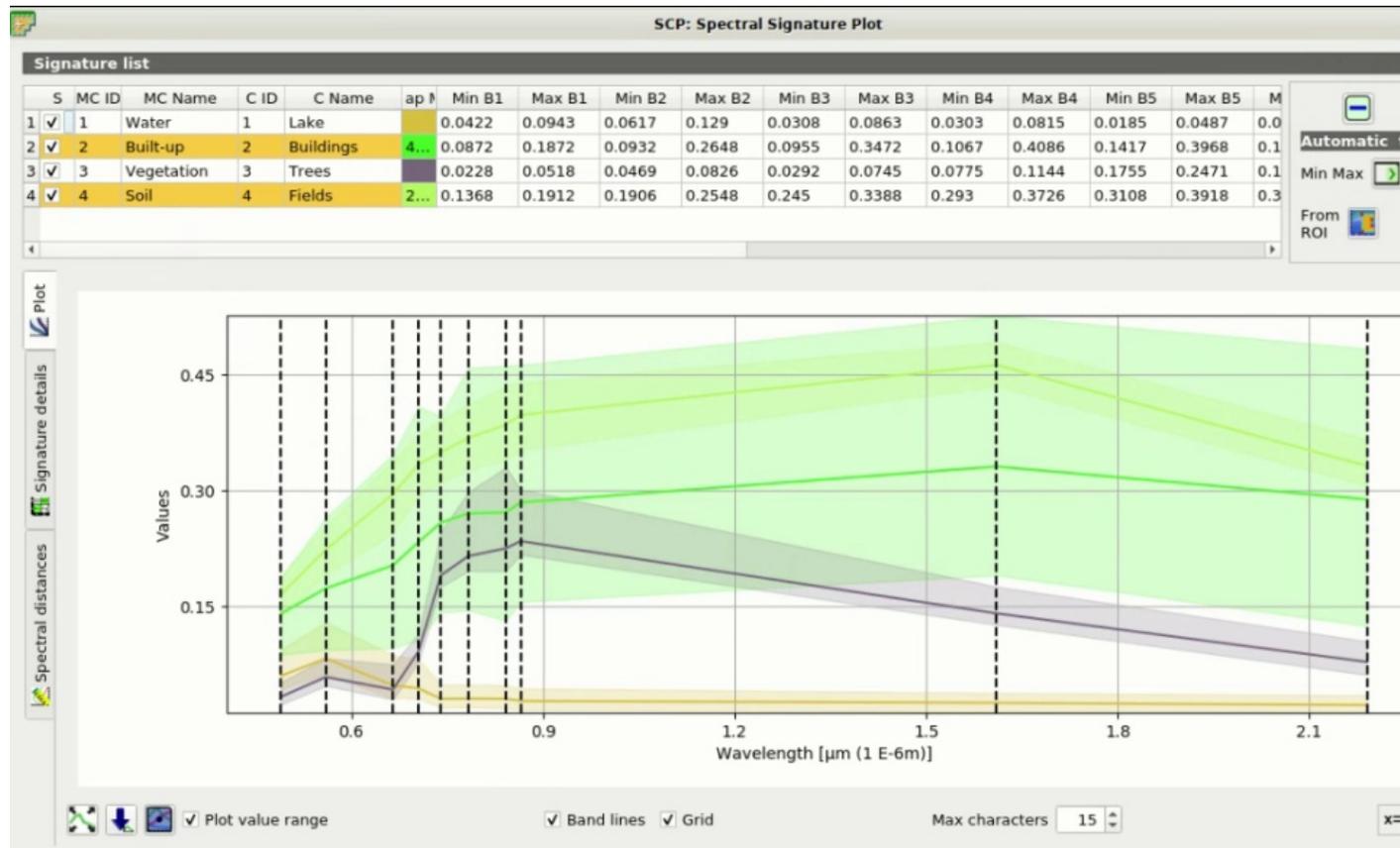
Fig. 21: *Spectral plot*

In the plot we can see the line of each signature (with the color defined in the *ROI & Signature list* (page 24)), 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 115).

Additionally, we can calculate the spectral distances of signatures (for more information see *Spectral Distance* (page 143)). Highlight two or more spectral signatures with click in the table *Plot Signature list* (page 115), then click the button ![icon]; distances will be calculated for each pair of signatures. Now open the tab *Spectral distances* (page 117); we can notice that similarity between signatures vary according to considered algorithm.

For instance, two signatures can be very similar for *Spectral Angle Mapping* (page 139) (very low *Spectral Angle* (page 144)), but quite distant for the *Maximum Likelihood* (page 138) (*Jeffries-Matusita Distance* (page 143) 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 117).

We need to create several ROIs (i.e. spectral signatures) for each macroclass (repeating the steps in *Create the ROIs* (page 167)), assigning a unique C ID to each spectral signature, and assess the spectral distance thereof
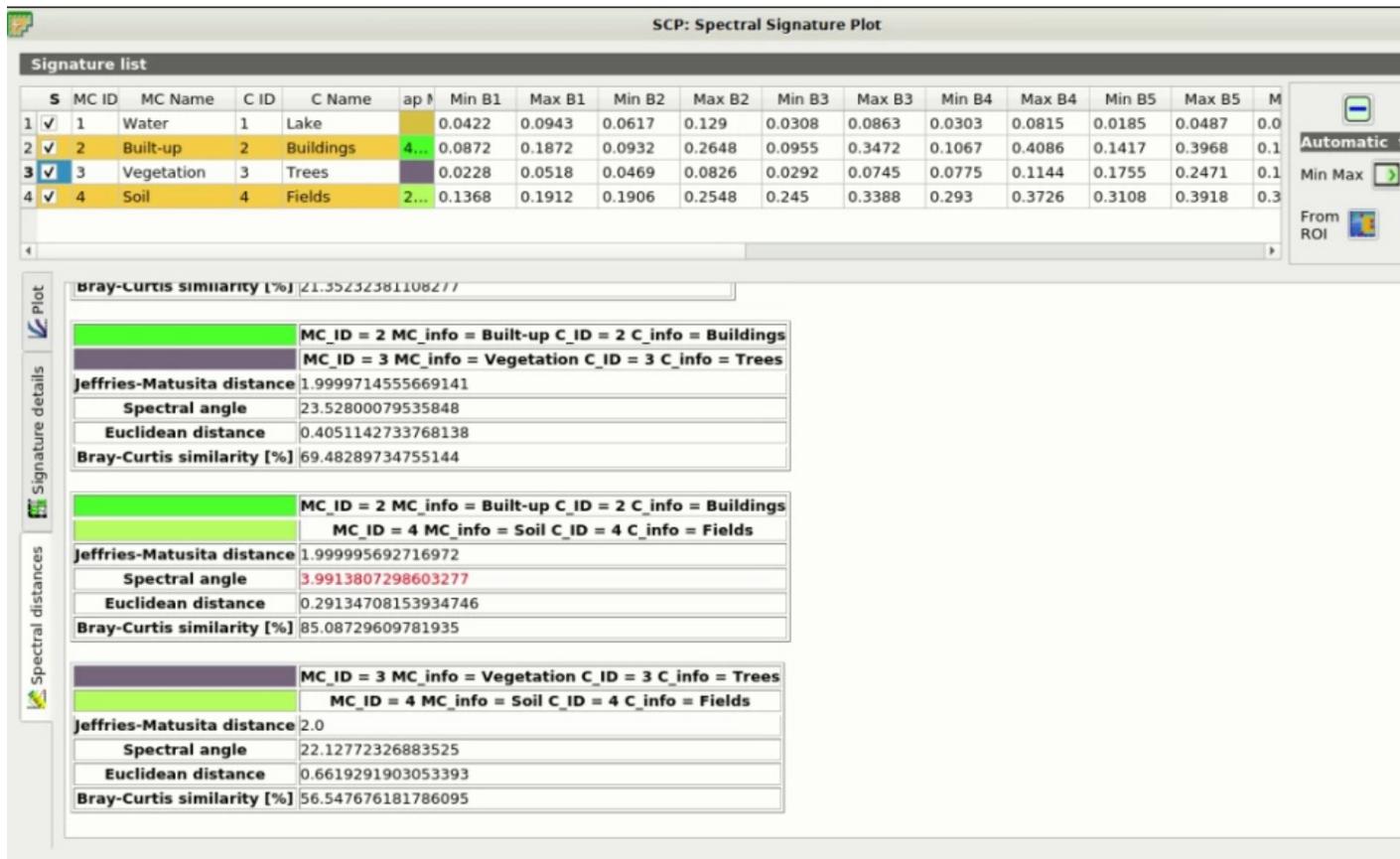
Fig. 22: *Spectral distances*

in order to avoid the overlap of spectral signatures belonging to different macroclasses.

In the list *RGB=* of the *Working toolbar* (page 29) type `10-3-2` (you can also use the tool *RGB list* (page 42)). Using this color composite, urban areas are grey, bare soils are light green, and vegetation is brown. This color composite `RGB = 10-3-2` can help the identification of soils more than natural color composite (`RGB = 3-2-1`).

It is worth mentioning that you can show or hide the temporary ROI clicking the button ⬤ *ROI* in *Working toolbar* (page 29).

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 30) 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 24), 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 *ROI & Signature list* (page 24).

Now we need to select the classification algorithm. In this tutorial we are going to use the *Maximum Likelihood* (page 138).

Open the tool *Classification* (page 72) to set the use of classes or macroclasses. Check *Use* ☑ *C ID* and in *Algorithm* (page 73) select the *Spectral Angle Mapping*. The *input band set* is 1 because it is the number of the band set containing the image (bands) that we want to classify.
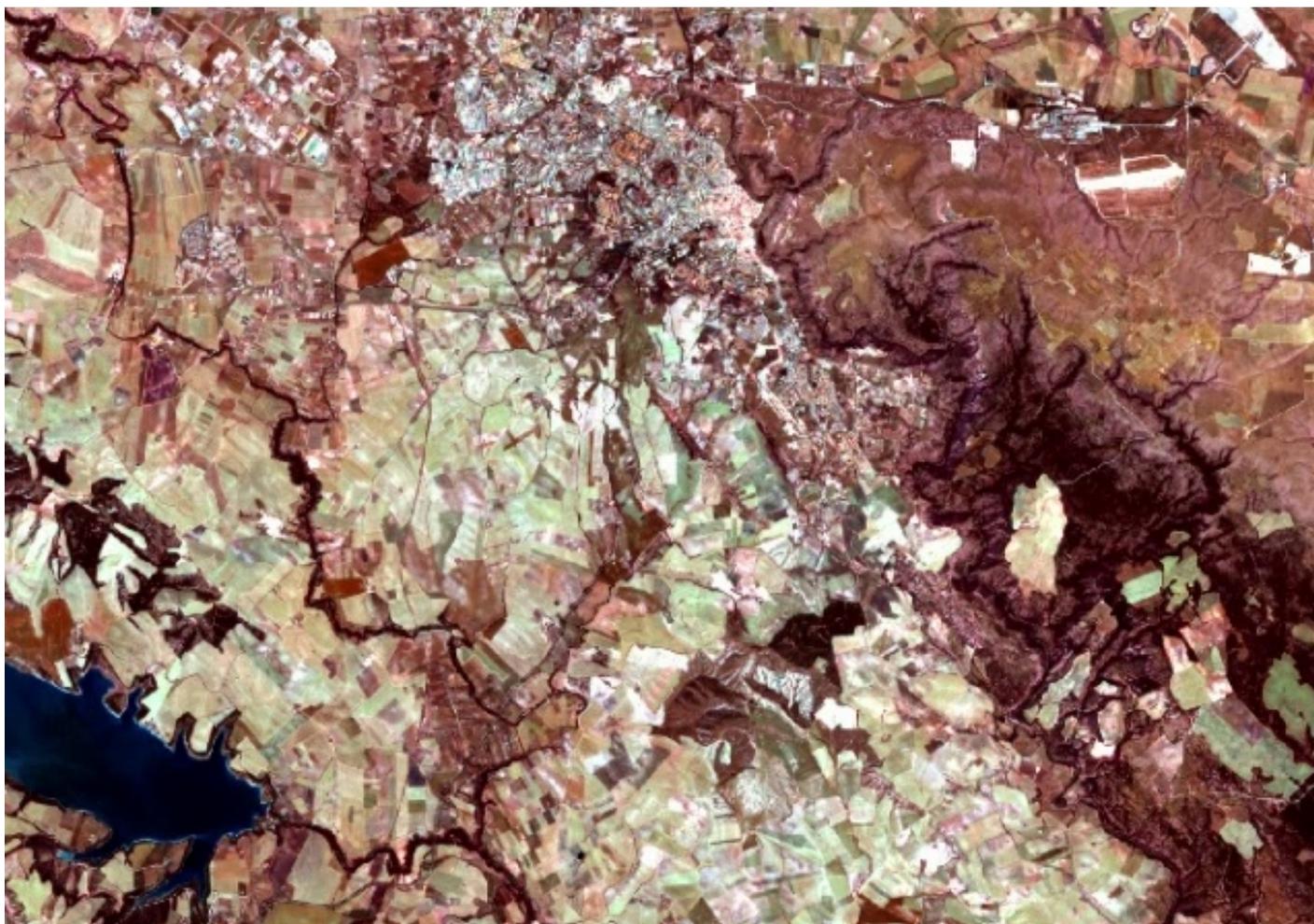
Fig. 23: *Color composite RGB = 3-7-10*

TIP : Change frequently the *Color Composite* (page 135) in order to clearly identify the materials at the ground; use the mouse wheel on the list *RGB=* of the *Working toolbar* (page 29) for changing the color composite rapidly; also use the

buttons and for better displaying the *Input image* (i.e. image stretching).

