Semi-Automatic Classification Plugin Documentation

Version 8.1.3.1

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mars 27, 2024

Table des matières

CHAPITRE 1

Introduction

Developed by Luca Congedo (ing.congedoluca@gmail.com), 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.

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.

SCP exploits the parallel processing of the tools provided by Remotior Sensus, a Python package that allows for the processing of remote sensing images and GIS data.

This **user manual** provides information about the *Plugin Installation* (page 3) of SPC and the *The Interface of SCP* (page 29), with detailed information about all the functions. In addition, the *Brief Introduction to Remote Sensing* (page 123) illustrates the basic concepts and definitions which are required for using the *SCP*.

For more information and tutorials visit the official site

From GIS to Remote Sensing

How to cite :

Congedo, Luca, (2021). Semi-Automatic Classification Plugin : A Python tool for the download and processing of remote sensing images in QGIS. Journal of Open Source Software, 6(64), 3172, https://doi.org/10.21105/joss.03172

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 and version 8 as personal commitment to the remote sensing field and open source philosophy.

License :

Translators :

Language : Author name

CHAPITRE 2

Plugin Installation

The Semi-Automatic Classification Plugin requires the installation of GDAL, OGR, NumPy, SciPy and Matplotlib
.

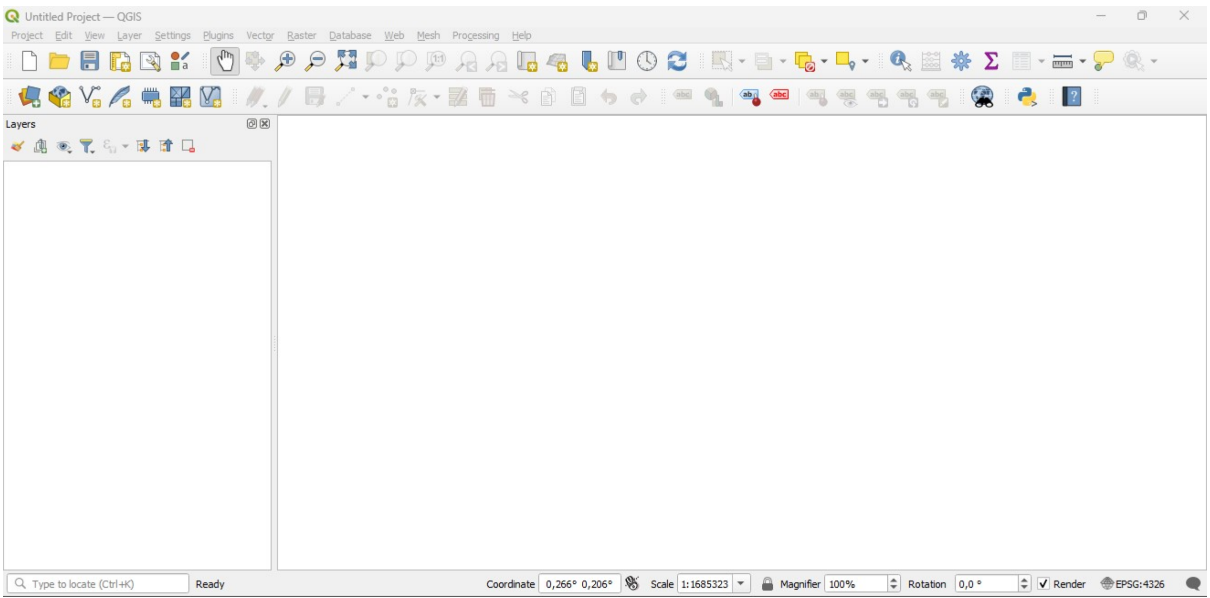
This chapter describes the installation of the Semi-Automatic Classification Plugin for the supported Operating Systems.

2.1 Installation in Windows 64 bit

2.1.1 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.

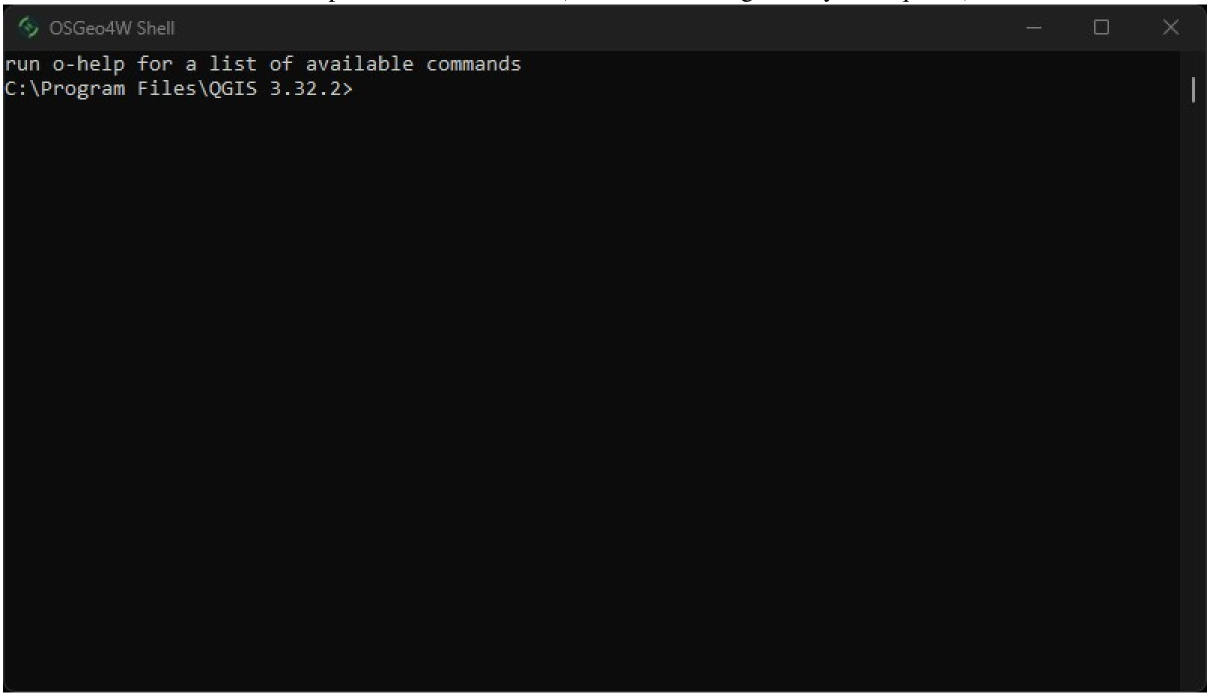


2.1.2 Installation of required dependencies

The Semi-Automatic Classification Plugin requires Remotior Sensus, GDAL, NumPy and SciPy for most functionalities. Optionally, scikit-learn and PyTorch are required for machine learning.

Therefore, we need to install the dependencies that are not included in the QGIS installation.

- Close QGIS ;
- From the Start menu, open OSGeo4W Shell (administrative rights may be required) ;



- Enter the following command :

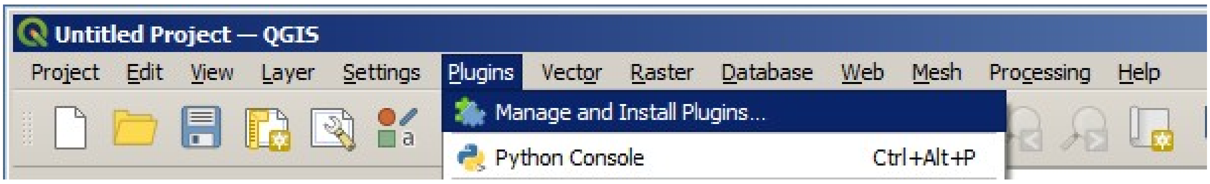
```
pip3 install --upgrade remotior-sensus scikit-learn torch
```

Follow the same procedure for updating the dependencies.

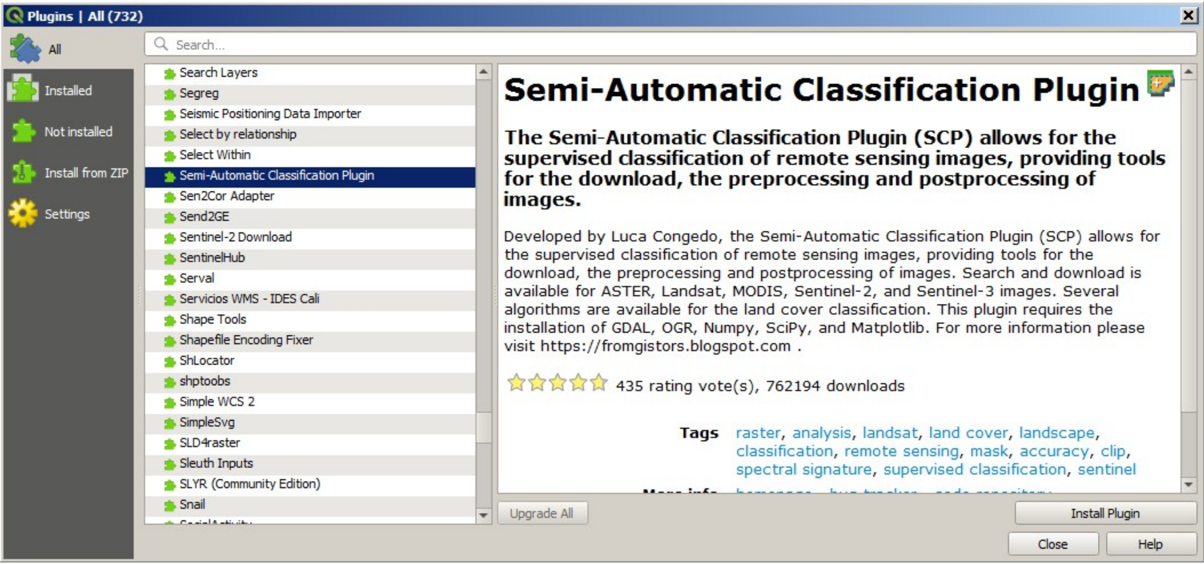
Astuce : In case the library Remotior Sensus is not found, an automatic procedure will try to download it in the plugin directory, allowing for using the main functions of the Semi-Automatic Classification Plugin ; however, this is not recommended as library Remotior Sensus won't be updated, and scikit-learn and PyTorch functions will not work. Alternatively, one may follow *Advanced installation using Conda* (page 23).