Fig. 24: *Definition of class colors*
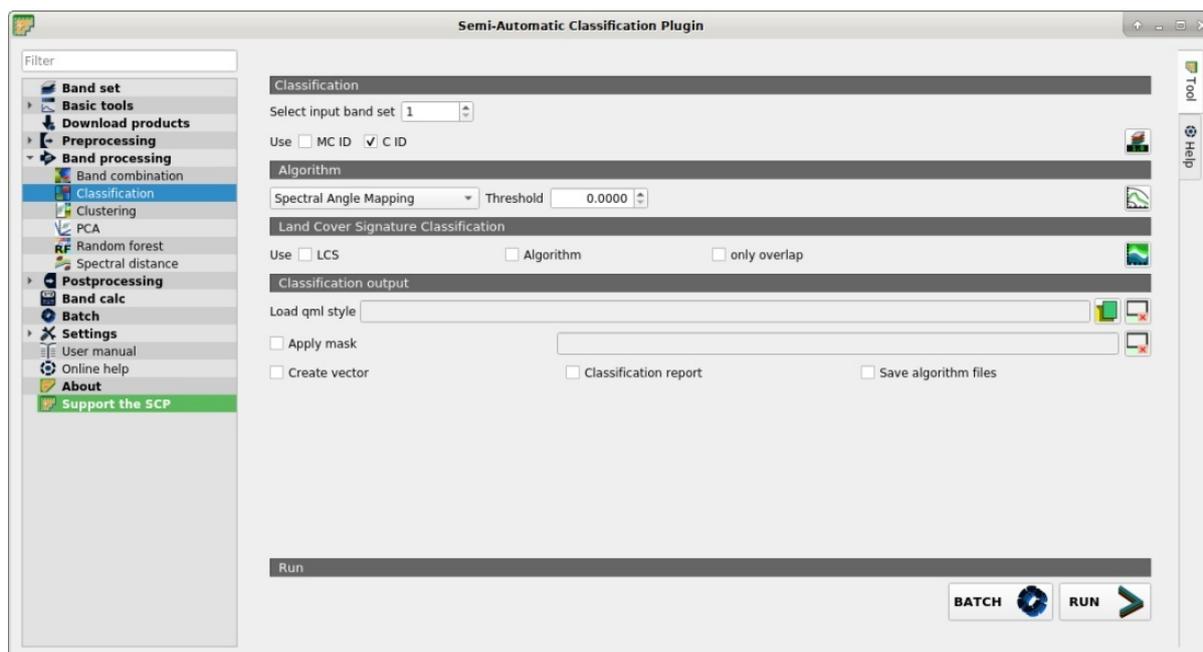
Fig. 25: *Setting the algorithm and using C ID*

In *Classification preview* (page 30) 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 72) check *Use* *MC ID* and click the button in *Classification preview* (page 30).

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 29).

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 24). Therefore, the phases *Create the ROIs* (page 167) and *Create a Classification Preview* (page 177) 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 24)), we can perform the actual land cover classification of the whole image.

In *Classification* (page 72) check *Use* *MC ID*. In the *Classification output* (page 74) 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 114) 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.
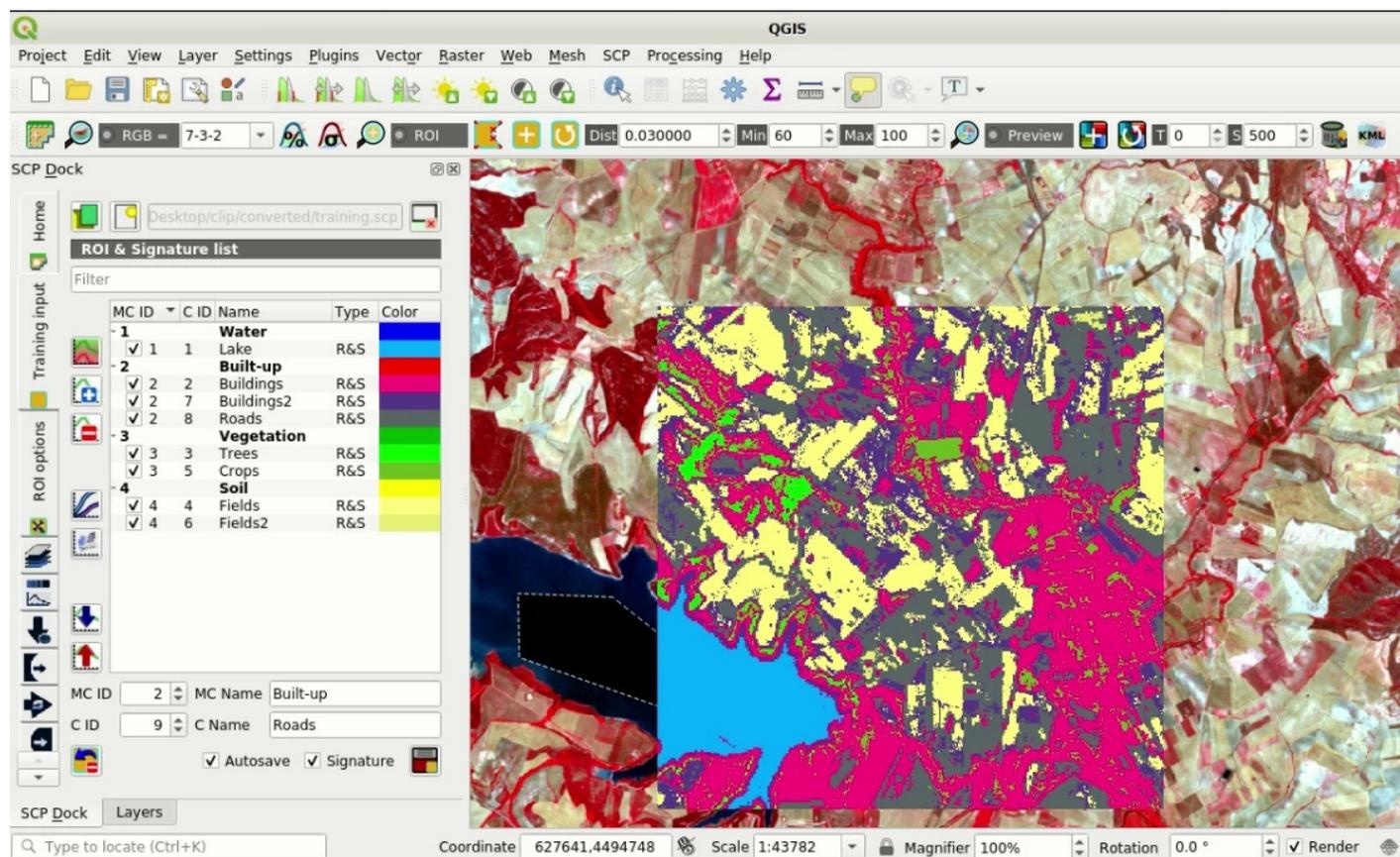
Fig. 26: *Classification preview displayed over the image using C ID*

5.2 Tutorial 2

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

- *Tutorial 2: Unsupervised Classification* (page 181)

  - *Input Data* (page 182)

  - *Clustering* (page 186)

  - *Reclassification of the output* (page 187)

  - *Refinement of the output* (page 188)

5.2.1 Tutorial 2: Unsupervised Classification

This is a basic tutorial about the use of *SCP* for the unsupervised classification of a multispectral image. It is recommended to read the *Brief Introduction to Remote Sensing* (page 125) before this tutorial, and in particular the part *Clustering* (page 148).

Clustering can be used for unsupervised classification, which means that no training input is required, producing classes (i.e. clusters) that have no definition and consequently the user must assign a land cover label to each class.

The purpose of the classification is to identify the land cover classes with the corresponding ID codes defined in the following table.
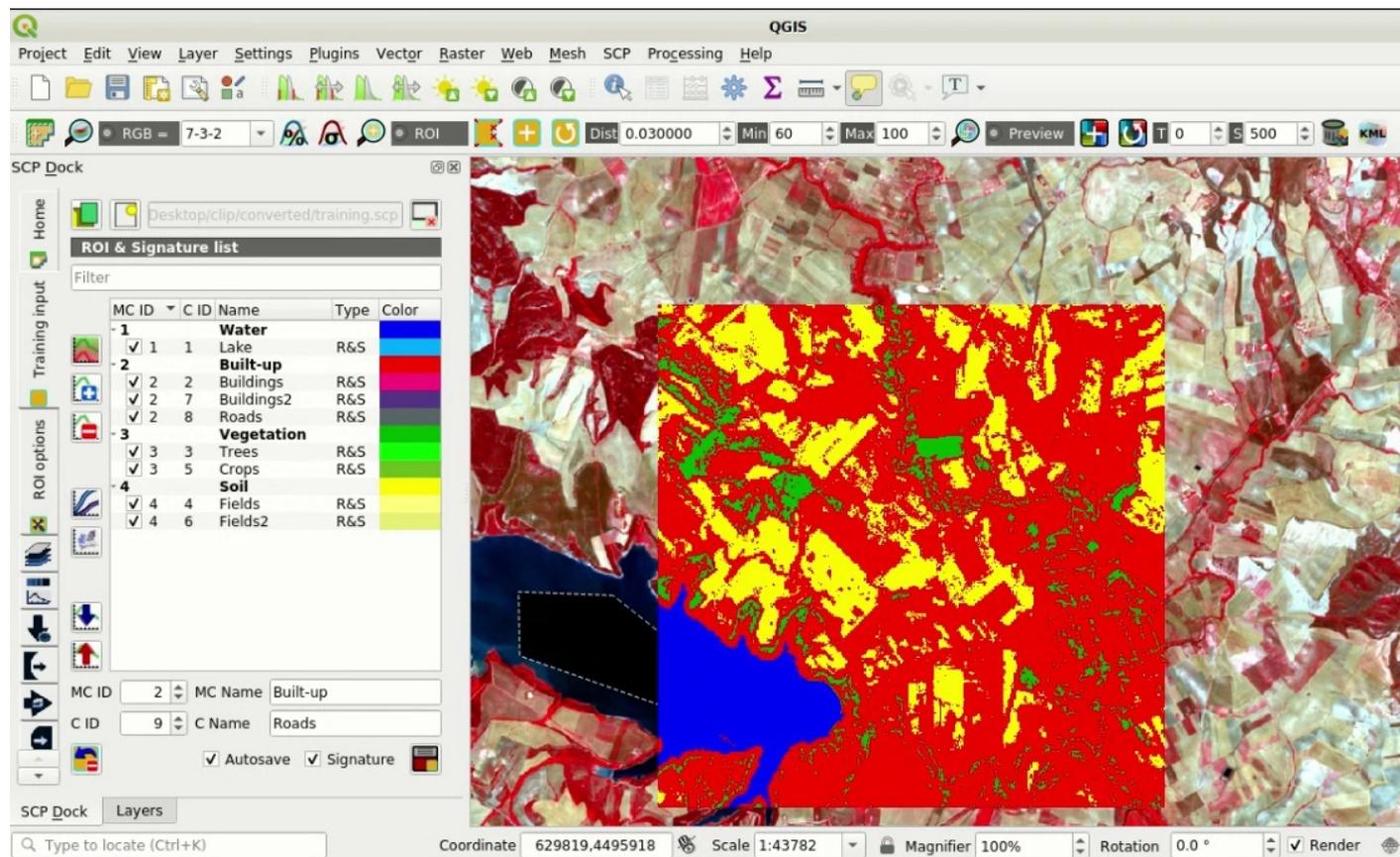
Fig. 27: *Classification preview displayed over the image using MC ID*

Classes

Class name	Class ID
Water	1
Built-up	2
Vegetation	3
Soil	4

Following the video of this tutorial.

http://www.youtube.com/watch?v=kRPNjNvrLPU

Input Data

Any multispectral image can be used for unsupervised classification. In this tutorial, we are going to use a subset of a *Sentinel-2 Satellite* (page 130) image (Copernicus land monitoring services) and use the bands illustrated in the following table. You can download the image from this archive (about 30 MB, © Copernicus Sentinel data 2020 downloaded from https://scihub.copernicus.eu/), and then unzip the downloaded file.
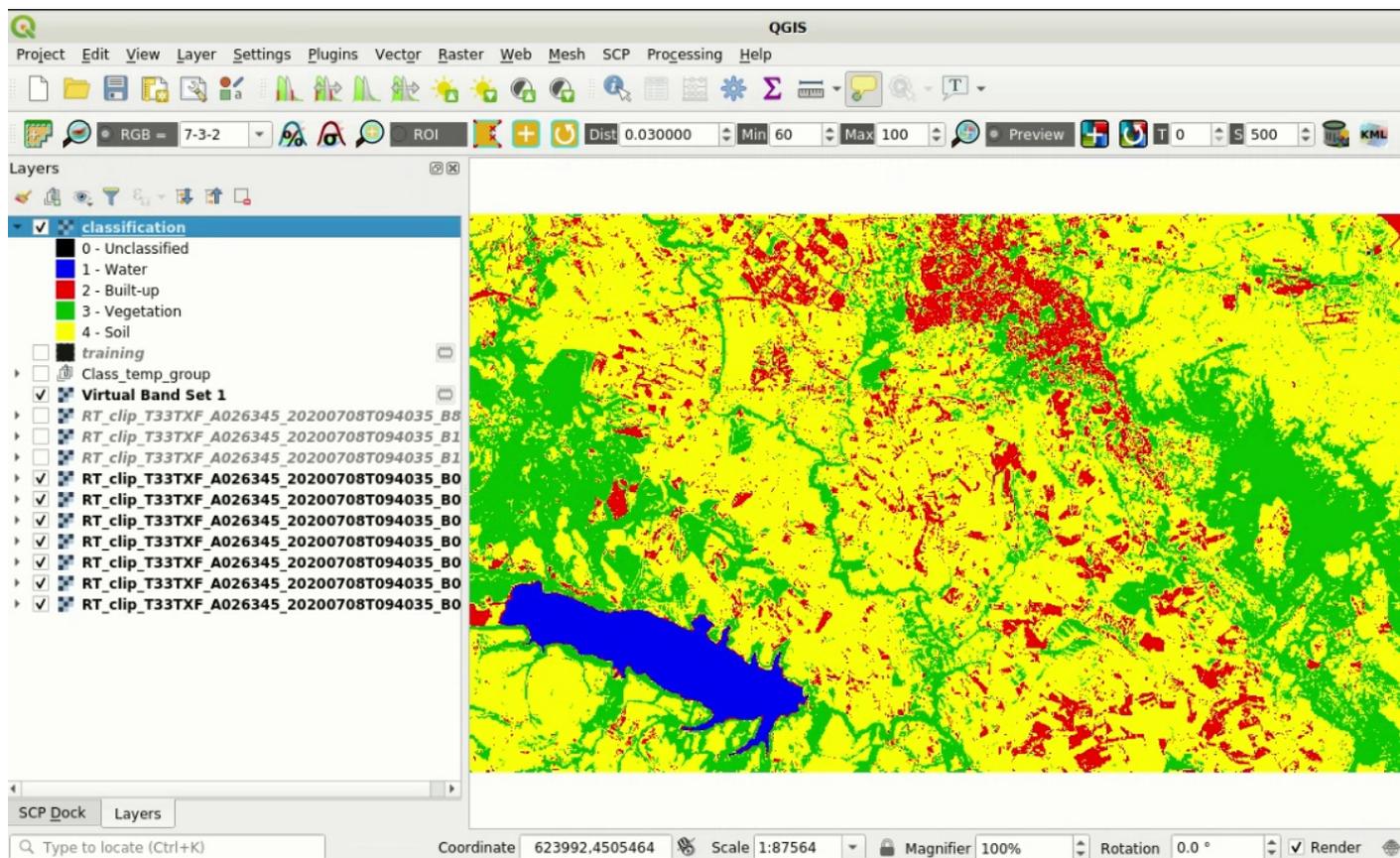
Fig. 28: *Result of the land cover classification*

RGB = 3-2-1
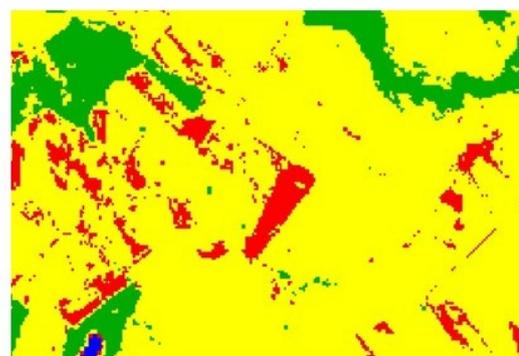
Classification

Fig. 29: *Example of error: Soil classified as Built-up*

RGB = 3-2-1
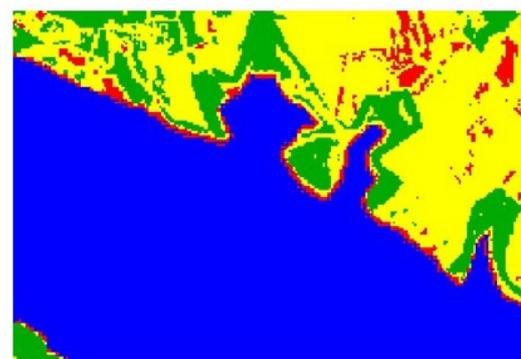
Classification

Fig. 30: *Example of error: Water bodies classified as Built-up*

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*.

The downloaded product is a Sentinel-2 Level 2A image, which is already atmospherically corrected (Level 1C images require atmospherical correction as described in *Image conversion to reflectance* (page 150)). Nevertheless, preprocessing is required to convert pixel values to a decimal value of reflectance.

Conversion to reflectance (see *Radiance and Reflectance* (page 128)) can be performed automatically. In order to convert bands to reflectance, open the *Preprocessing* (page 50) clicking the button ![icon] in the *SCP menu* (page 19) or the *SCP dock* (page 20), and select the tab *Sentinel-2* (page 59).

Click the button *Directory containing Sentinel-2 bands* ![icon] and select the directory of Sentinel-2 bands. The list of bands is automatically loaded in the table *Metadata* (page 60).

You can ignore *Select metadata file* because this conversion doesn't require additional information.

Check the option ![icon] *Create Band set and use Band set tools* in order to create automatically the input *Band set* that will be used for clustering.

To start the conversion process, click the button *RUN* ![icon] and select the directory where converted bands are saved. After a few minutes, converted bands are loaded and displayed (file name beginning with RT_).

Open the tab *Band set* (page 31) clicking the button ![icon] in the *SCP menu* (page 19) or the *SCP dock* (page 20). The bands are already listed in the first *Band set*.
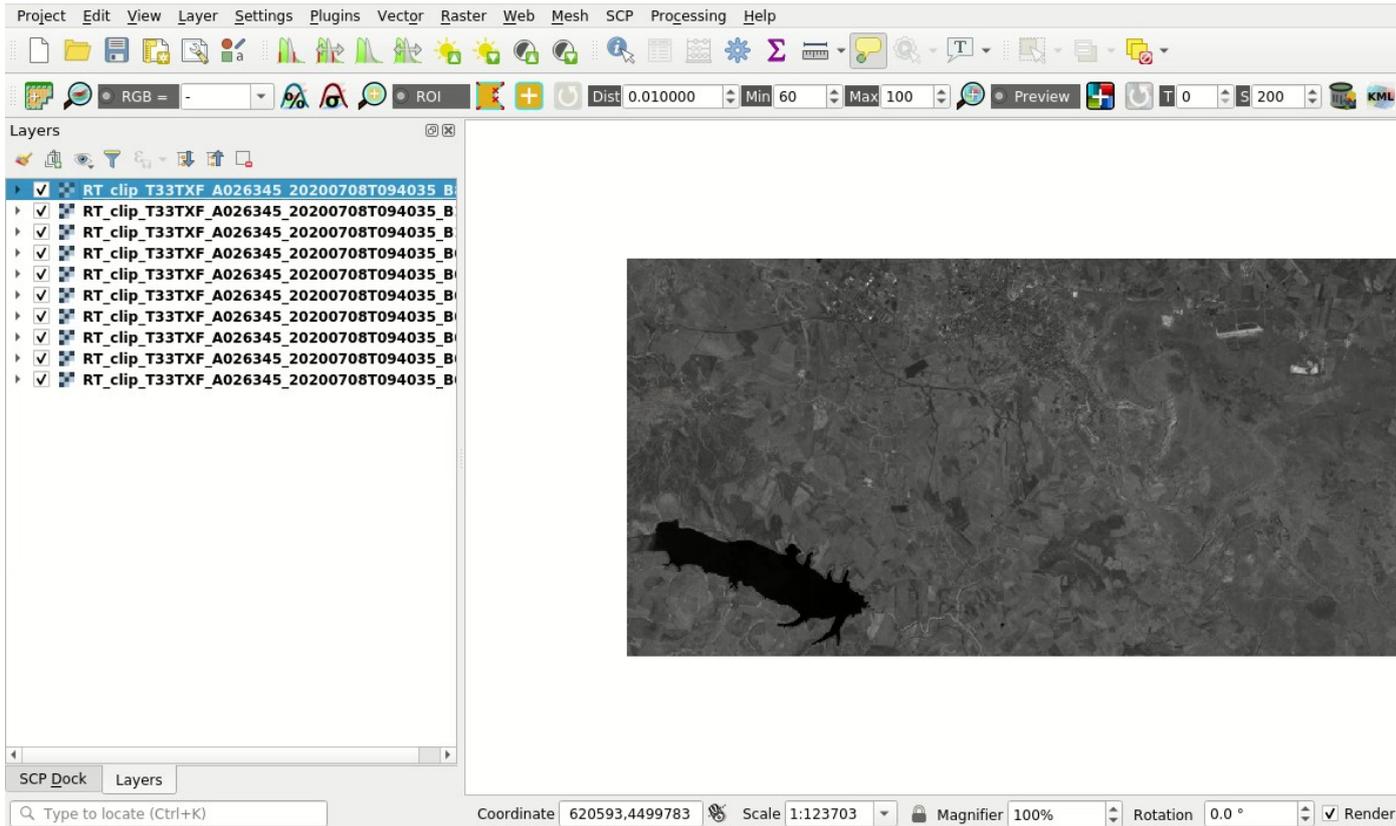
Fig. 31: *Converted bands*
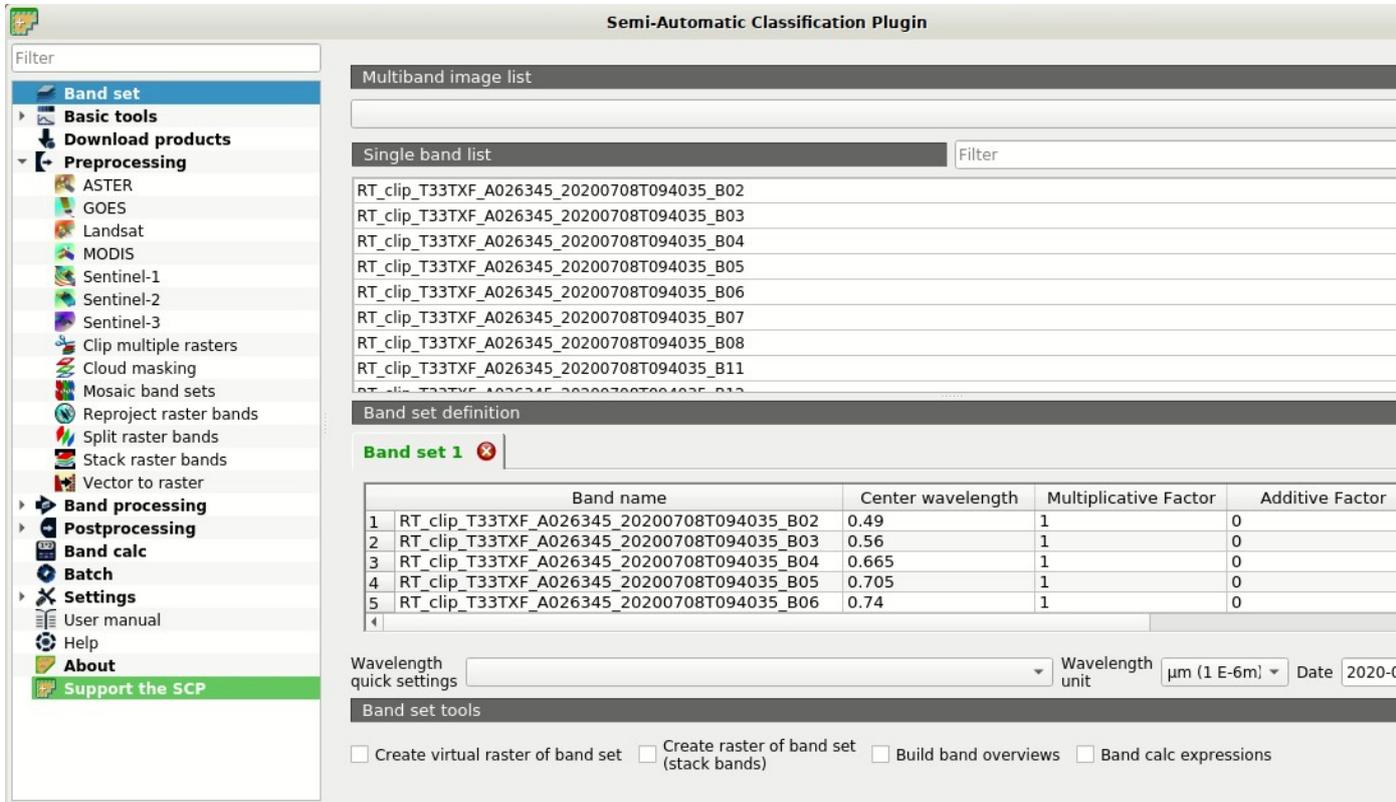
Fig. 32: *Band set*

Clustering

Clustering requires the user to define the number of clusters (i.e. classes) expected in the image, which correspond to as many spectral signatures (i.e. seeds). During the first iteration clusters are produced calculating the pixel spectral distance with initial spectral signatures. Pixels are assigned according to the most similar spectral signature, therefore producing clusters. In this tutorial we are going to perform clustering using the ISODATA algorithm, which includes steps for merging clusters having similar spectral signatures and splitting clusters having too high variability. We are going to select randomly the starting spectral signatures and use the algorithm *Euclidean Distance* (page 144) for distance calculation.

Open the tab *Clustering* (page 75) clicking the button ![icon] in the *SCP menu* (page 19) or the *SCP dock* (page 20). In *Select input band set* ![1] we set 1 because we are going to classify the first *Band set*.

In *Method* check *ISODATA*. In ![checkbox] *Distance threshold* set 0.01, which is the distance required for merging clusters.

In *Number of classes* set 10; we set a number higher than the land cover classes defined at the beginning of this tutorial because we try to account for spectral variability of classes. In *Max number of iterations* set 10; in general, the more the iterations the better the result.

In *ISODATA max standard deviation* we set the maximum standard deviation considered for splitting a class; we can set the value 0.2 here. In *ISODATA minimum class size in pixels* we can set 10.

We check the option *Use random seed signatures* to randomly selects the spectral signatures of seed pixels from

Band set. Now click the button *RUN* ![icon] and define the path of the classification output.
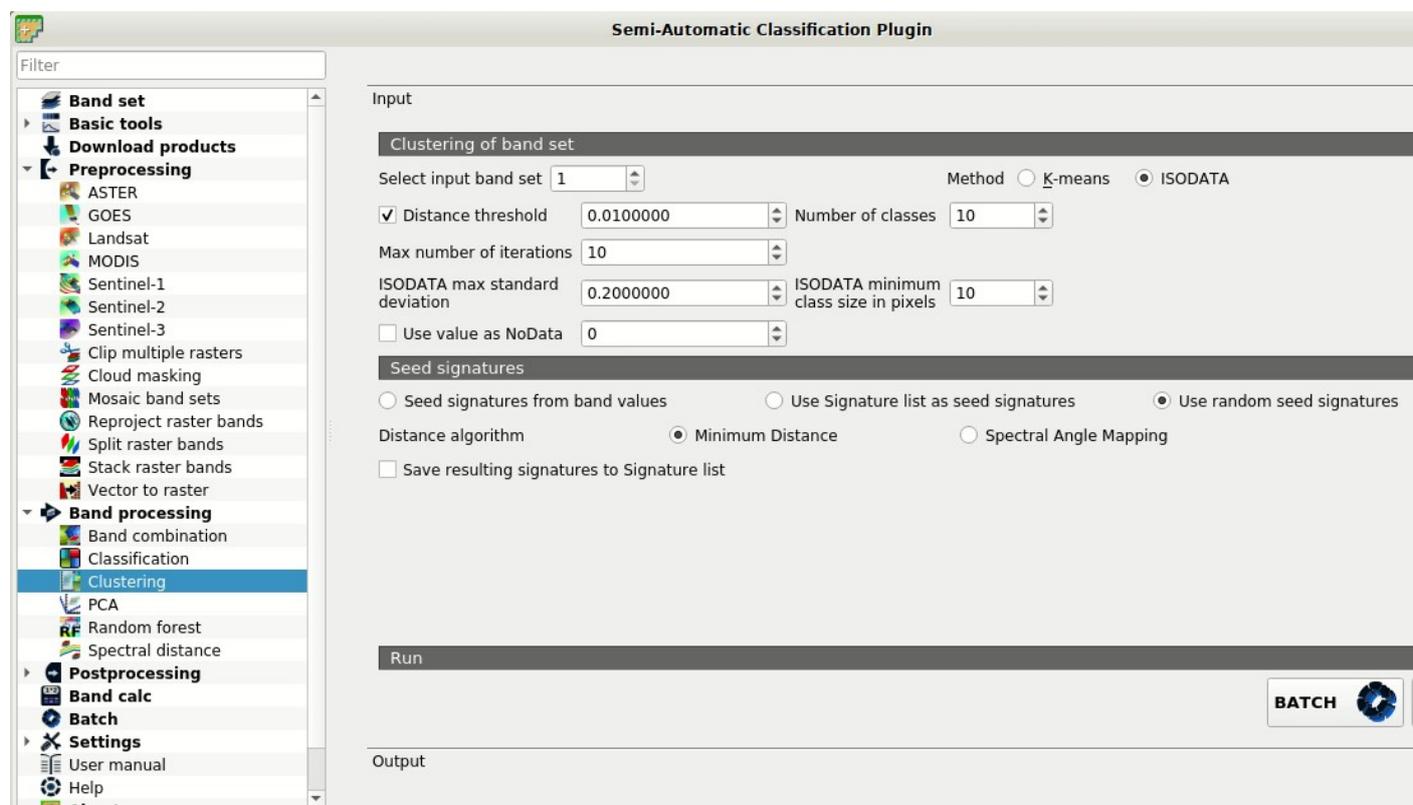
Fig. 33: *Clustering tool*