2.1.3 Semi-Automatic Classification Plugin installation

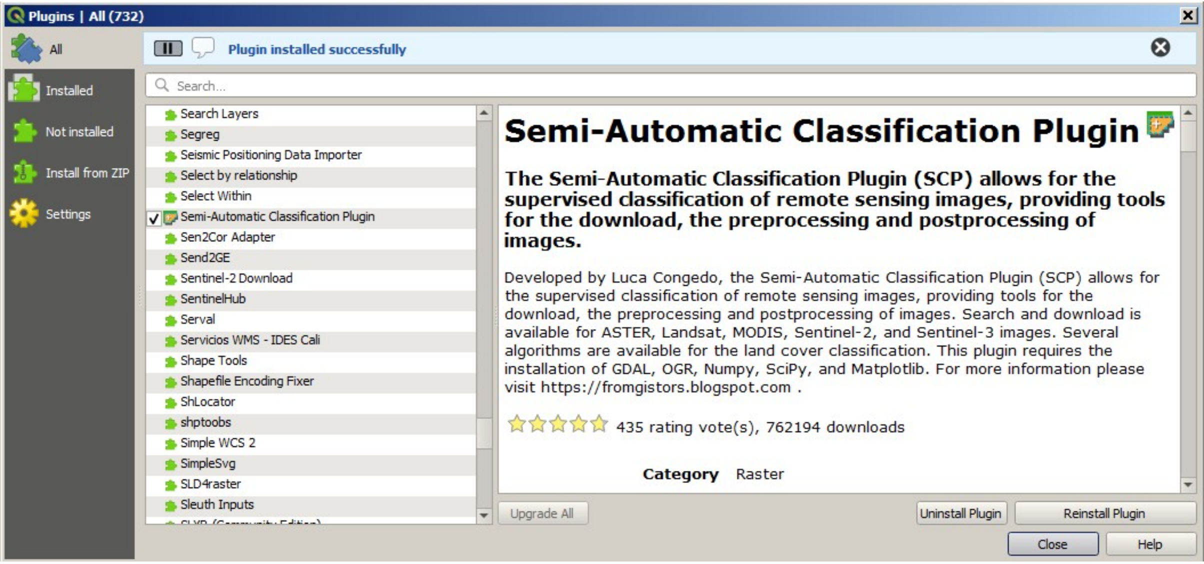
- Run QGIS ;
- From the main menu, select `Plugins` > `Manage and Install Plugins` ;



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

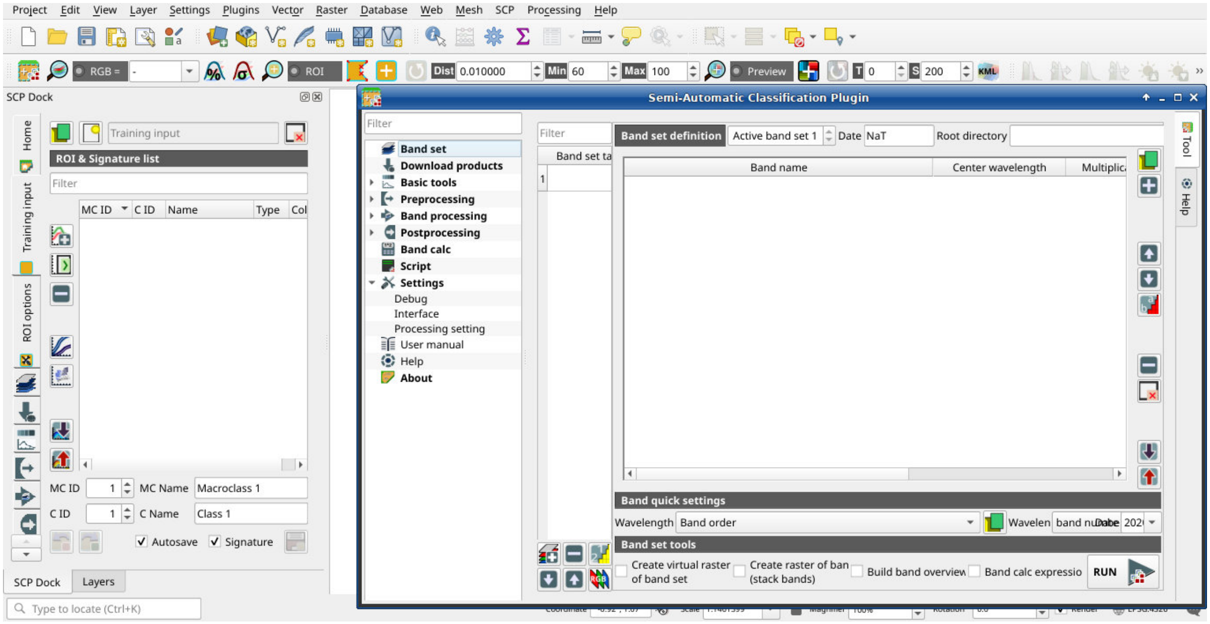


— The SCP should be automatically activated ; however, be sure that the Semi-Automatic Classification Plugin is checked in the menu `Installed` (the restart of QGIS could be necessary to complete the SCP installation) ;

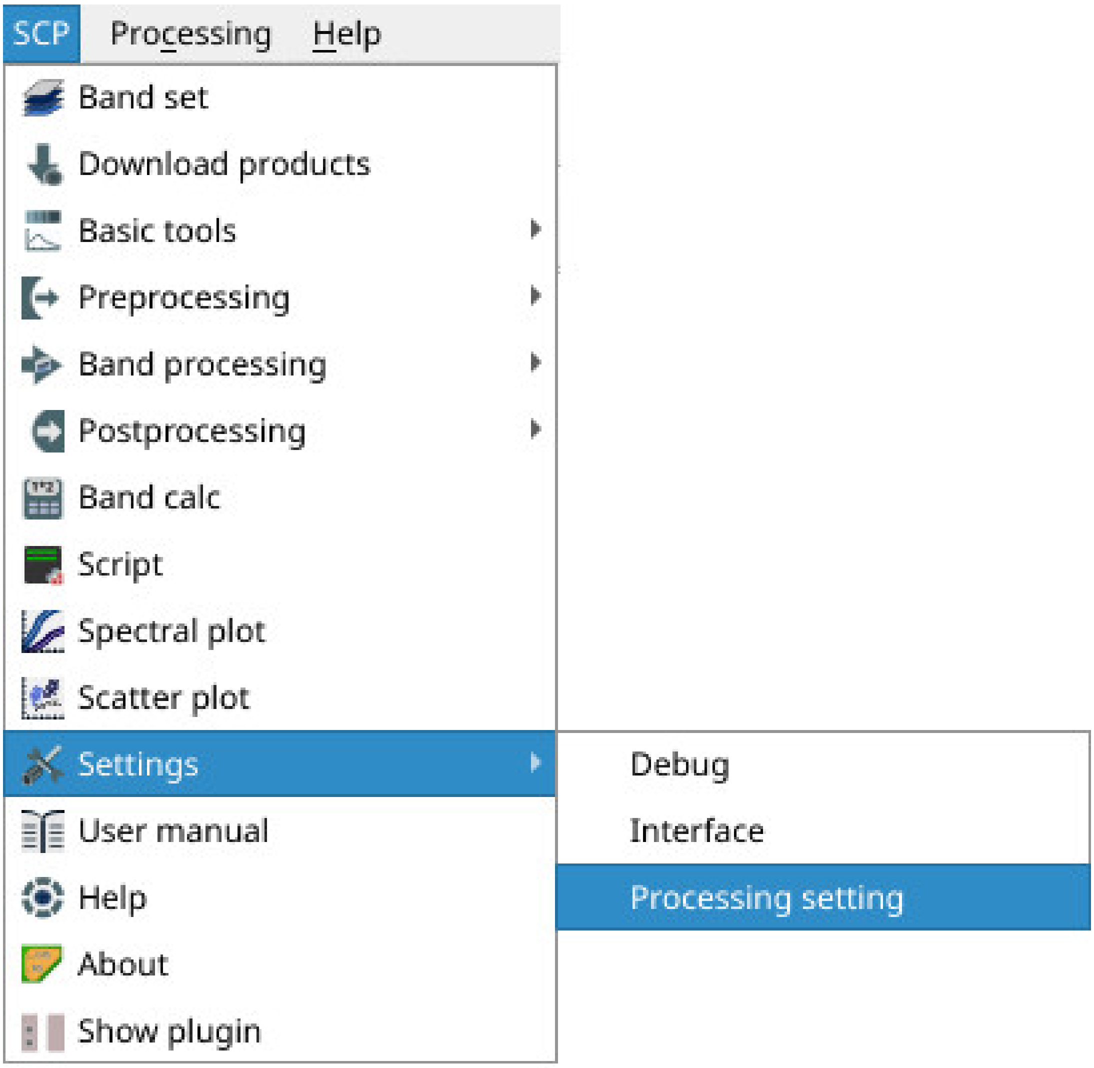


2.1.4 Configuration of the plugin

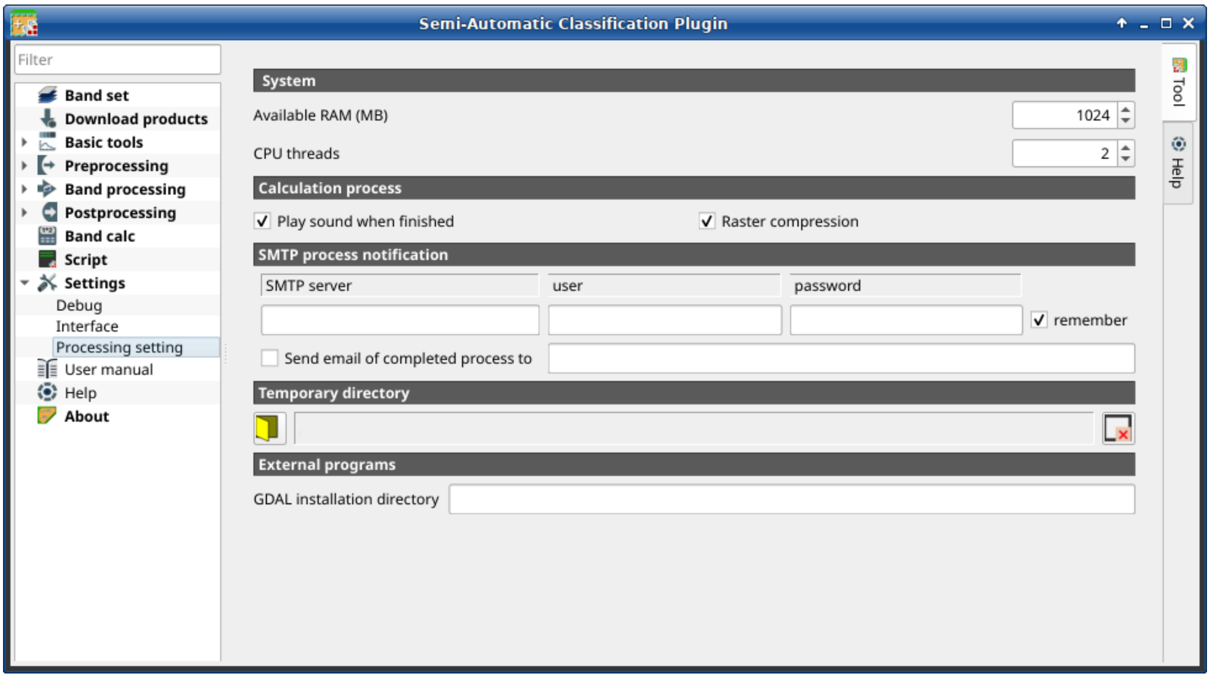
Now, the Semi-Automatic Classification Plugin is installed and a dock and a toolbar should be added to QGIS. Also, a SCP menu is available in the Menu Bar of QGIS. It is possible to move the toolbar and the dock according to your needs, as in the following image.



The configuration of available RAM is recommended in order to reduce the processing time. From the *SCP menu* (page 29) select `Settings > Processing`.

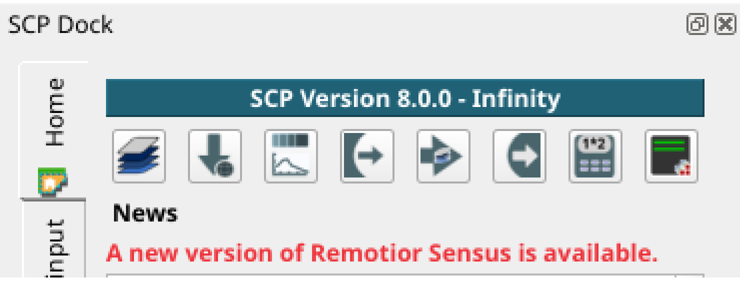


In the *Settings* (page 107), set the `Available RAM (MB)` to a value that should be half of the system RAM. For instance, if your system has 2GB of RAM, set the value to 1024MB.



2.1.5 Update of required dependencies

The dependency Remotior Sensus is frequently updated. The Semi-Automatic Classification Plugin can check automatically if a new version is available, and display a message in the *SCP dock* (page 31).