After the process, the result is displayed in the map. The result of the unsupervised classification is a raster having values that don't correspond to the class IDs defined at the beginning of this tutorial. The number of classes can vary depending on the various iterations.
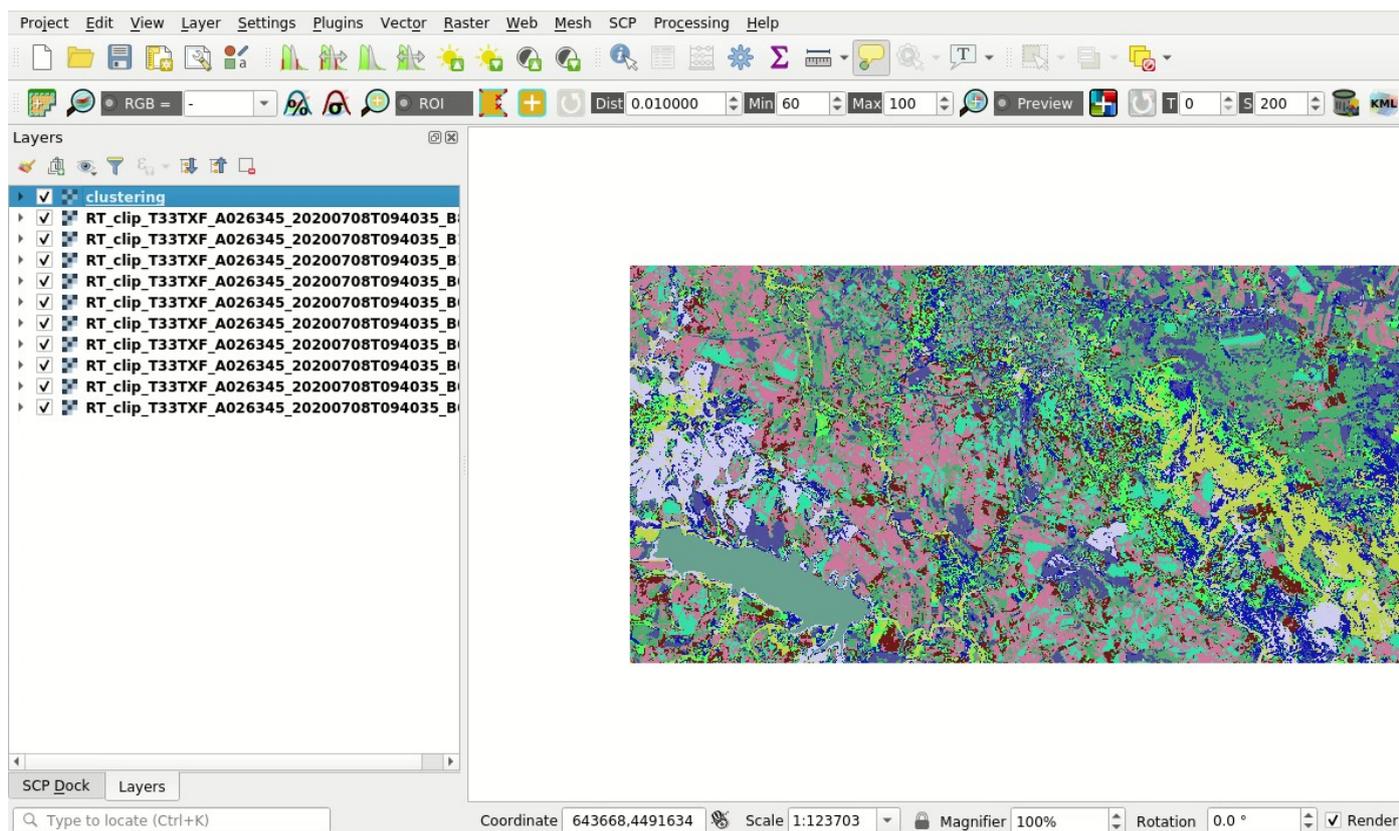
Fig. 34: *Result of clustering*

The mean spectral signature of output classes is displayed in the panel. We could also save these spectral signatures in a previously created *Training input* (page 23) if we wanted to use these in other supervised classifications.

Reclassification of the output

We must identify the correspondence between raster classes and the land cover class IDs defined at the beginning of this tutorial.

We can perform this task through photointerpretation. We can display a *Color Composite* (page 135) of bands: Near-Infrared, Red, and Green: in the *Working toolbar* (page 29), click the list *RGB=* and select the item `7-3-2` (corresponding to the band numbers in *Band set* (page 31)). 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).

We should take note of the corresponding values, similarly to the following table as example. Please note that you should define different values according to the result of your classification output.

Class name	Cluster ID	New class ID
Vegetation	1	3
Built-up	2	2
Vegetation	3	3
Vegetation	4	3
Vegetation	5	3
Soil	6	4
Soil	7	4
Water	8	1
Vegetation	9	3
Soil	10	4
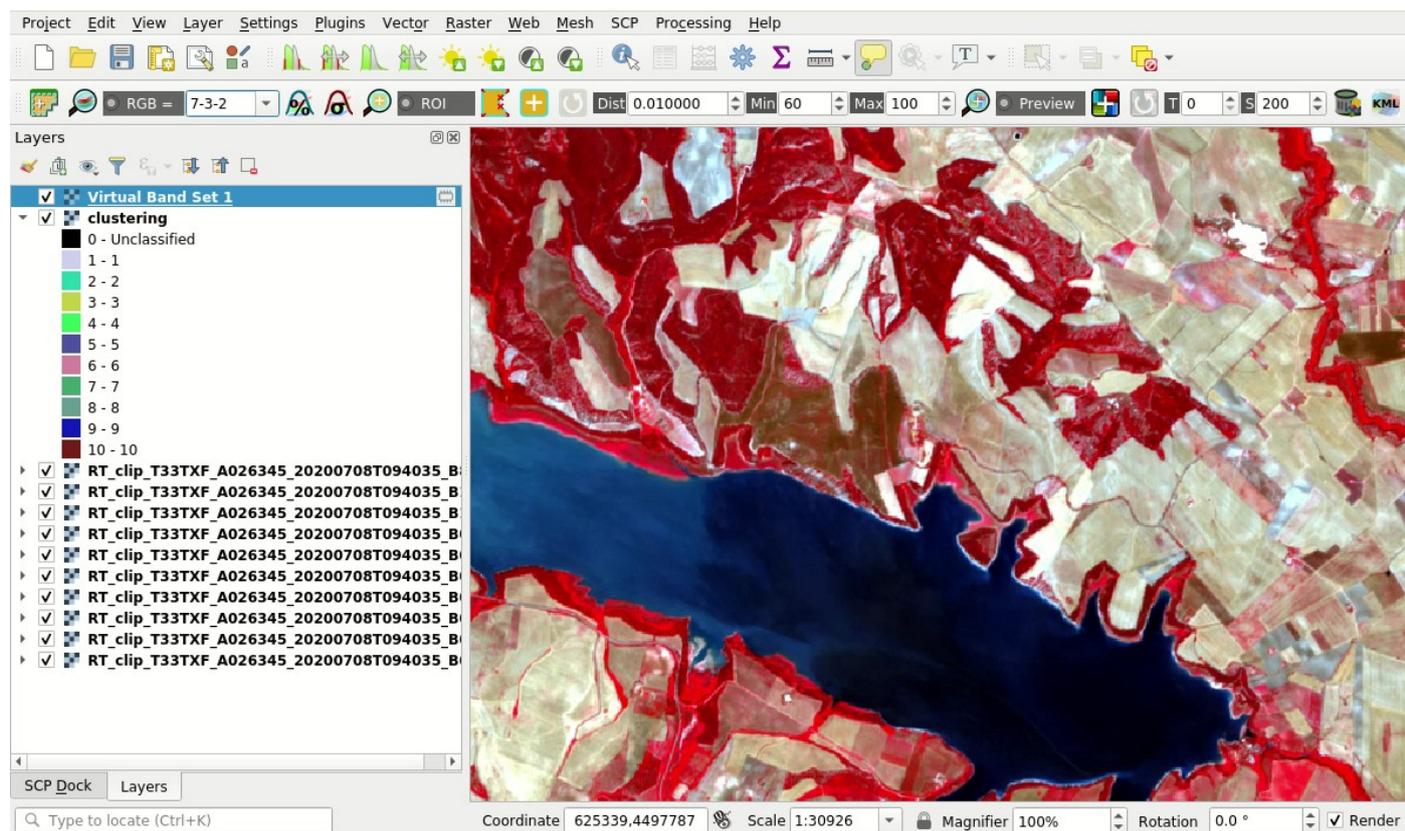
Fig. 35: *Color composite RGB=7-3-2*

Now we can reclassify the output raster according to out classification system.

Open the tool *Reclassification* (page 90) clicking the button in the *SCP menu* (page 19) or the *SCP dock* (page 20). Click *Calculate unique values* to automatically calculate unique values in the classification and fill the reclassification table. In *New value* set the corresponding New class ID.

When the table is complete, click the button *RUN* and define the path of the classification output. After the process, the raster is added to the map. We can define a symbology according to our classes.

Of course, the result of an unsupervised classification can have many classification errors. In this example, several pixels of soil have been classified as built-up. For reducing those errors we could repeat the clustering step increasing the *Number of classes*, reducing the value *ISODATA max standard deviation*, and increasing the value *Distance threshold*.

Refinement of the output

The classification could contain small patches of pixels that we would like to remove from the classification result.

We can use the tool *Classification sieve* (page 84) to remove small patches of isolated pixel replacing them with the value of the largest neighbour patch. Open the tool *Classification sieve* (page 84) clicking the button in the *SCP menu* (page 19) or the *SCP dock* (page 20).

In *Select the classification* select the raster reclassified in the previous step (click to refresh the layer list if the classification is not listed). In *Size threshold* enter 2 to set the maximum size of the patch to be replaced
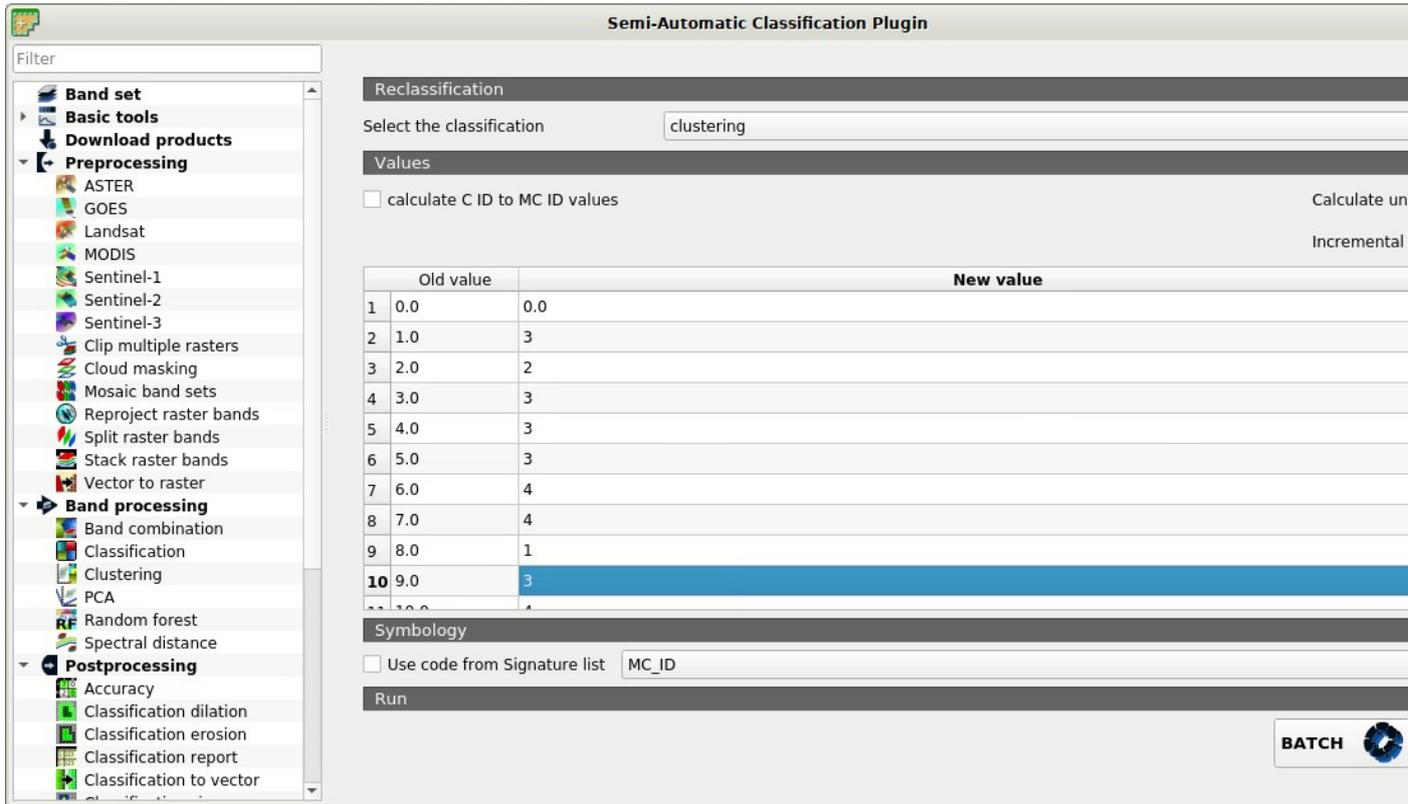
Fig. 36: *Reclassification*
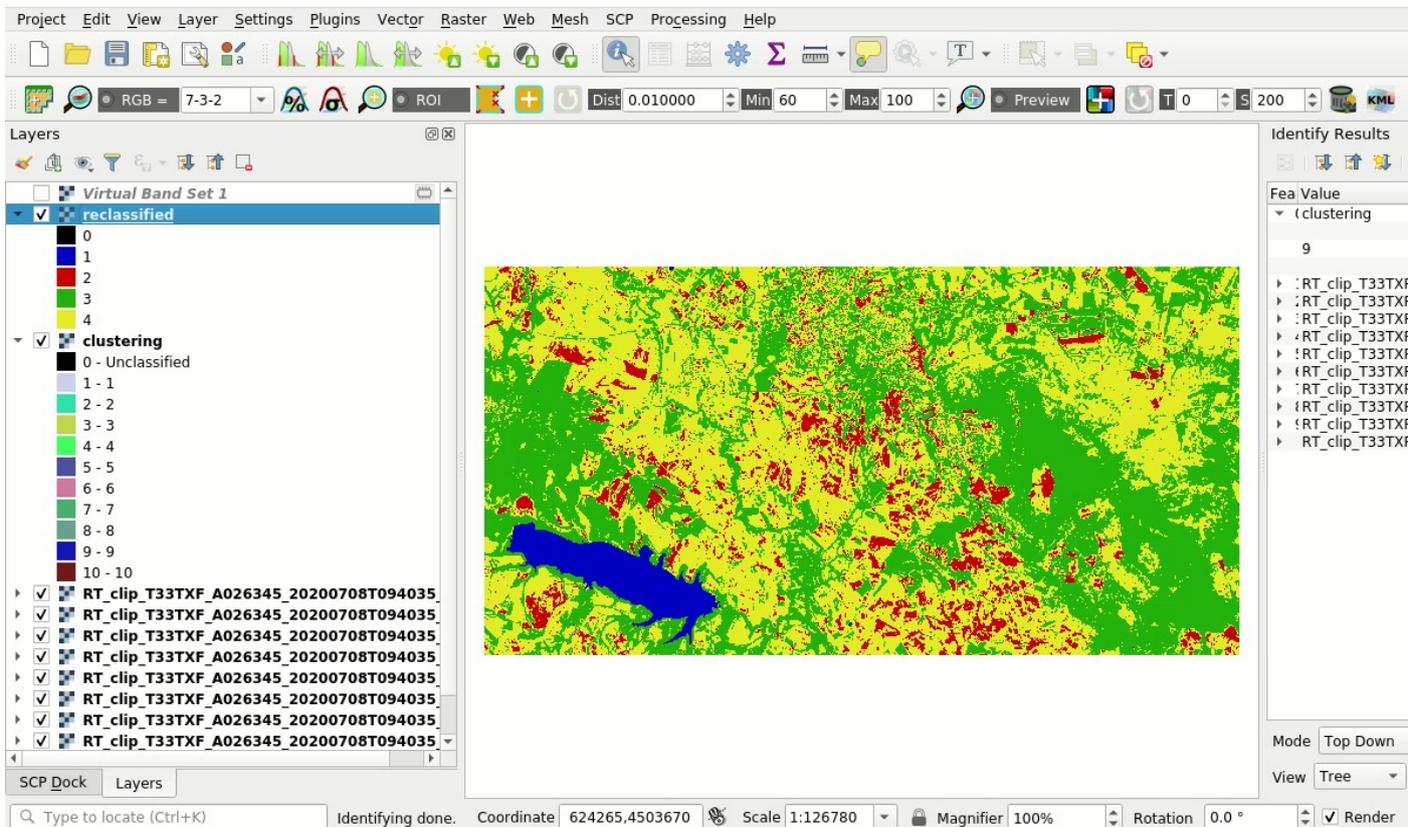
Fig. 37: *Reclassified raster*

(in pixel unit); all patches smaller than the selected number of pixels will be replaced by the value of the largest neighbour patch. Setting the value 2 we are going to remove isolated single pixels.
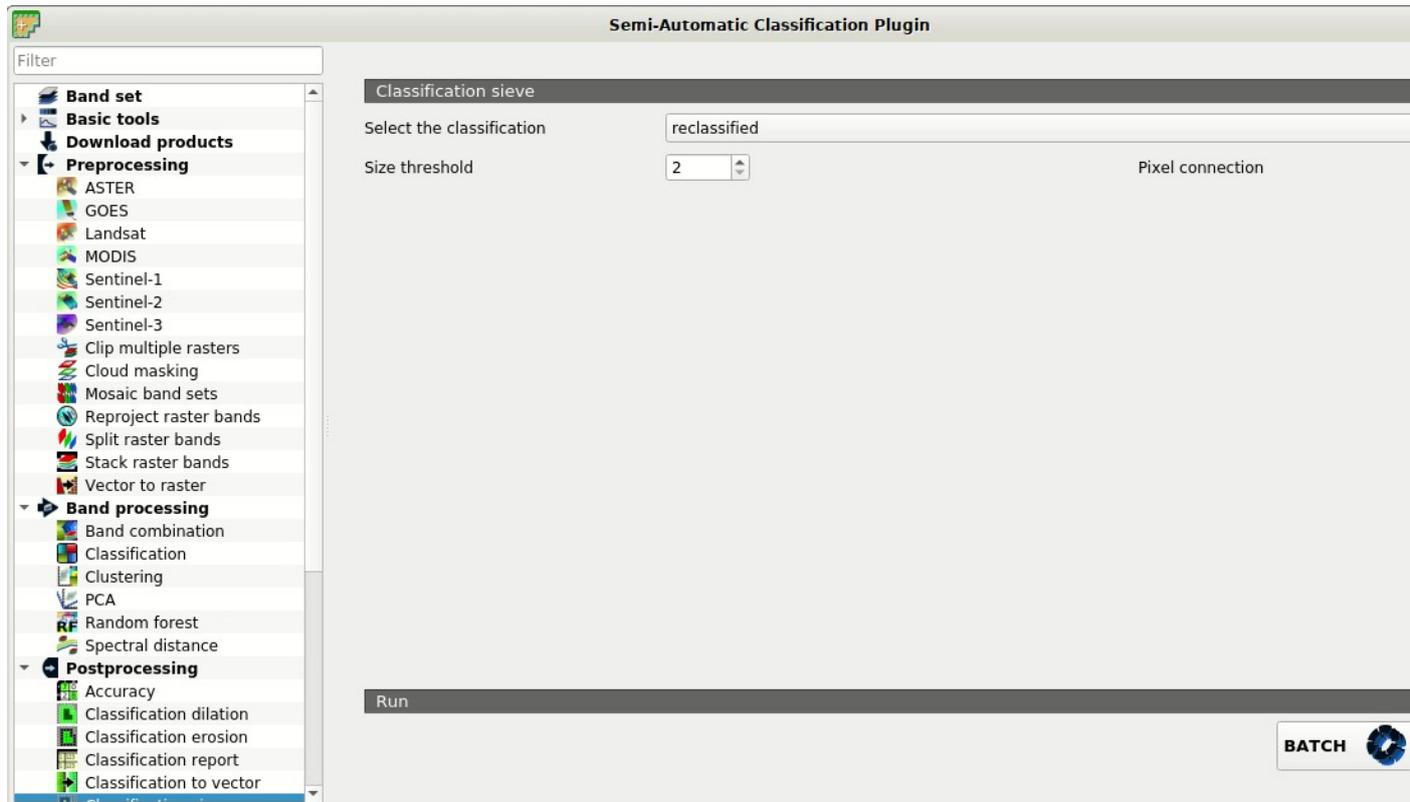
Fig. 38: *Sieve tool*

In *Pixel connection* [⌄]: select *8* as the type of pixel connection in a 3x3 window (i.e. diagonal pixels are considered connected). Now click the button *RUN* [▶] and define the path of the classification output. After the process, the raster is added to the map. We should see that single pixels have been replaced by the largest neighbour patch, resulting in a cleaner classification.

Well done! We have performed an unsupervised classification of a remote sensing image. We can improve the classification using some of the tools that will be described in other tutorials.
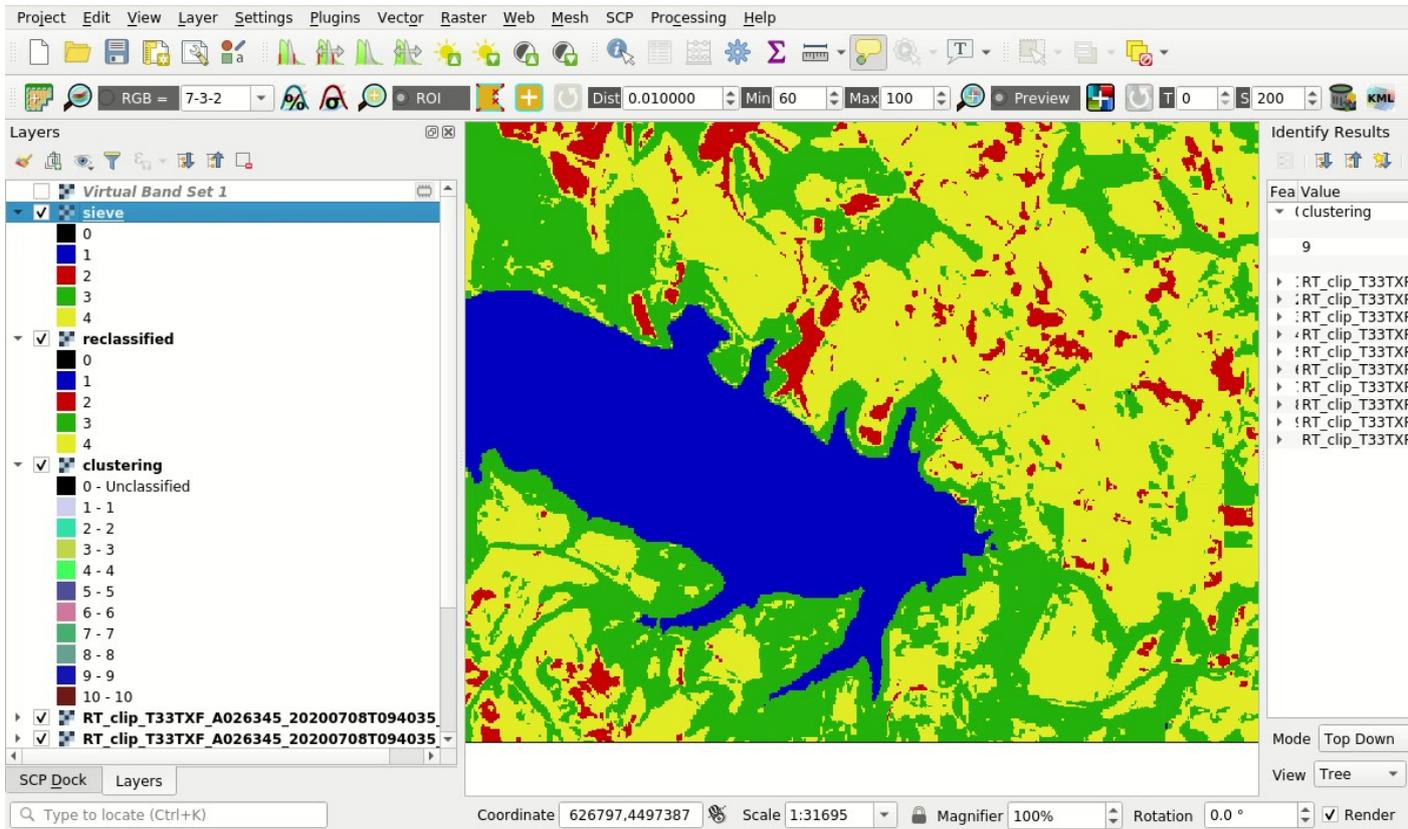
Fig. 39: *Refined classification*

Thematic Tutorials

The following are thematic tutorials. Before these tutorials, it is recommended to read the *Basic Tutorials* (page 157).

6.1 Tutorial: Random Forest Classification

- *Input Data* (page 193)
- *Create the ROIs* (page 194)
- *Random Forest Classification* (page 196)

This tutorial is about the *Random Forest* (page 143) classification. It is assumed that one has the basic knowledge of *SCP* and *Basic Tutorials* (page 157).

Random Forest is a particular machine learning technique, based on the iterative and random creation of decision trees (i.e. a set of rules and conditions that define a class).

> **WARNING**: ESA SNAP is required. The *ESA SNAP GPT executable* must be defined in *External programs* (page 114) settings.

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

1. Water;
2. Built-up;
3. Vegetation;
4. Soil.

Following the video of this tutorial.

http://www.youtube.com/watch?v=FtHsGlLiNaw

6.1.1 Input Data

Any raster data can be used with Random Forest. In this tutorial, we are going to use a subset of a *Sentinel-2 Satellite* (page 130) image (Copernicus land monitoring services), already converted to reflectance, and use the

bands illustrated in the following table.

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

You can download the image from this archive (about 20 MB, © Copernicus Sentinel data 2020 downloaded from https://scihub.copernicus.eu/), and then unzip the downloaded file. The downloaded product is already converted to reflectance and no preprocessing is required in this case.

Start QGIS and the *SCP*.

Open the tab *Band set* (page 31) clicking the button ![layers icon] in the *SCP menu* (page 19) or the *SCP dock* (page 20).

Click the button ![open icon] and open the directory containing the input bands and select all the `.tif` files. The selected bands will be added to the *active band set*.

In the table *Band set definition* order the band names in ascending order (click ![abc icon] to sort bands by name automatically). Finally, select *Sentinel-2* from the list *Wavelength quick 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 135) of bands: Near-Infrared, Red, and Green: in the *Working toolbar* (page 29), click the list *RGB=* and select the item `7-3-2` (corresponding to the band numbers in *Band set* (page 31)). 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). This color composite will be useful later for ROI creation.

Now we need to create the *Training input* (page 23) in order to collect *Training Areas* (page 135) (ROIs).

In the *SCP dock* (page 20) select the tab *Training input* (page 23) and click the button ![create icon] 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).

6.1.2 Create the ROIs

ROIs must be created by manually drawing a polygon. You could also import polygons from a vector file using this tool *Import vector* (page 38).

> **WARNING**: because of compatibility with software SNAP only ROIs defined manually with a polygon will be used for classification; region growing ROIs and spectral signatures will not be used as training input.

We are going to create ROIs defining the *Classes and Macroclasses* (page 136). 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). 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*

Fig. 1: *Band set*

Fig. 2: *Color composite RGB=7-3-2*

Macroclass name	Macroclass ID
Water	1
Built-up	2
Vegetation	3
Soil	4

Create a few ROIs and save them in the *Training input* (page 23).

Please note that classification previews are not available with Random Forest.

6.1.3 Random Forest Classification

The *Random Forest* (page 77) tool allows for classifying a *Band set* (page 31) using the ROI polygons in the *Training input* (page 23).

Open the tab *Random Forest* (page 77) clicking the button in the *SCP menu* (page 19) or the *SCP dock* (page 20). In *Select input band set* we set 1 because we are going to classify the first *Band set*.