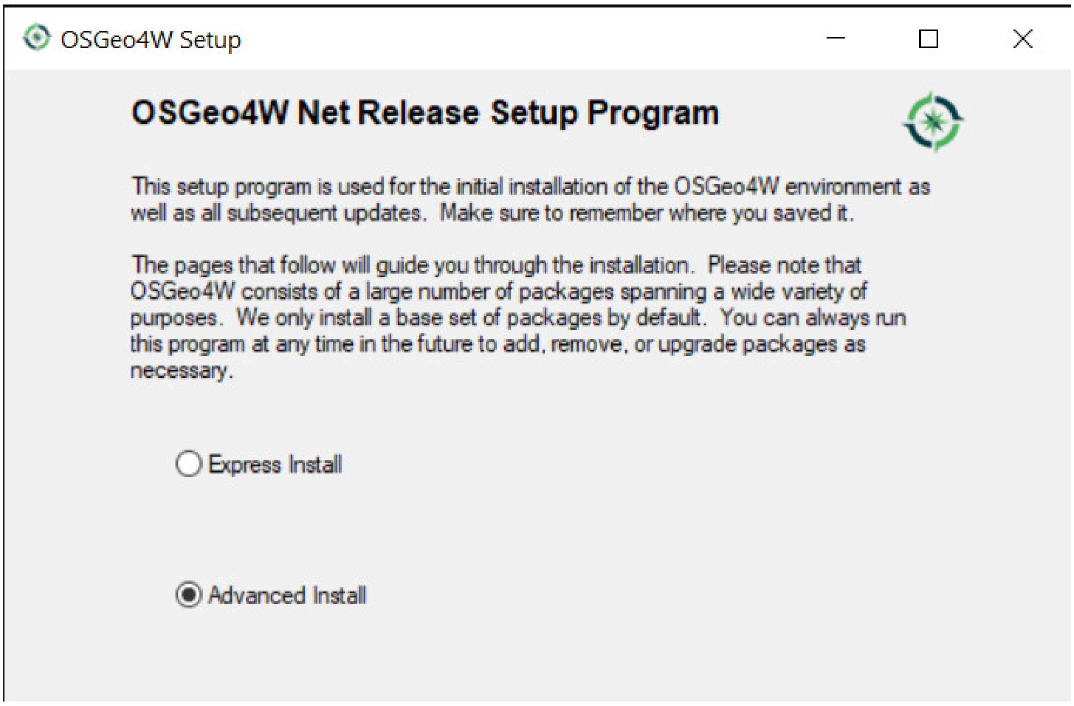


It is recommended to close QGIS and update Remotior Sensus following the same installation steps described in *Installation of required dependencies* (page 4) .

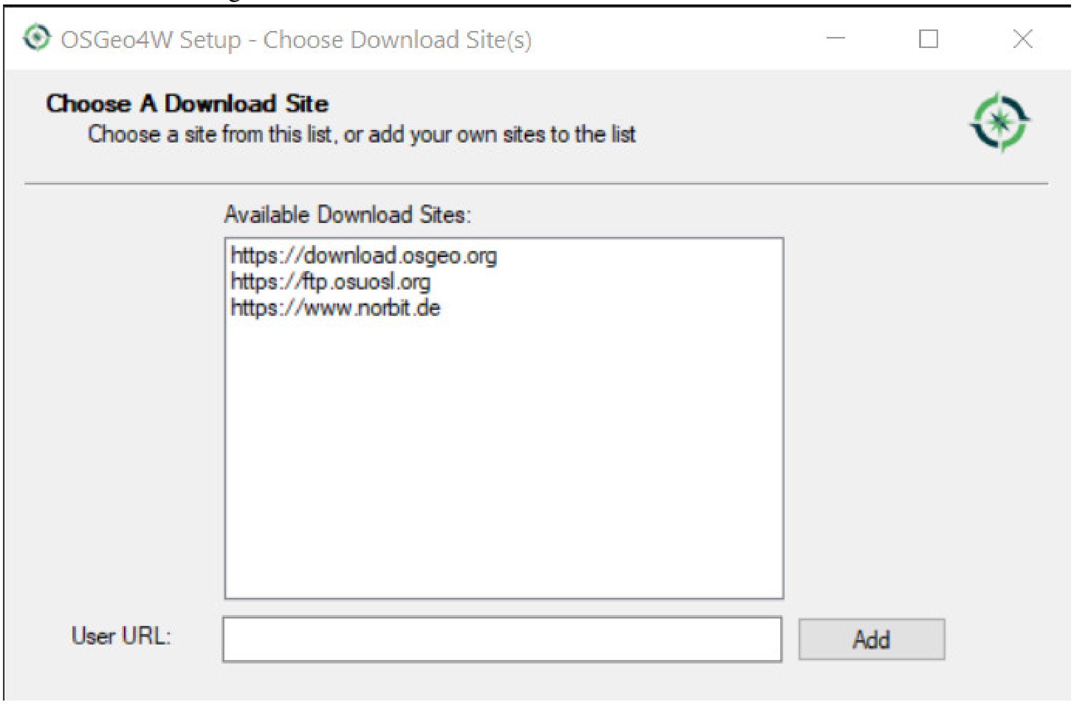
2.2 Network installation in Windows 64 bit

2.2.1 QGIS download and installation

- Download the latest QGIS version 64 bit using the OSGeo4W network installer from here;
- Execute the QGIS installer with administrative rights and select `Advanced Install`;

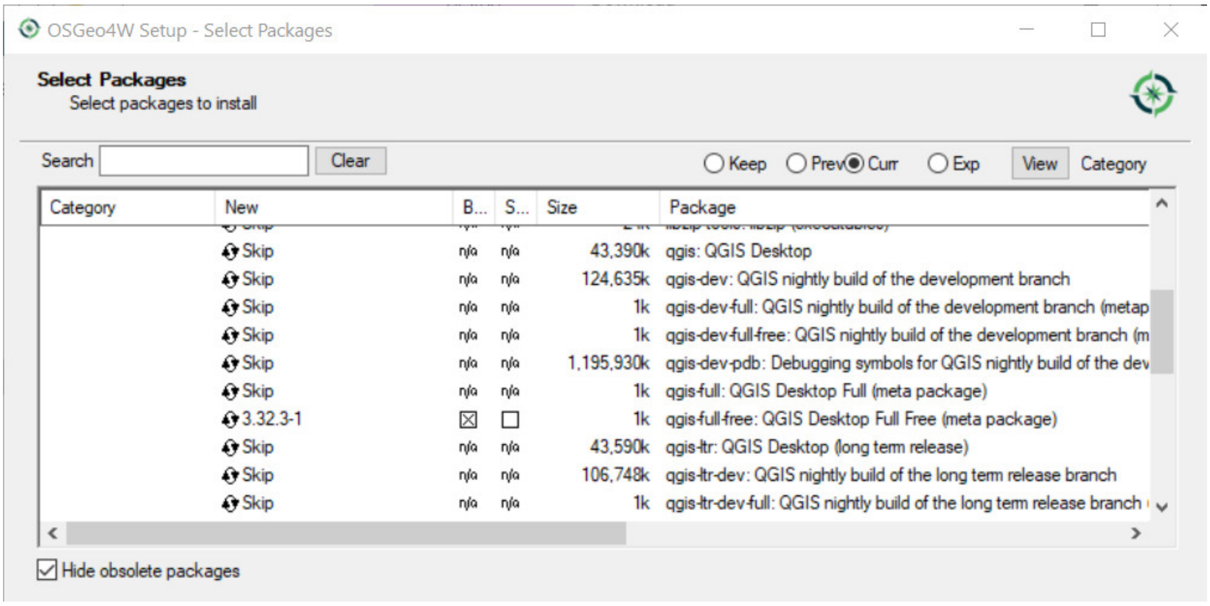


— Select `Install from Internet`; proceed selecting the default installation directory and the preferred network configuration;



The Semi-Automatic Classification Plugin requires Remotior Sensus, GDAL, NumPy and SciPy for most functionalities. Optionally, scikit-learn and PyTorch are required for machine learning.

— In the menu `Select packages` select `All > Desktop > qgis-full-free`; also select `All > Libs > python3-remotior-sensus`, `All > Libs > python3-scikit-learn` and `All > Libs > python3-torch`;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Skip n/a n/a 1k qgis-ltr-dev-full: QGIS nightly build of the long term release branch
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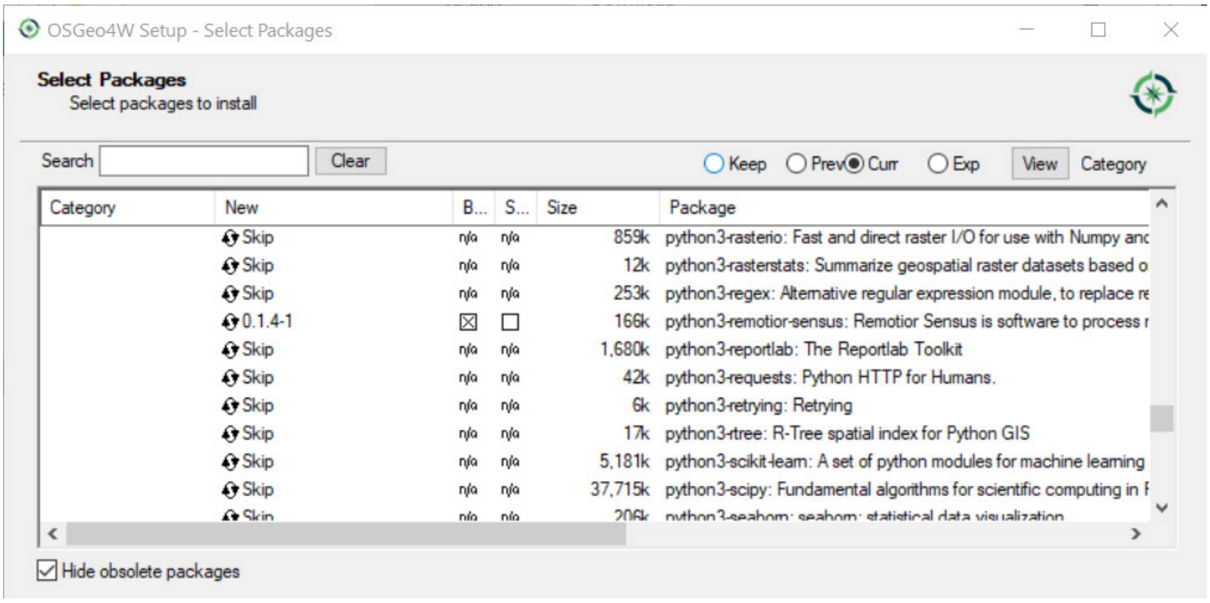
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Skip n/a n/a 6k python3-retrying: Retrying
Skip n/a n/a 17k python3-rtree: R-Tree spatial index for Python GIS
Skip n/a n/a 5,181k python3-scikit-learn: A set of python modules for machine learning
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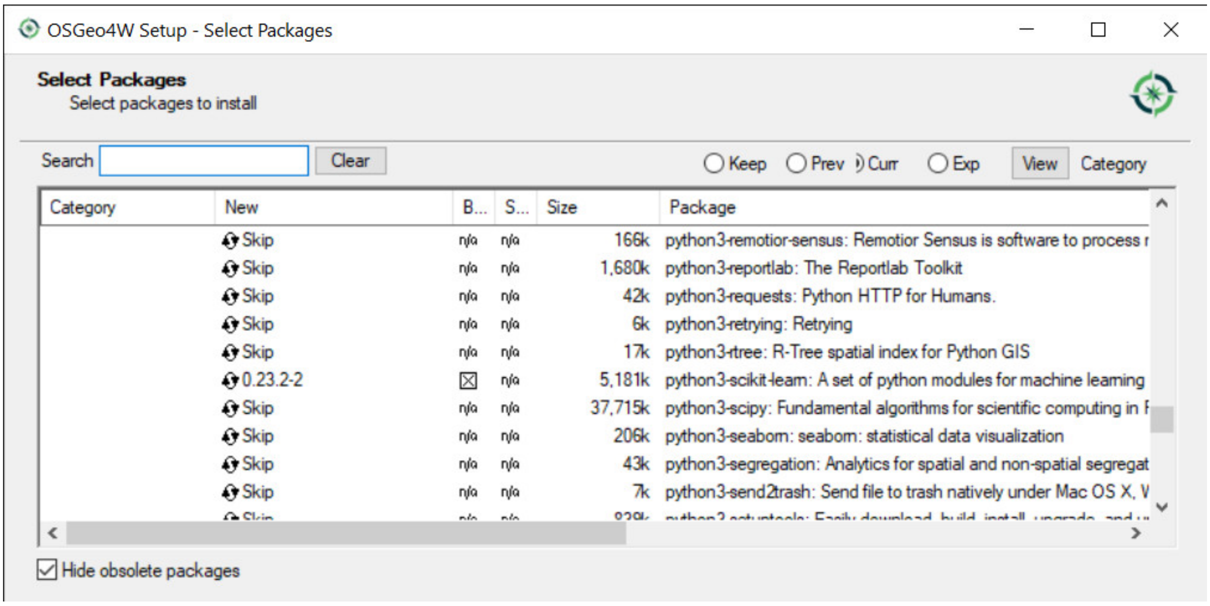
Hide obsolete packages


OSGeo4W Setup - Select Packages
Select Packages
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Skip n/a n/a 42k python3-requests: Python HTTP for Humans.
Skip n/a n/a 6k python3-retrying: Retrying
Skip n/a n/a 17k python3-rtree: R-Tree spatial index for Python GIS
0.23.2-2 n/a 5,181k python3-scikit-learn: A set of python modules for machine learning
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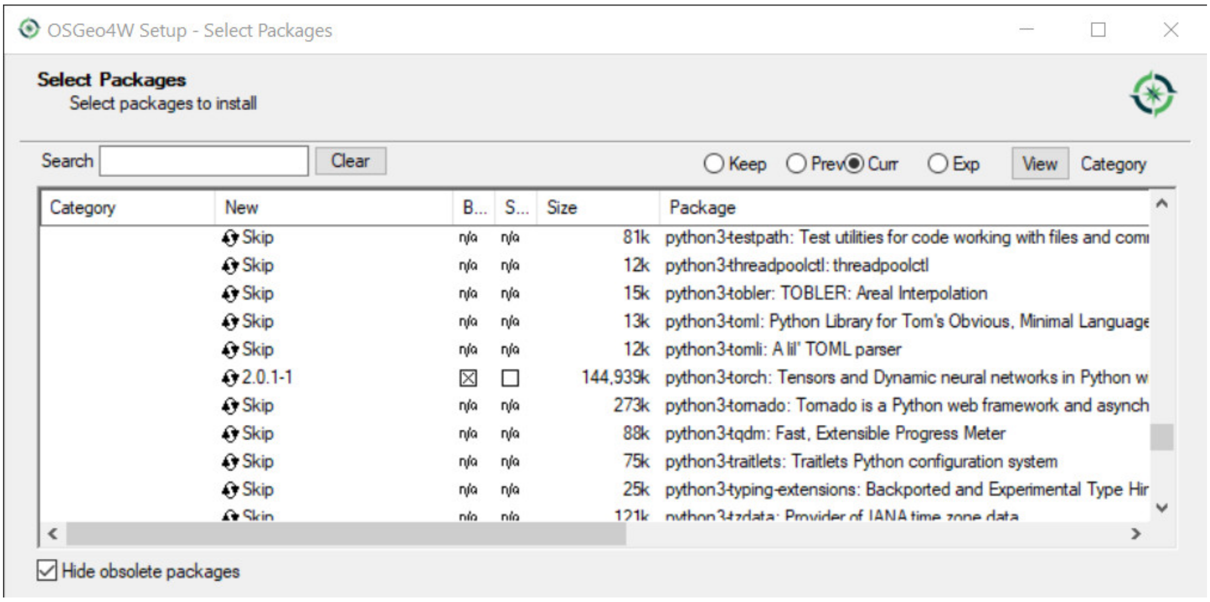
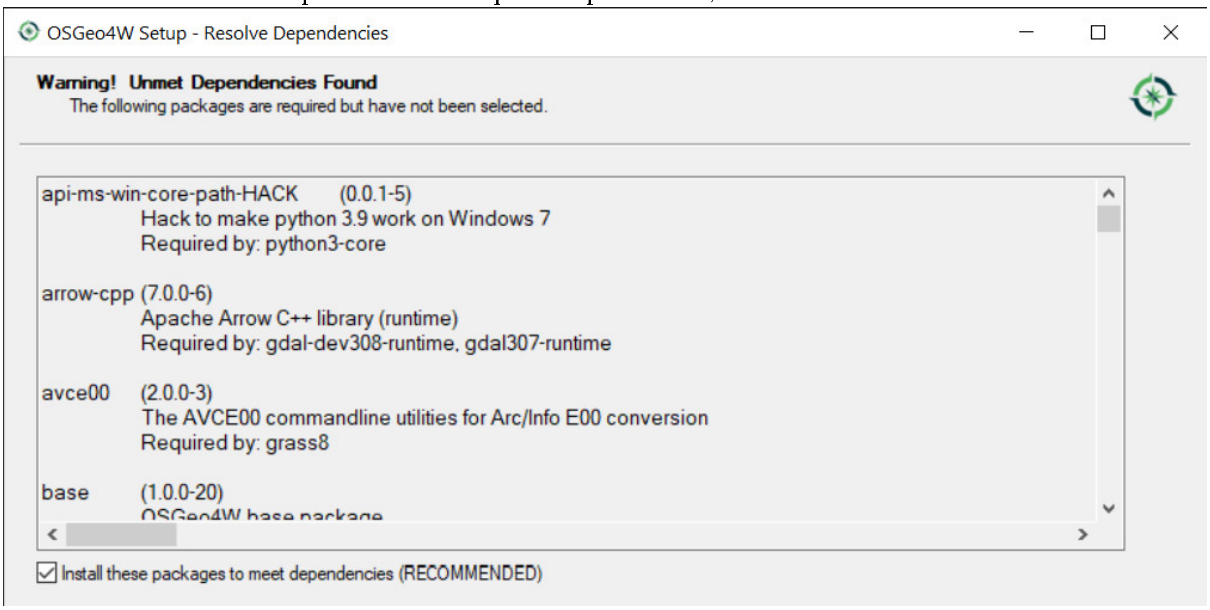
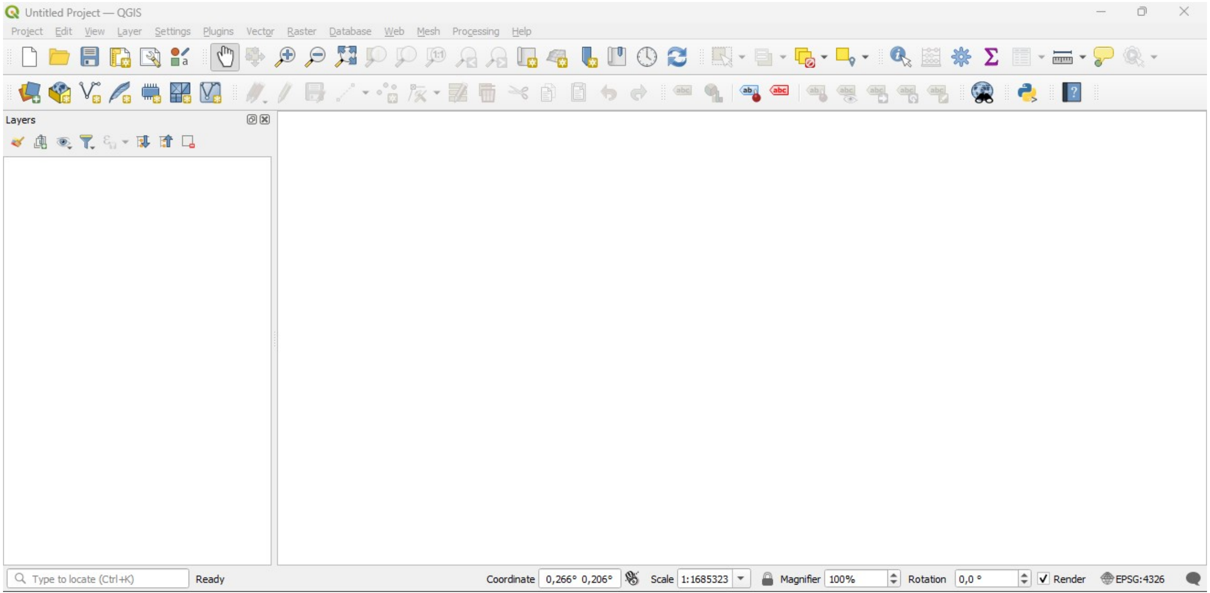
Hide obsolete packages



— Click `Next` and accept to install the required dependencies ;

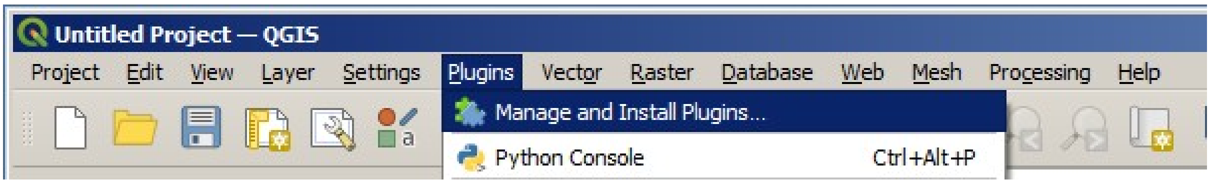


The download of the programs will start, and QGIS will be installed along with the required dependencies.