Check *Use* *MC ID* in order to use the Macroclass ID code of ROIs.

In *Number of training samples* enter 5000 as the number of training data (pixels) randomly used to traing the model. You can increase this number if the ROI polygons are very large and cover more than 5000 pixels.

In *Number of trees* enter 100 as the number of decision trees (a higher number allows for more accurate models, but it also increases the calculation time). Also check *Evaluate classifier* to report the evaluation of the classifier at the end of the process. You can ignore the option *Evaluate feature power set*.

Fig. 3: *Definition of Training input in SCP*
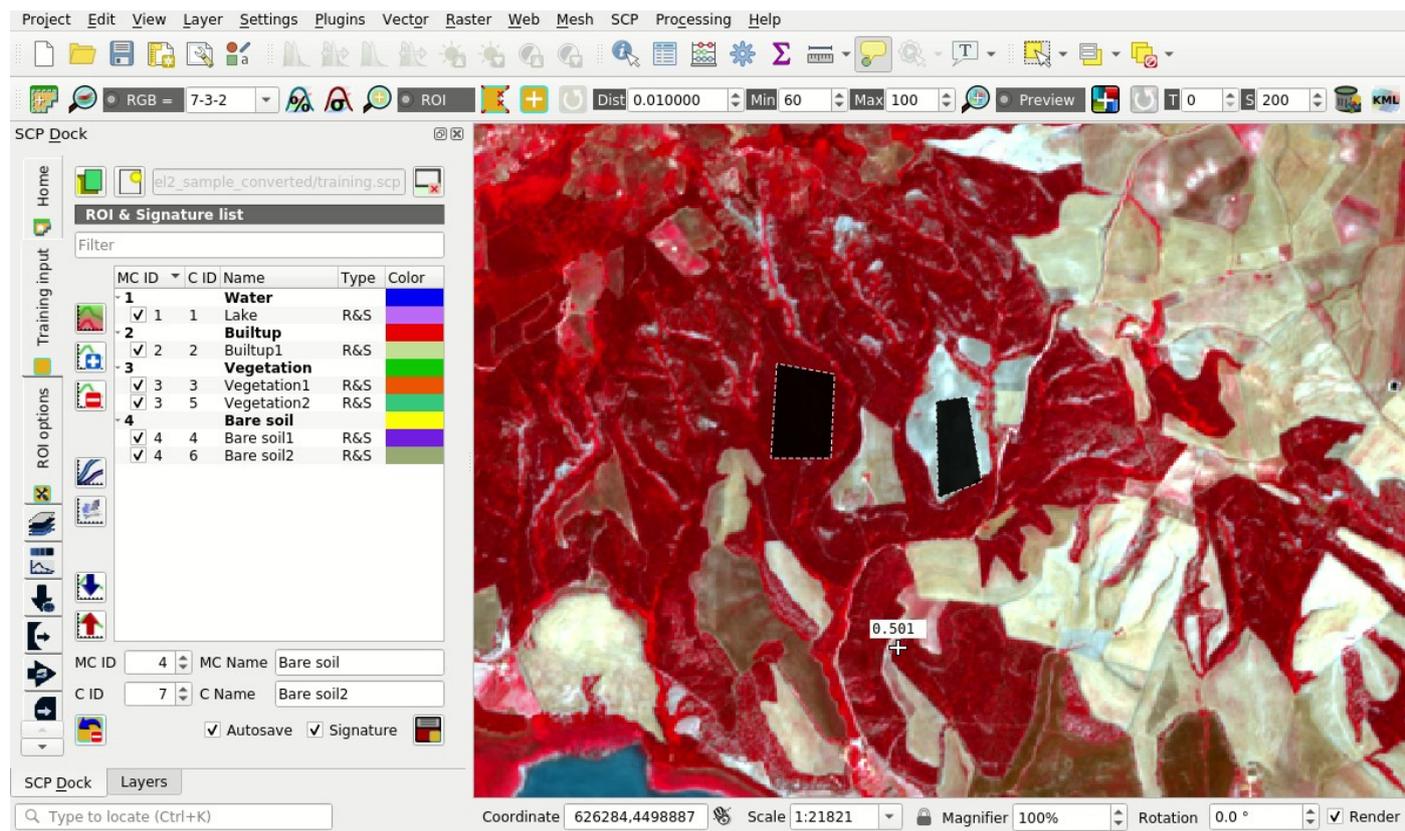
Fig. 4: *Created ROIs*

TIP : You can save the classifier for later use, for instance classifying a different input band set, by checking ☑ *Save classifier*, and later select *Load classifier* 🟩 to open the previously saved classifier; when loading a saved classifier no training input is required and the processing time is reduced.

Now click the button *RUN* ⤳ and define the path of the classification output.

Also, a confidence raster is created which assess the reliability (from 0 minimum to 1 maximum) of the model at pixel levels.

We can see several classification errors especially in pixels with low confidence values. If pixels have low confidence values, we need to create new ROIs for these pixels.

The evaluation report allows for assessing the performance of the model (not the accuracy of the whole classification). We can also read the feature importance score, which is the importance of single bands in the *Band set definition*. For instance, we could try to remove the bands with the lowest score to reduce the computation time and obtaining similar results.

Well done! We have performed a Random Forest classification of a remote sensing image.

For other unofficial tutorials, also in languages other than English, see *Other tutorials about SCP, also in languages other than English* (page 217).
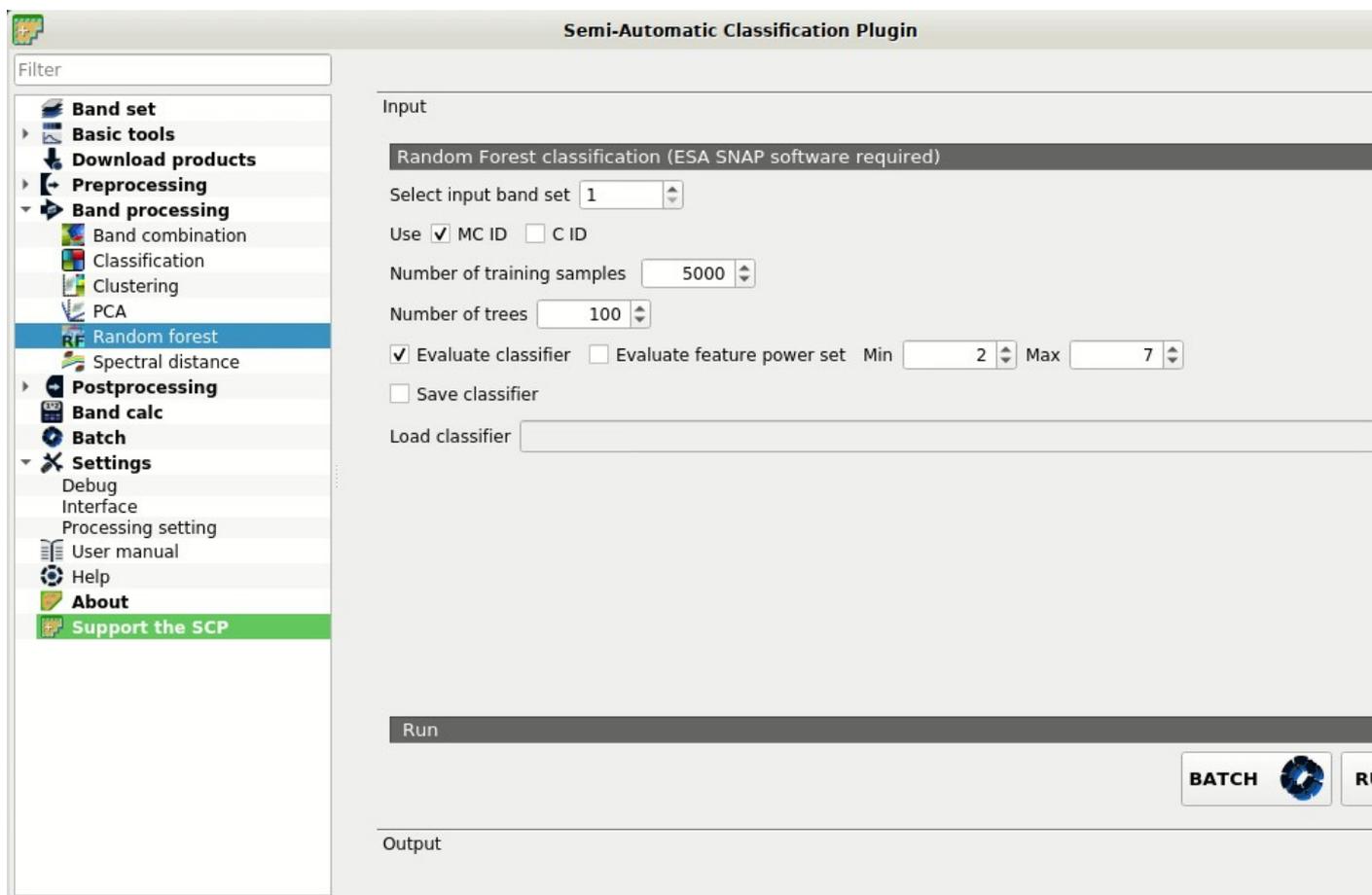
Fig. 5: *Random Forest tool*
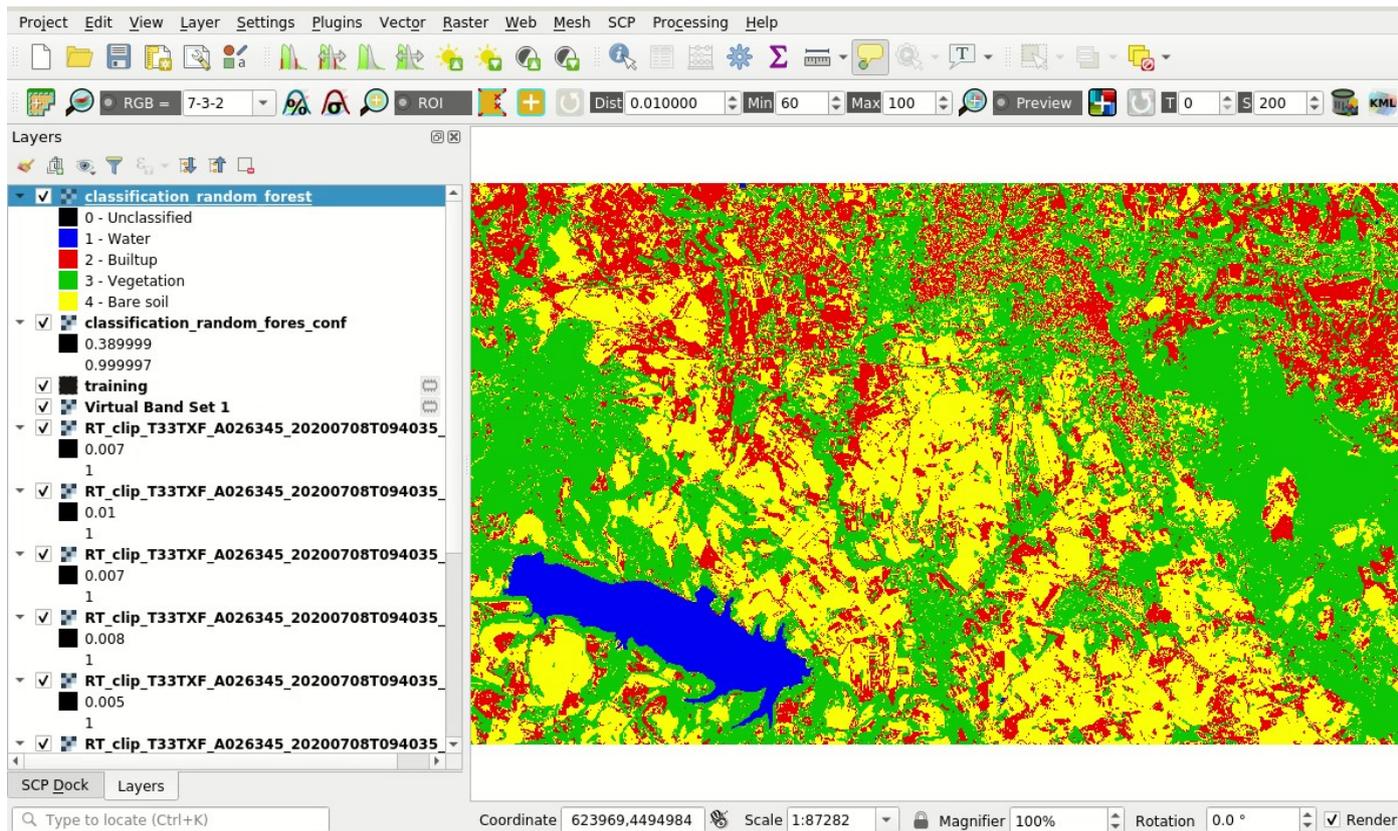
Fig. 6: *Random Forest classification*
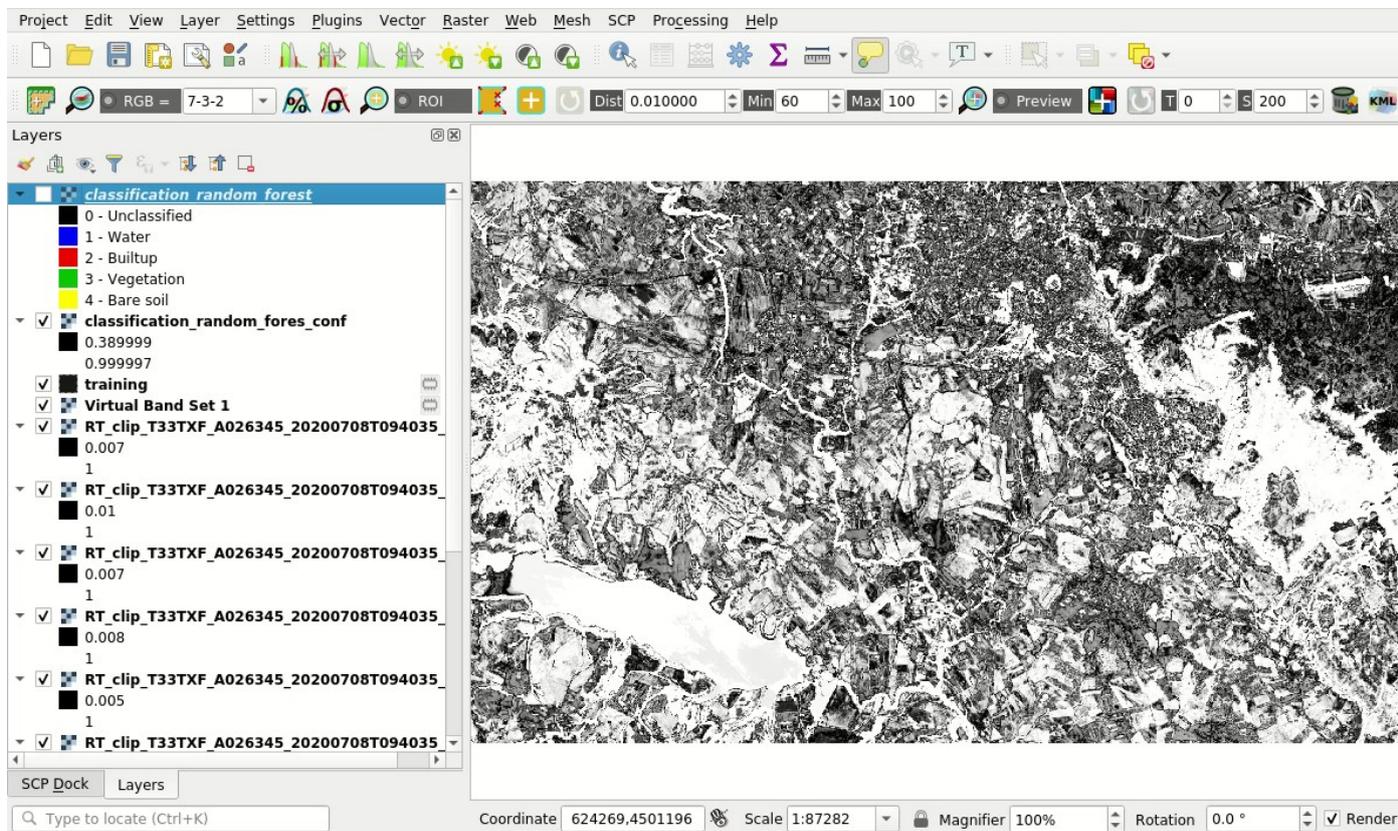
Fig. 7: *Random Forest confidence*