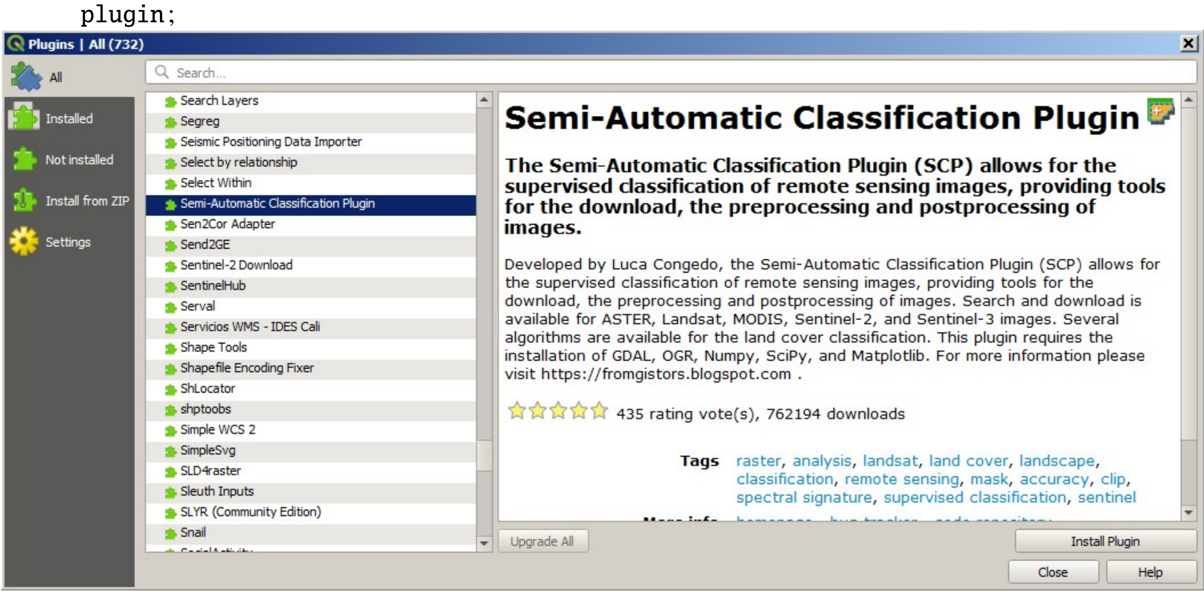


2.2.2 Semi-Automatic Classification Plugin installation

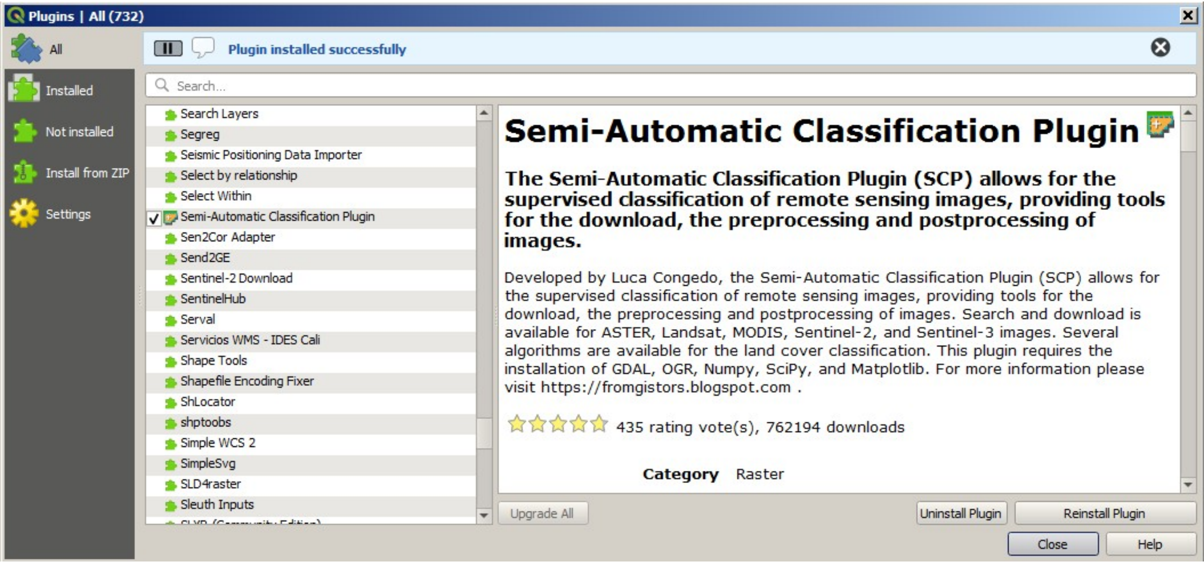
- Run QGIS ;
- From the main menu, select `Plugins` > `Manage and Install Plugins` ;



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

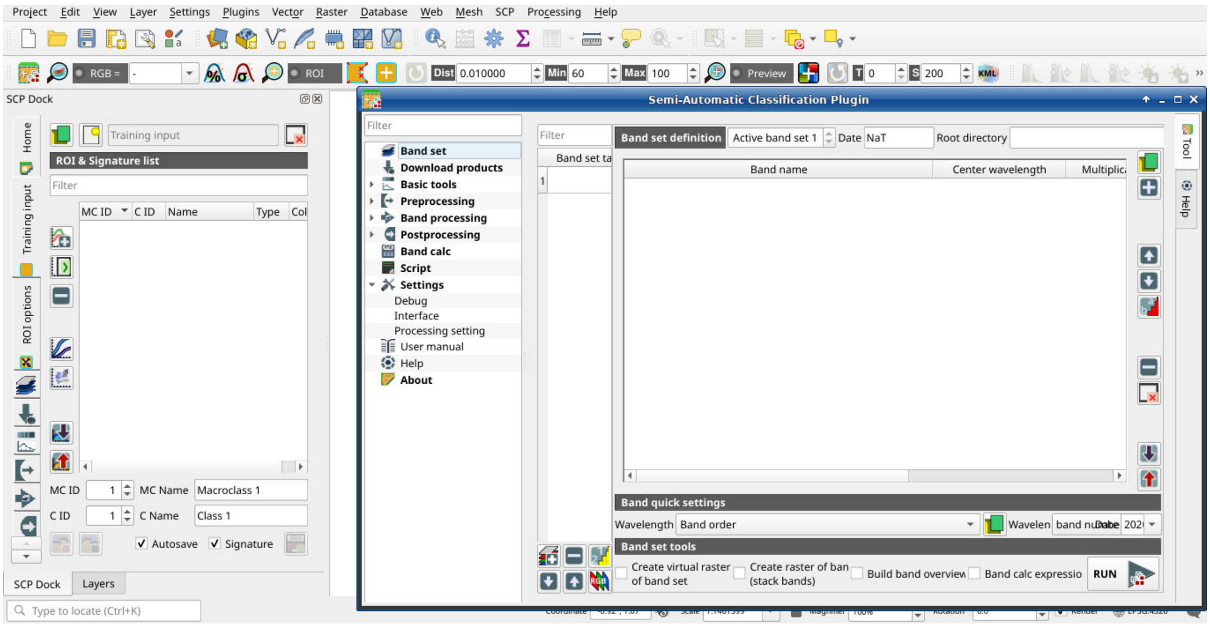


- The SCP should be automatically activated ; however, be sure that the Semi-Automatic Classification Plugin is checked in the menu `Installed` (the restart of QGIS could be necessary to complete the SCP installation) ;

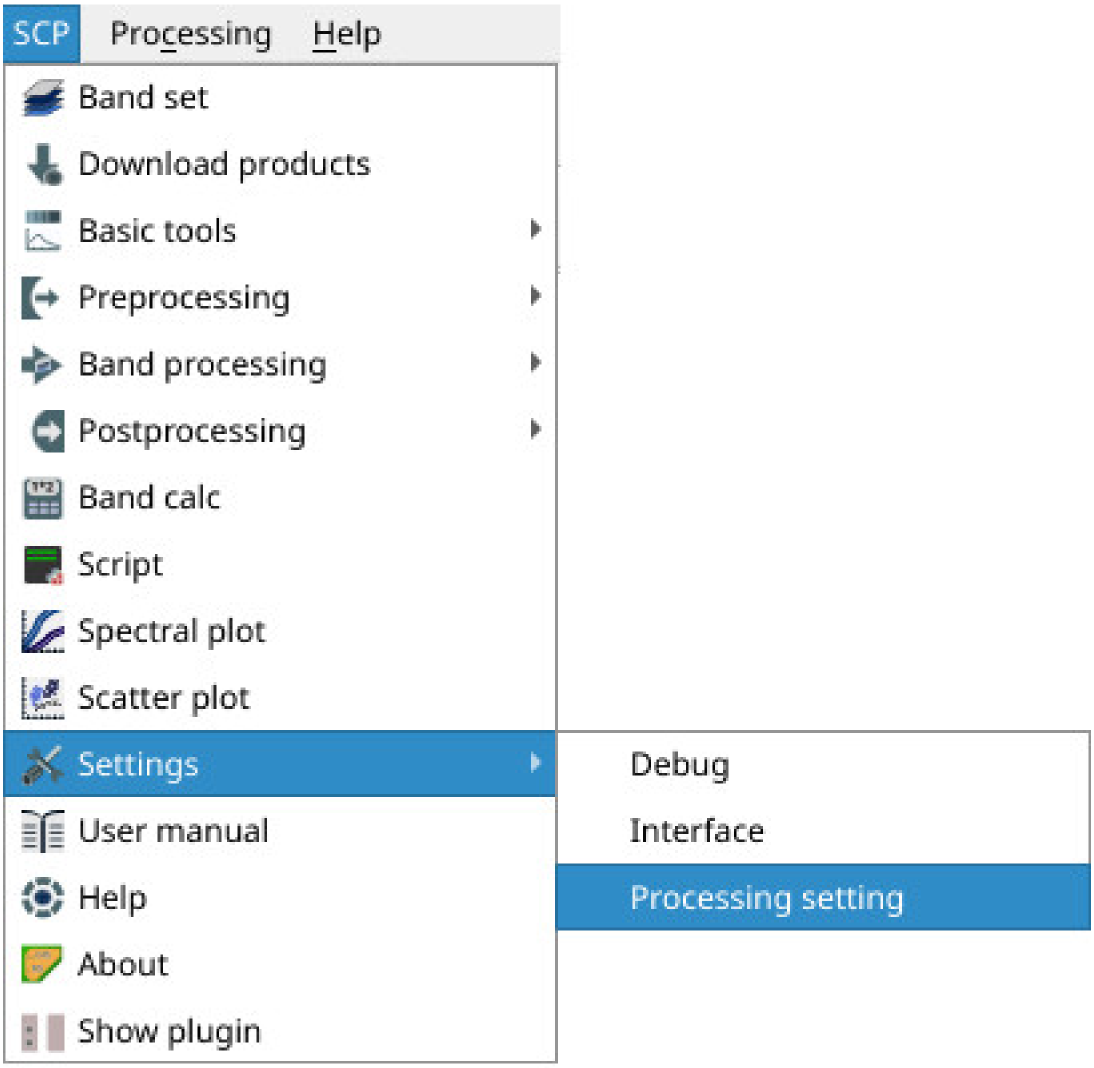


2.2.3 Configuration of the plugin

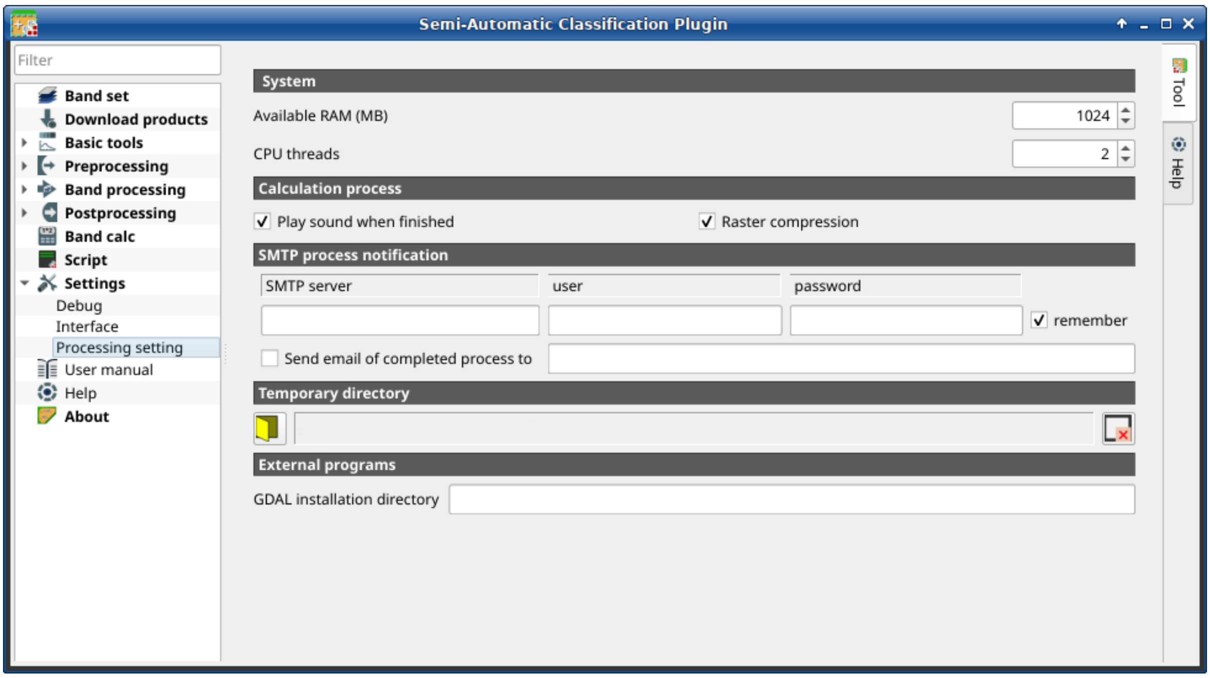
Now, the Semi-Automatic Classification Plugin is installed and a dock and a toolbar should be added to QGIS. Also, a SCP menu is available in the Menu Bar of QGIS. It is possible to move the toolbar and the dock according to your needs, as in the following image.



The configuration of available RAM is recommended in order to reduce the processing time. From the *SCP menu* (page 29) select `Settings > Processing` .