Fig. 8: *Random Forest evaluation*

CHAPTER 7

Semi-Automatic OS

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.
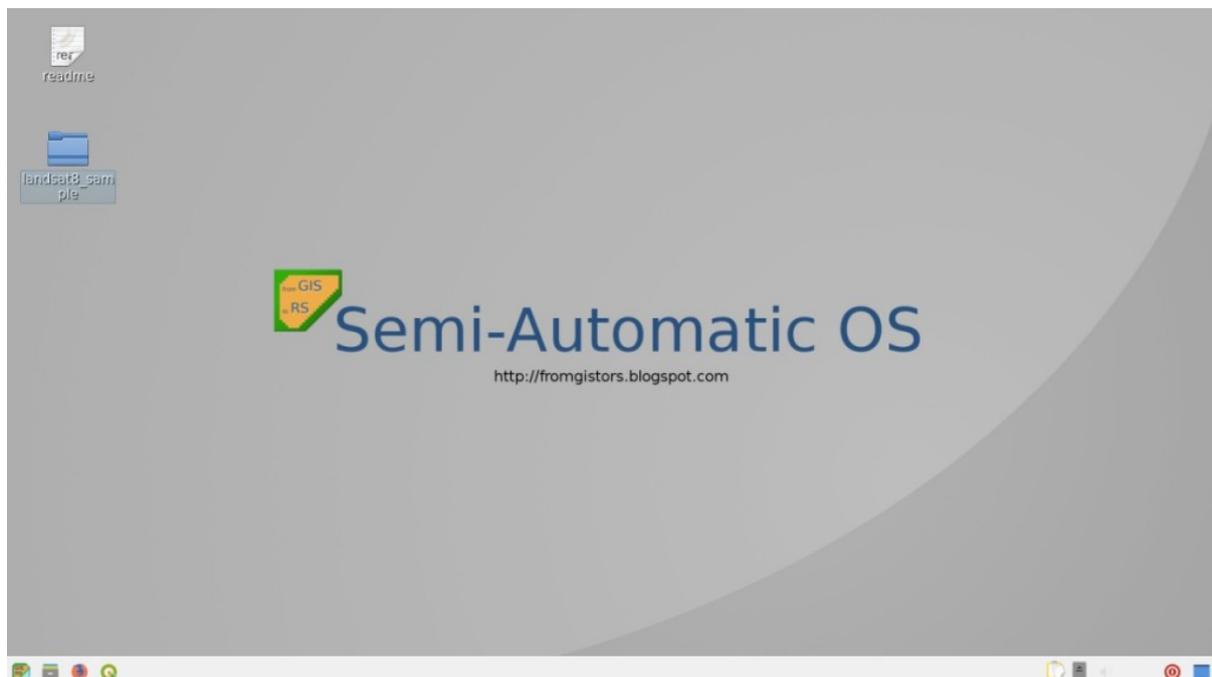

Fig. 1: *Semi-Automatic OS desktop*

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.
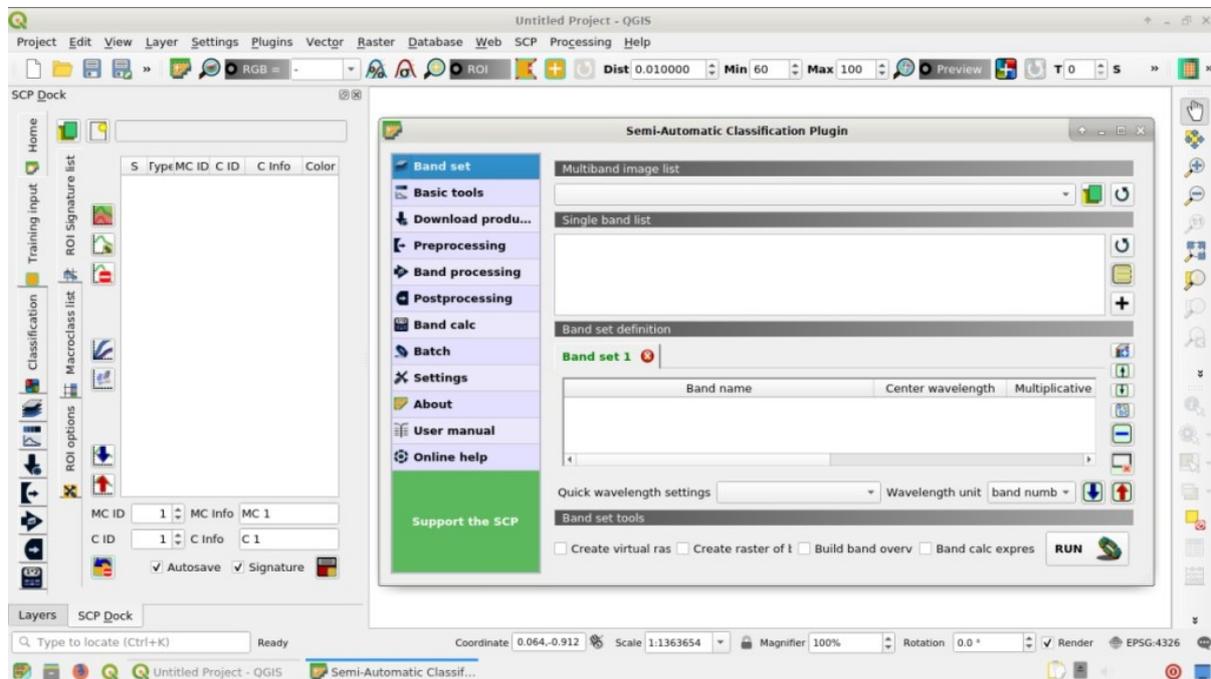

```
Semi-Automatic OS is free software:  you can redistribute it and/or modify
it under the terms of the GNU General Public License as published by the
Free Software Foundation, version 3 of the License. Semi-Automatic OS is
distributed in the hope that it will be useful, but WITHOUT ANY WARRANTY;
without even the implied warranty of MERCHANTABILITY or FITNESS FOR A
PARTICULAR PURPOSE. See the GNU General Public License for more details.
```

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.

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:
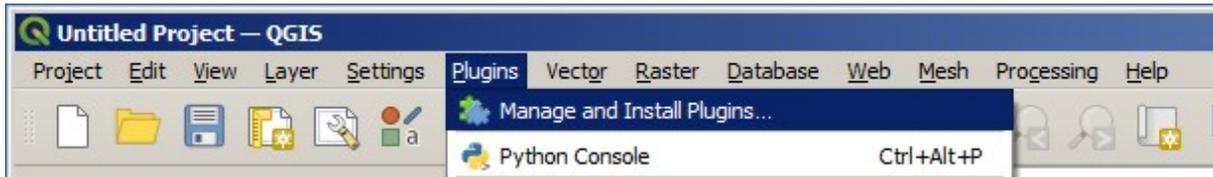
1. download the SCP zip archive from https://github.com/semiautomaticgit/SemiAutomaticClassificationPlugin/archive/master.zip ;

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\p` in Linux and Mac usually `/home/username/.local/share/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.

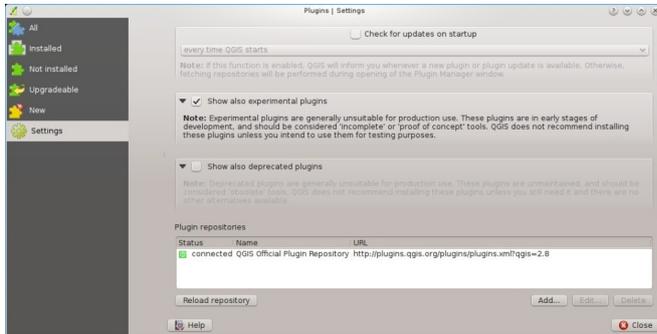### 8.1.2 How to install the plugin from the official SCP repository?

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;
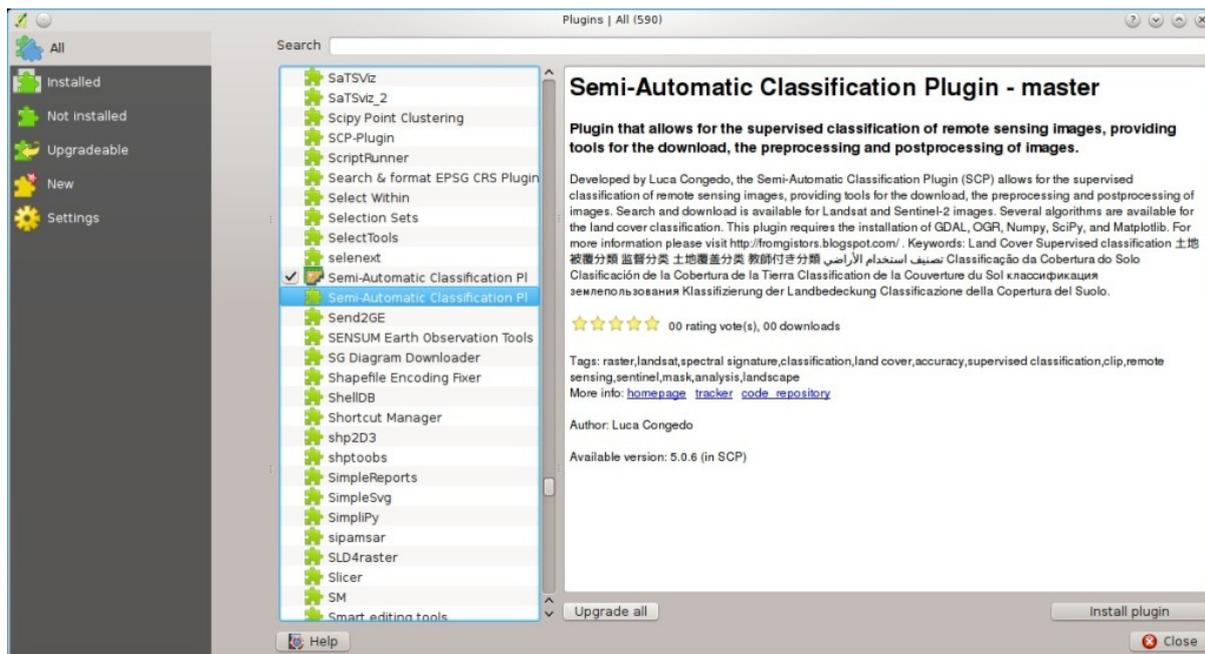
- From the menu `All`, select the `Semi-Automatic Classification Plugin - master` and click the button `Install plugin`; the latest version of SCP should be automatically activated (ignore errors, the restart of QGIS could be necessary to complete the SCP installation); it is possible to deactivate the other SCP installed in the QGIS repository;

8.1.3 Can I use the previous version 6 of SCP?

It is possible to install the previous version 6 of SCP using the official repository. Also, this version can be installed along with the SCP version 7.

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`;
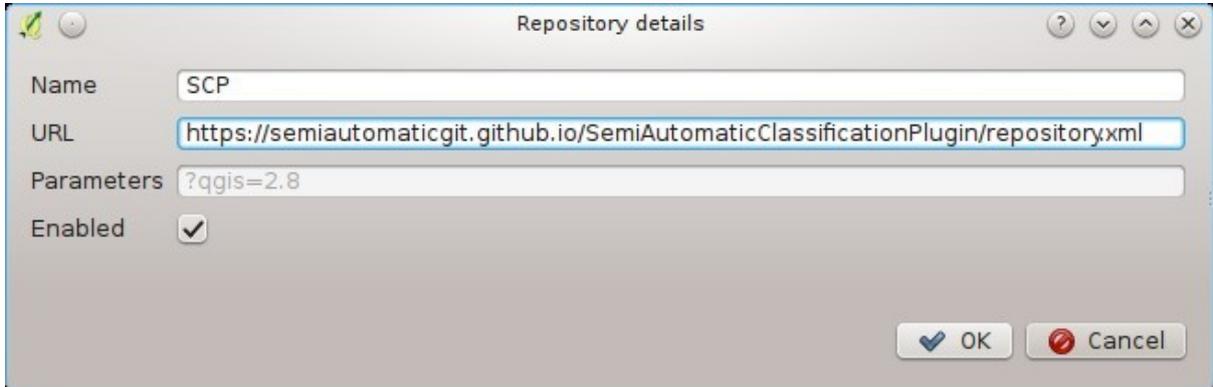
- Inside the `Repository details` enter:

Name:

```
SCP
```

URL:
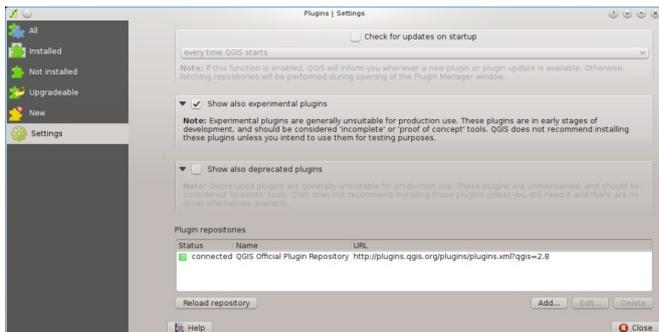
```
https://semiautomaticgit.github.io/SemiAutomaticClassificationPlugin_v6/repository.
↪xml
```

and click `OK`;

- After the repository update, the item `Semi-Automatic Classification Plugin - master` should be listed with the other plugins;

8.1. Plugin installation 211
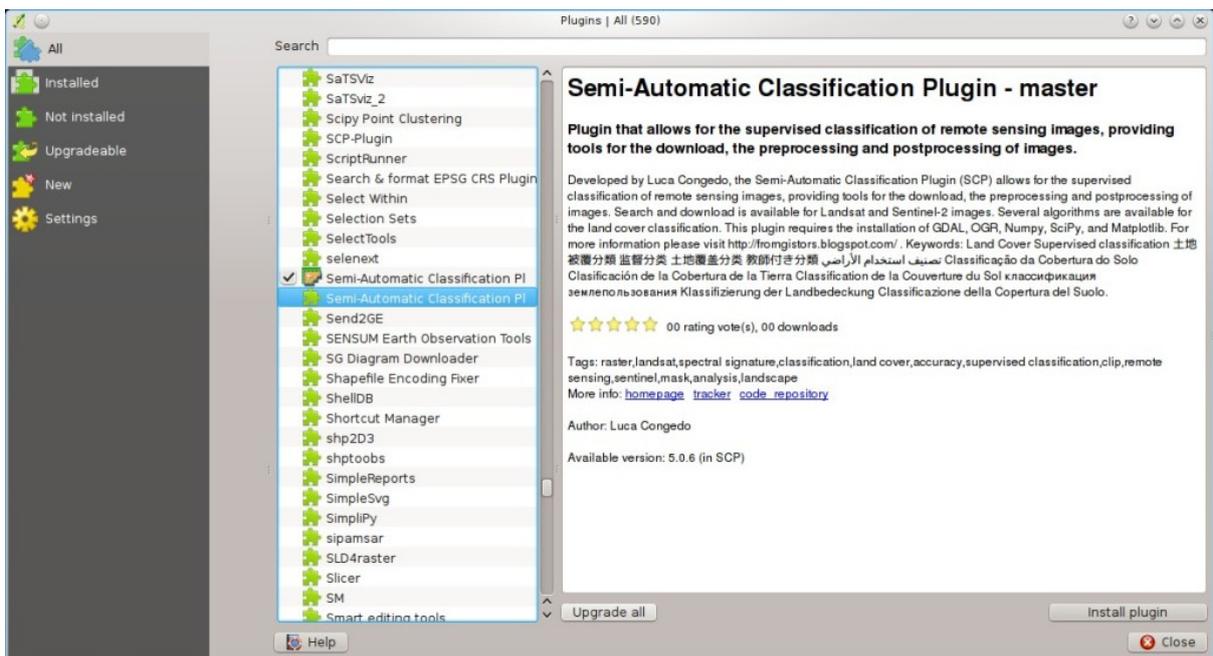
- From the menu `All`, select the `Semi-Automatic Classification Plugin - master` and click the button `Install plugin`; the latest version of SCP should be automatically activated (ignore errors, the restart of QGIS could be necessary to complete the SCP installation); it is possible to deactivate the other SCP installed in the QGIS repository;
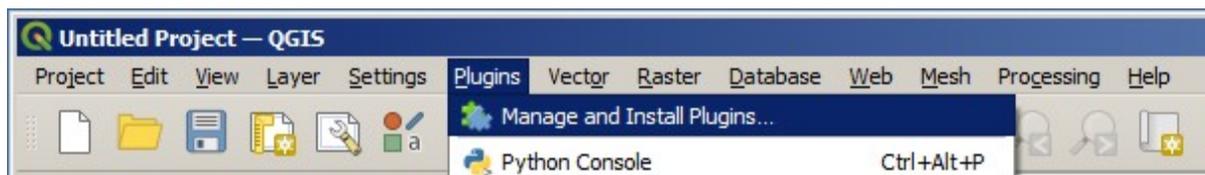

8.2 Pre processing

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 60). Images are converted to reflectance.

8.2.4 Can I apply the conversion to Sentinel-2 L2A download from the web?

Yes, you should move all the .jp2 files inside the same directory and rename the files with the band number in the ending of the name (e.g. from name_02_10m.jp2 to name_02.jp2) Then select this directory in *Sentinel-2 conversion* (page 60). Images are converted to reflectance.

8.2.5 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.

8.2.6 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).

8.2.7 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 value as NoData` and set the value to 0. This is because DOS is an image based technique, and NoData values must be excluded from the calculation.

8.2.8 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.

Also, see the following video-tutorial.

8.2.9 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 129)). Therefore, the pan-sharpening process can't improve the resolution of NIR and SWIR bands (see *Pan-sharpening* (page 147)), 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 115) to assess their similarity. You can also use a *Signature threshold* (page 44) 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 141) 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 136).

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 138) 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 110) and check the checkbox ☑ *Records events in a log file* ;

3. click the button *Test dependencies* ▶ in the tab *Debug* (page 110) ;

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 110) 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;
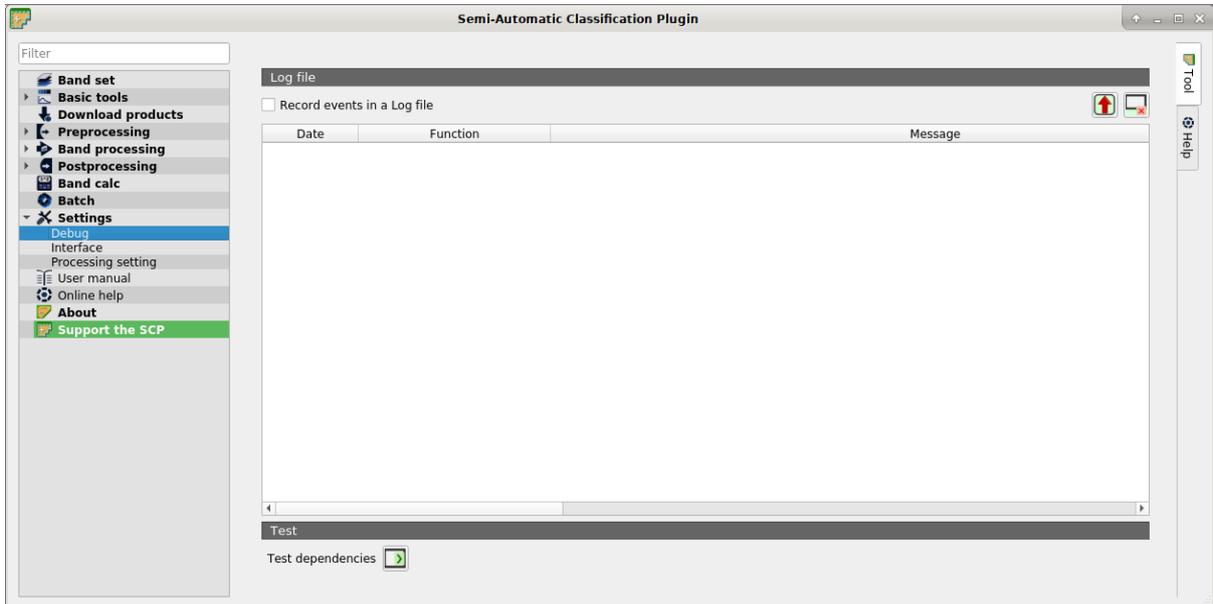
Fig. 1: *Debug*
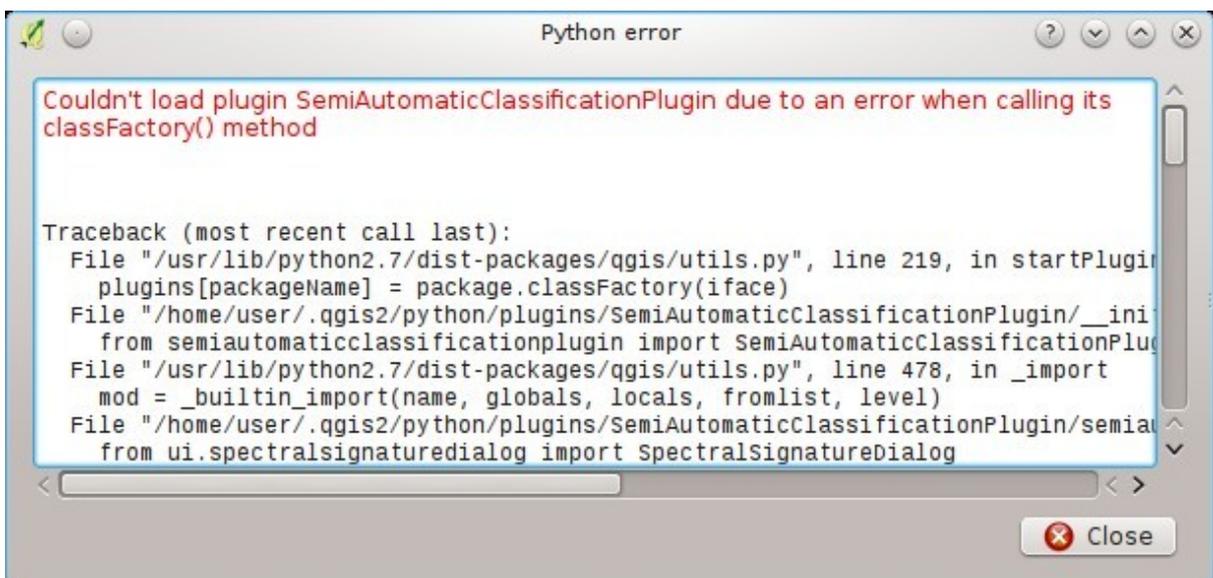
Fig. 2: *Error message*

8. join the Facebook group , create a new post and copy the error message and the **log file** (or attach them).

8.5.2 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 214).

8.5.3 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 135). You can produce a land cover raster using one of the *Classification Algorithms* (page 137) available in SCP. These algorithms require spectral signatures or ROIs as input (for definitions please read *Brief Introduction to Remote Sensing* (page 125)) that define the land cover classes to be identified in the image.
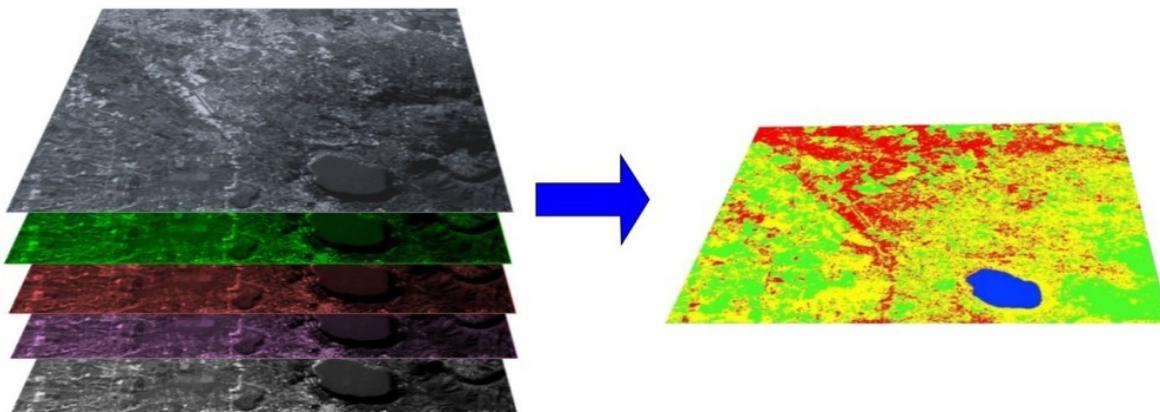

Fig. 3: *A multispectral image processed to produce a land cover classification*
(Landsat image provided by USGS)

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 45)). 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 31), which is used as input for the classification. *SCP* provides several tools for the *Preprocessing* (page 50) of downloaded images, such as the conversion to reflectance and manipulation of bands.

Classification results can be assessed with the tools *Accuracy* (page 79) and *Classification report* (page 82). Also, rasters can be manipulated using *Postprocessing* (page 79) tools such as *Classification to vector* (page 83), *Reclassification* (page 90), *Edit raster* (page 87) directly, *Classification sieve* (page 84), *Classification erosion* (page 81), and *Classification dilation* (page 80).

The *Spectral Signature Plot* (page 115) and *Scatter Plot* (page 120) allow for the **analysis of spectral signatures and ROIs**. Also, several *Basic tools* (page 34) 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 93) with bands in the *Band set* (page 31), calculating mathematical expressions and spectral indices. Also, an output raster can be calculated based on *Decision rules* (page 100).

The tool *Batch* (page 101) allows for the automatic execution of several *SCP* functions using a scripting interface.

See the *Basic Tutorials* (page 157) 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 219)), or translating the user manual (see *How can I translate this user manual to another language?* (page 218)).

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.

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;

- French: Télédétection des feux de forêts;

- German: 2015 Jakob Erfassung von Landnutzungsveränderungen mit FOSS Image Processing Tools;

- Greek: Landsat radiometric correction with QGIS - $P\alpha\delta\iota o\mu\epsilon\tau\rho\iota\kappa$ $\delta\iota\rho\theta\omega\sigma\eta$ $\delta\epsilon\delta o\mu\nu\omega\nu$;

- Greek: Supervised classification of Landsat image and accuracy assessment with QGIS;

- Indonesian: Koreksi Radiometrik Menggunakan QGIS:Semi Automatic Classification;

- Italian: Geobreak 7 - I dati satellitari Sentinel 2 in QGIS;

- Korean: QGIS Semi-Automatic Classification Plugin;

- Portuguese: Workshop de Deteção Remota e Processamento Digital de Imagem com o QGIS e o Semi-Automatic Classification Plugin;

- Portuguese: Avaliação do erro de uma imagem de satélite usando o QGIS e o SCP;

- Portuguese: QGIS 3.10: Baixar Bandas Individuais do Sentinel-2 pelo Plugin SCP;

- Russian: Sentinel- 2a Semi-Automatic Classification Plugin QGIS;

- Spanish: Descargar imágenes Landsat, calcular NDVI y NDWI con QGIS;

- Spanish: Clasificación Supervisada con Imágenes Landsat8 en QGIS "Pi" y Semi-Automatic Classification Plugin;

- 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 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