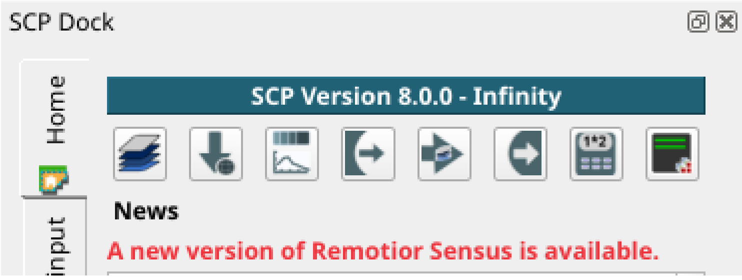


In the *Settings* (page 107), set the `Available RAM (MB)` to a value that should be half of the system RAM. For instance, if your system has 2GB of RAM, set the value to 1024MB.



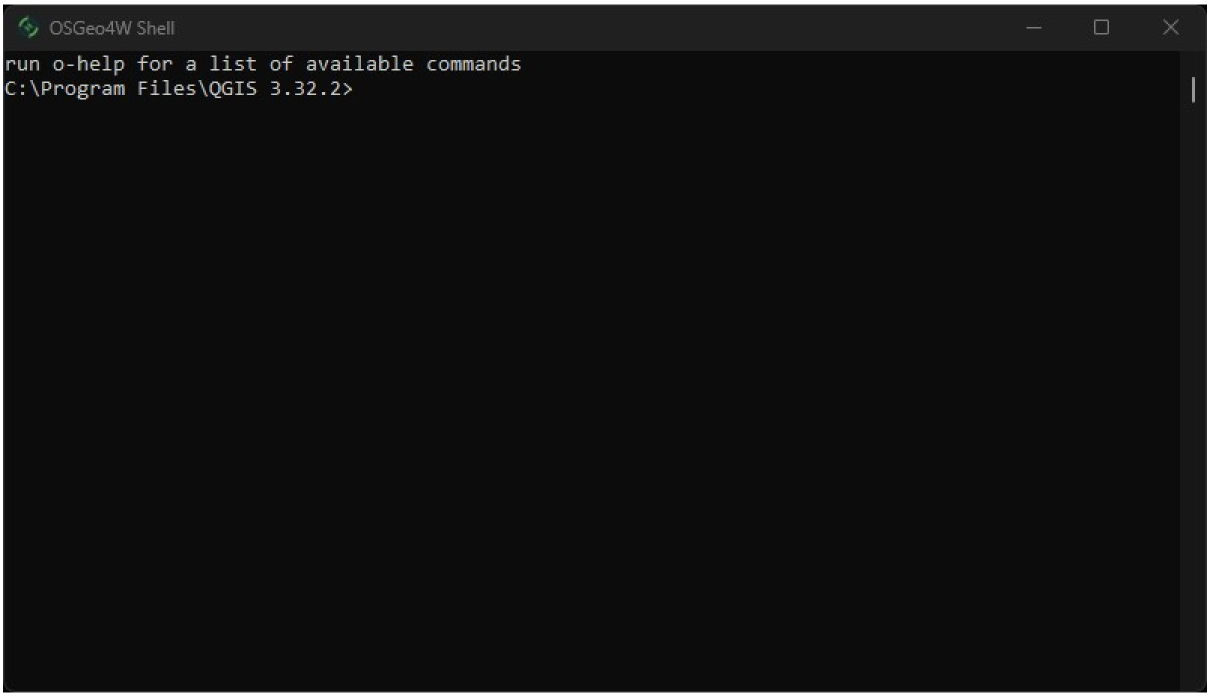
2.2.4 Update of required dependencies

The dependency Remotior Sensus is frequently updated. The Semi-Automatic Classification Plugin can check automatically if a new version is available, and display a message in the *SCP dock* (page 31).



It is recommended to close QGIS and update Remotior Sensus following the same installation steps described in *QGIS download and installation* (page 7).

In case the library Remotior Sensus is outdated, it is possible to open the OSGeo4W Shell (administrative rights may be required) :



and run the following command :

```
pip3 install --upgrade remotior-sensus
```

2.3 Installation in Debian/Ubuntu Linux

2.3.1 QGIS download and installation

— Open a terminal and type :

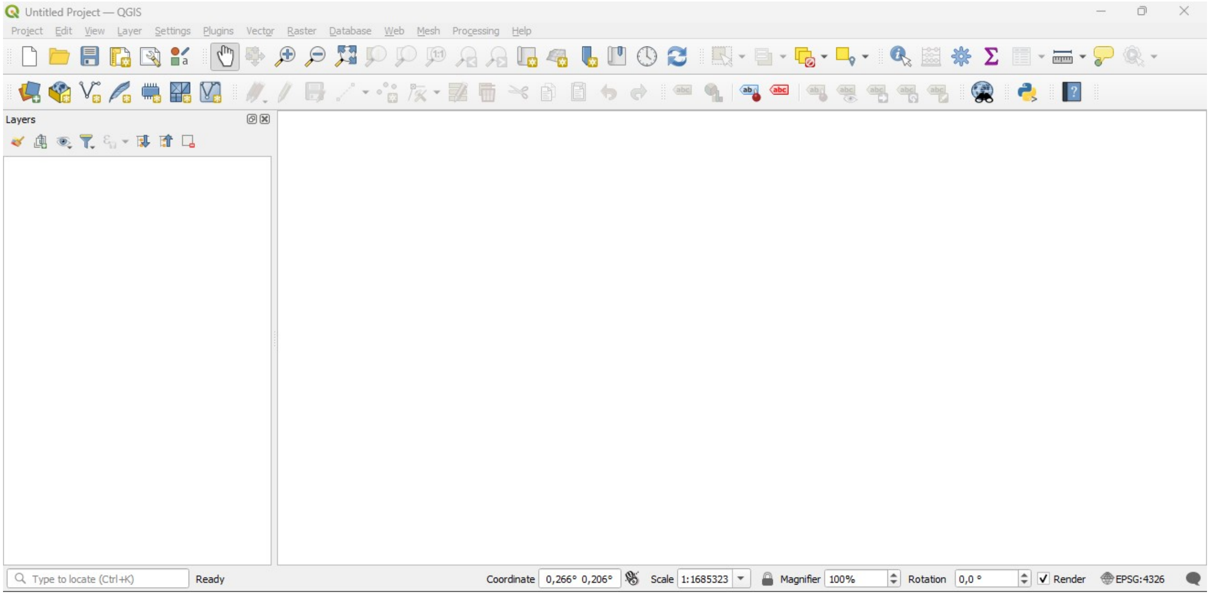
```
sudo apt-get update
```

— 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 Installation of required dependencies

The Semi-Automatic Classification Plugin requires Remotior Sensus, GDAL, NumPy and SciPy for most functionalities. Optionally, scikit-learn and PyTorch are required for machine learning.

Therefore, we need to install the dependencies that are not included in the QGIS installation.

— Close QGIS ;
— Open the terminal (administrative rights may be required) ;
— Enter the following command :

```
pip3 install --upgrade remotior-sensus scikit-learn torch
```

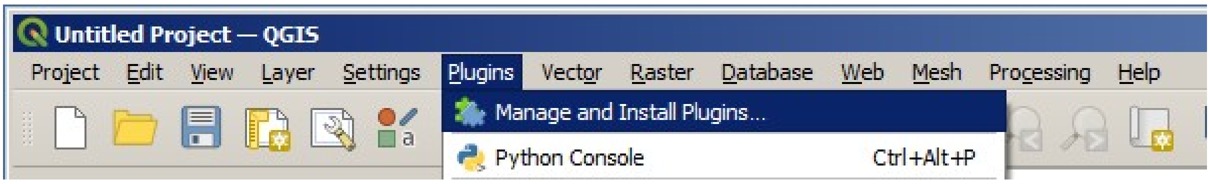
Avertissement : In case you get an error message related to externally managed environment, you may use (at the risk of breaking the OS or the Python installation) the option `--break-system-packages` ; alternatively, it is possible to create a virtual environment `python3 -m venv env`, install the packages in it, and start QGIS from the activated environment.

Follow the same procedure for updating the dependencies.

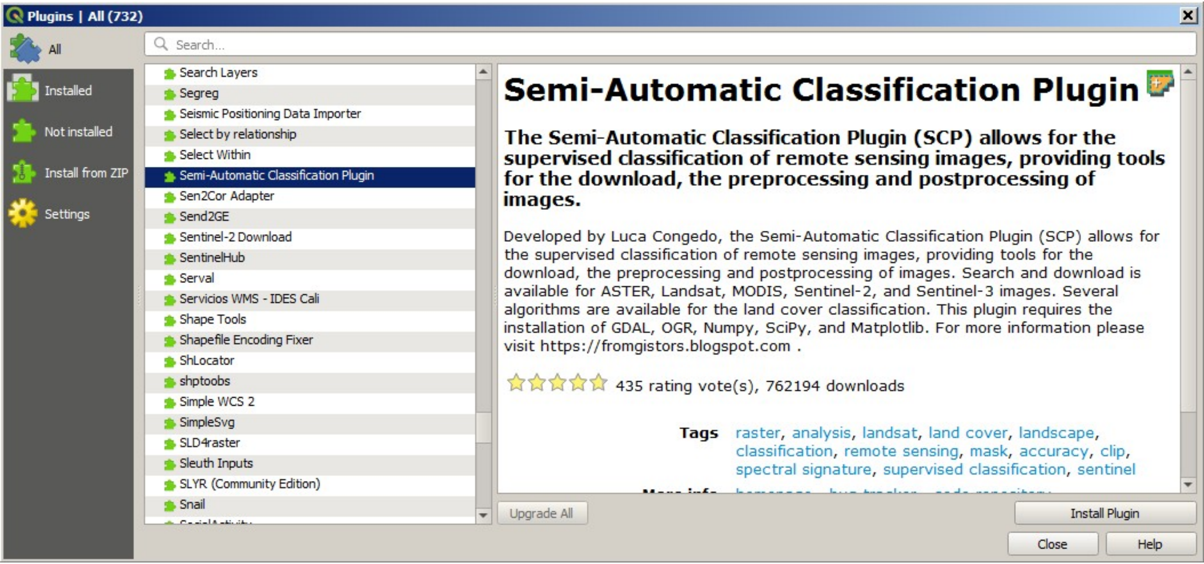
Astuce : In case the library Remotior Sensus is not found, an automatic procedure will try to download it in the plugin directory, allowing for using the main functions of the Semi-Automatic Classification Plugin ; however, this is not recommended as library Remotior Sensus won't be updated, and scikit-learn and PyTorch functions will not work. Alternatively, one may follow *Advanced installation using Conda* (page 23).

2.3.3 Semi-Automatic Classification Plugin installation

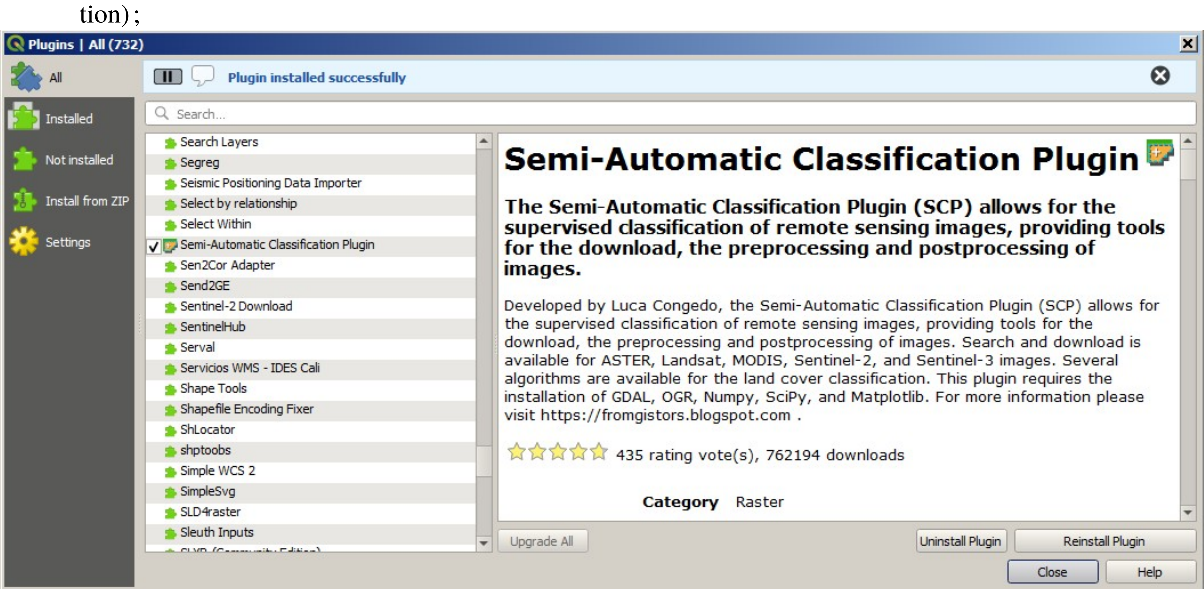
— Run QGIS ;
— From the main menu, select `Plugins` > `Manage and Install Plugins` ;



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

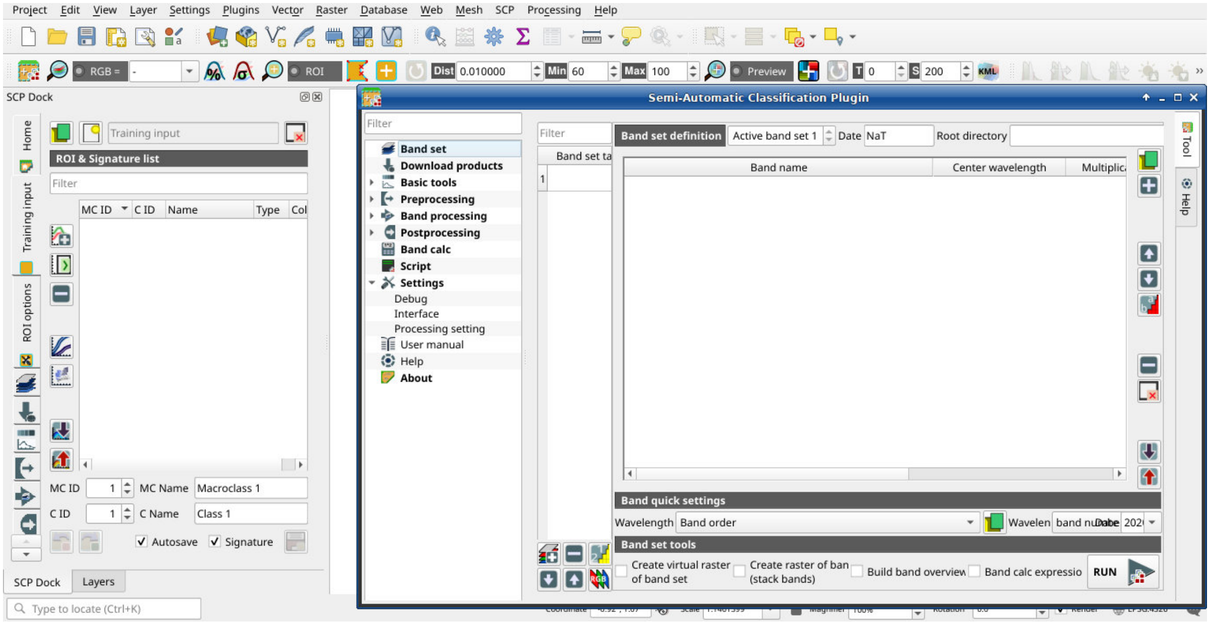


— The SCP should be automatically activated ; however, be sure that the Semi-Automatic Classification Plugin is checked in the menu `Installed` (the restart of QGIS could be necessary to complete the SCP installation) ;

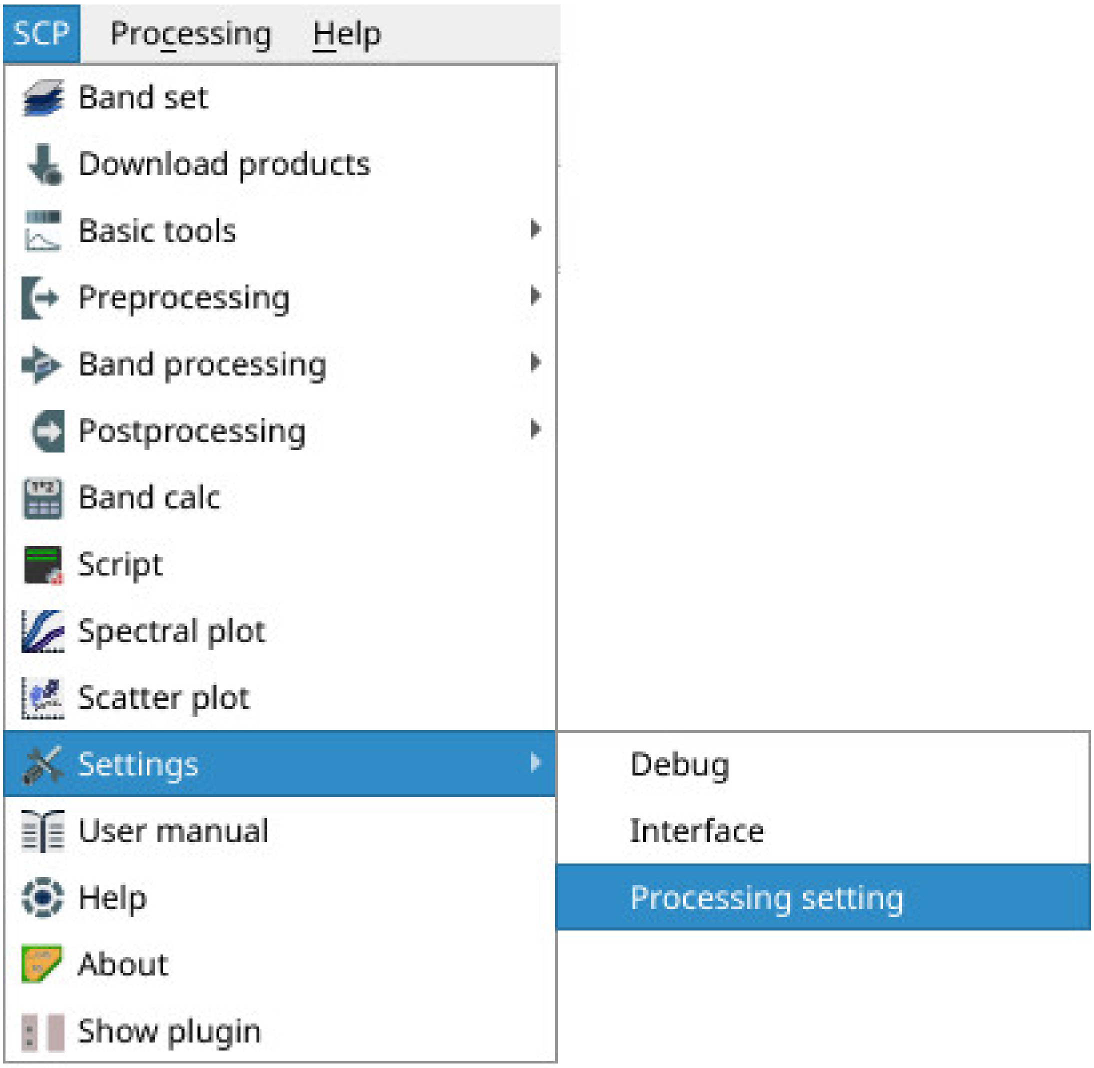


2.3.4 Configuration of the plugin

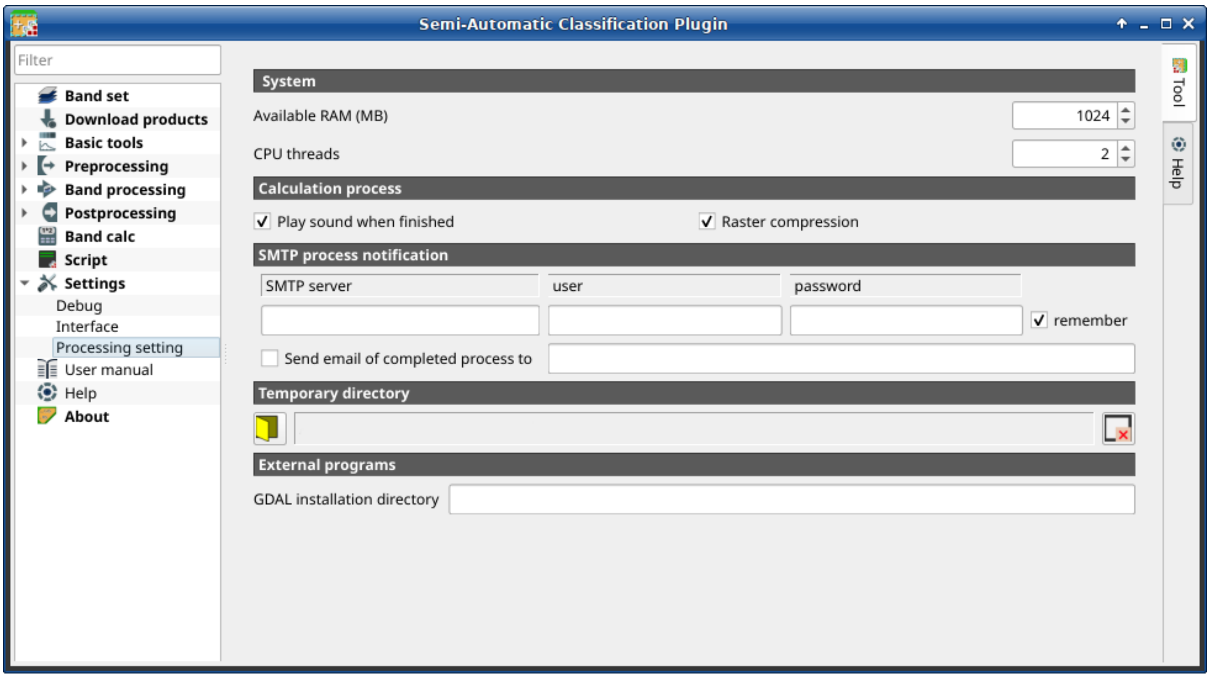
Now, the Semi-Automatic Classification Plugin is installed and a dock and a toolbar should be added to QGIS. Also, a SCP menu is available in the Menu Bar of QGIS. It is possible to move the toolbar and the dock according to your needs, as in the following image.



The configuration of available RAM is recommended in order to reduce the processing time. From the *SCP menu* (page 29) select `Settings > Processing`.

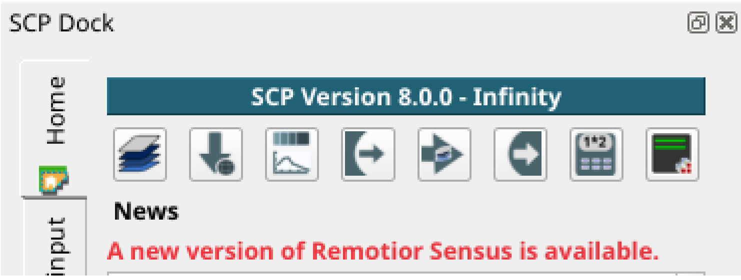


In the *Settings* (page 107), set the `Available RAM (MB)` to a value that should be half of the system RAM. For instance, if your system has 2GB of RAM, set the value to 1024MB.



2.3.5 Update of required dependencies

The dependency Remotior Sensus is frequently updated. The Semi-Automatic Classification Plugin can check automatically if a new version is available, and display a message in the *SCP dock* (page 31).



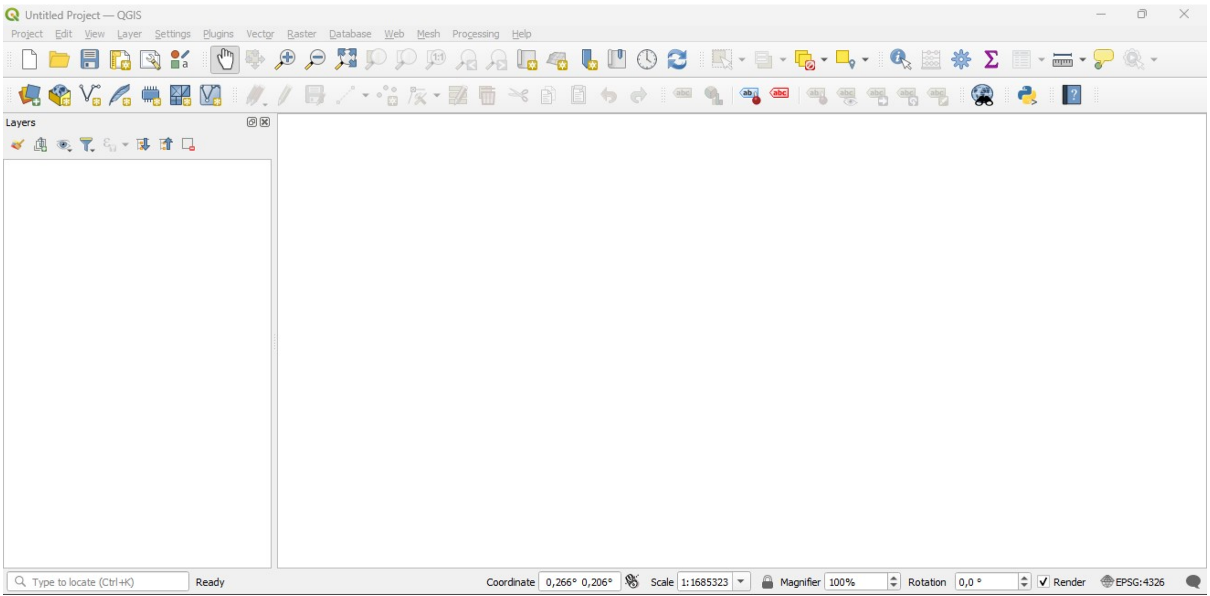
It is recommended to close QGIS and update Remotior Sensus following the same installation steps described in *Installation of required dependencies* (page 15) .

2.4 Installation in macOS

2.4.1 QGIS download and installation

— Download the latest QGIS version from here ;
— Execute the QGIS installer with administrative rights, accepting the default configuration.

Now, QGIS is installed.



2.4.2 Installation of required dependencies

The Semi-Automatic Classification Plugin requires Remotior Sensus, GDAL, NumPy and SciPy for most functionalities. Optionally, scikit-learn and PyTorch are required for machine learning.

Therefore, we need to install the dependencies that are not included in the QGIS installation.

— Close QGIS ;
— Open the terminal (administrative rights may be required) ;
— Type the following command (you may need to adapt the path */Applications/QGIS.app* to the actual QGIS installation directory) :

```
/Applications/QGIS.app/Contents/MacOS/bin/pip3 install --upgrade remotior-sensus␣
↪scikit-learn torch
```

or in case you installed QGIS LTR :

```
/Applications/QGIS-LTR.app/Contents/MacOS/bin/pip3 install --upgrade remotior-sensus␣
↪scikit-learn torch
```

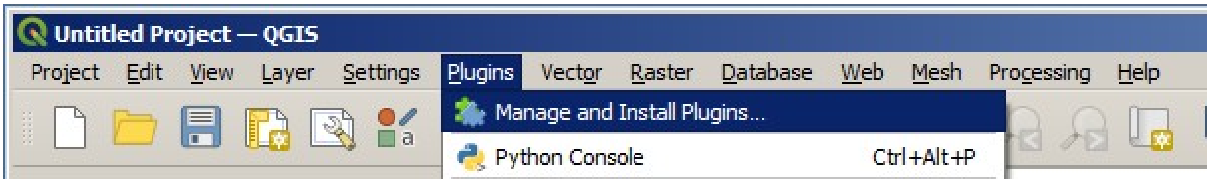
Astuce : In case of error messages such as scikit-learn is already installed, you can just run `/Applications/QGIS.app/Contents/MacOS/bin/pip3 install --upgrade remotior-sensus torch`

Follow the same procedure for updating the dependencies.

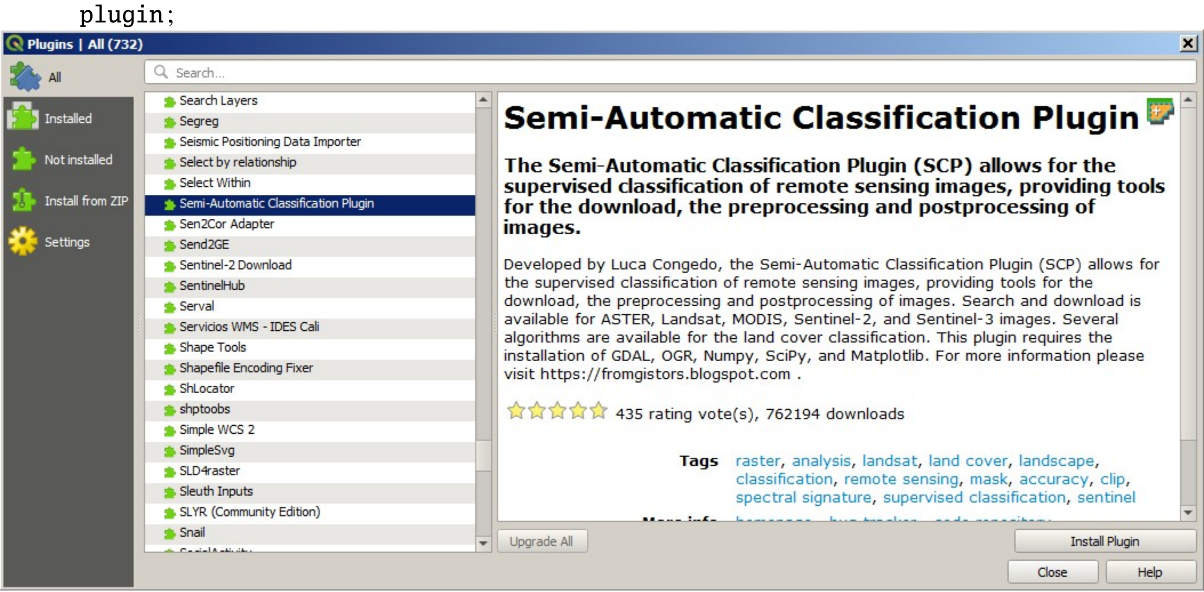
Astuce : In case the library Remotior Sensus is not found, an automatic procedure will try to download it in the plugin directory, allowing for using the main functions of the Semi-Automatic Classification Plugin ; however, this is not recommended as library Remotior Sensus won't be updated, and scikit-learn and PyTorch functions will not work. Alternatively, one may follow *Advanced installation using Conda* (page 23).

2.4.3 Semi-Automatic Classification Plugin installation

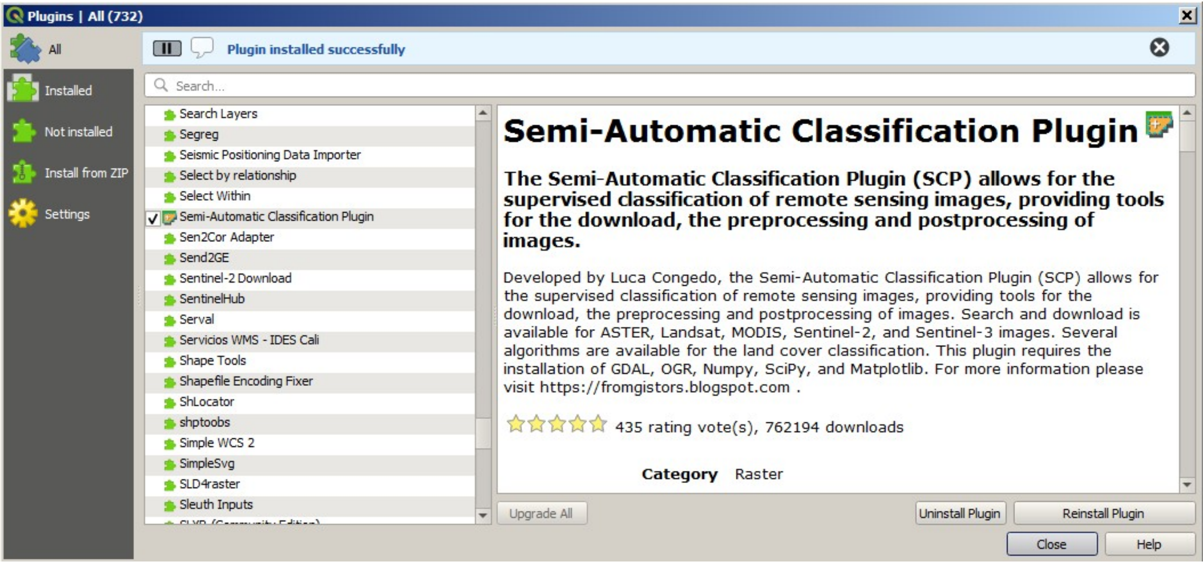
— Run QGIS ;
— From the main menu, select `Plugins` > `Manage and Install Plugins` ;



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

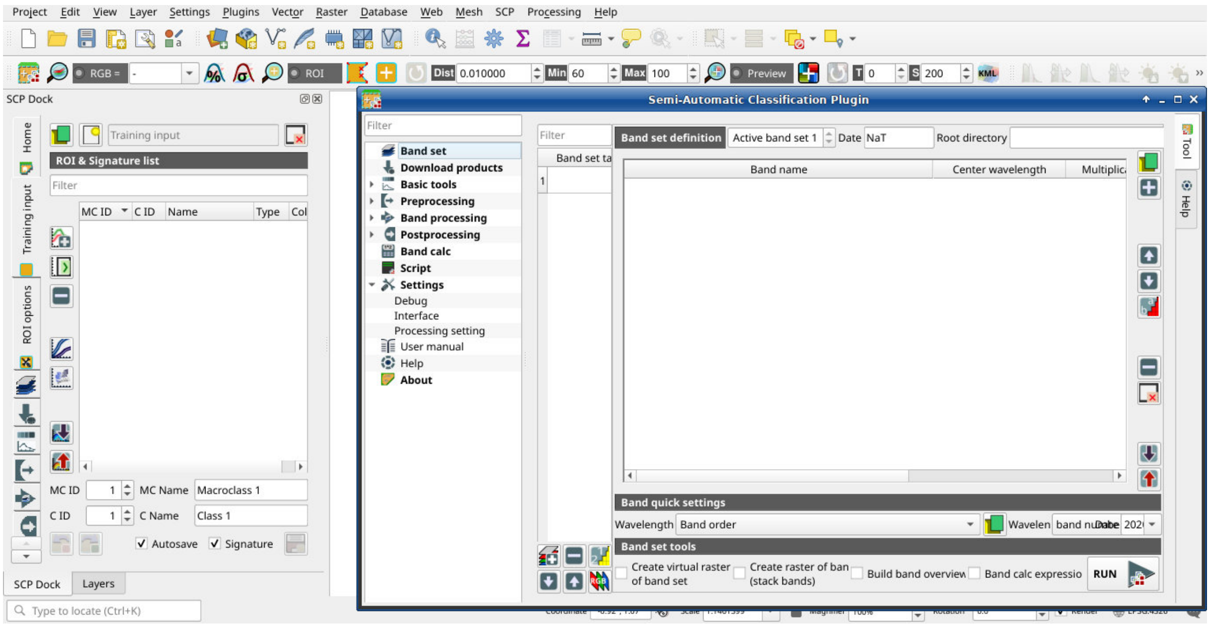


— The SCP should be automatically activated ; however, be sure that the Semi-Automatic Classification Plugin is checked in the menu `Installed` (the restart of QGIS could be necessary to complete the SCP installation) ;

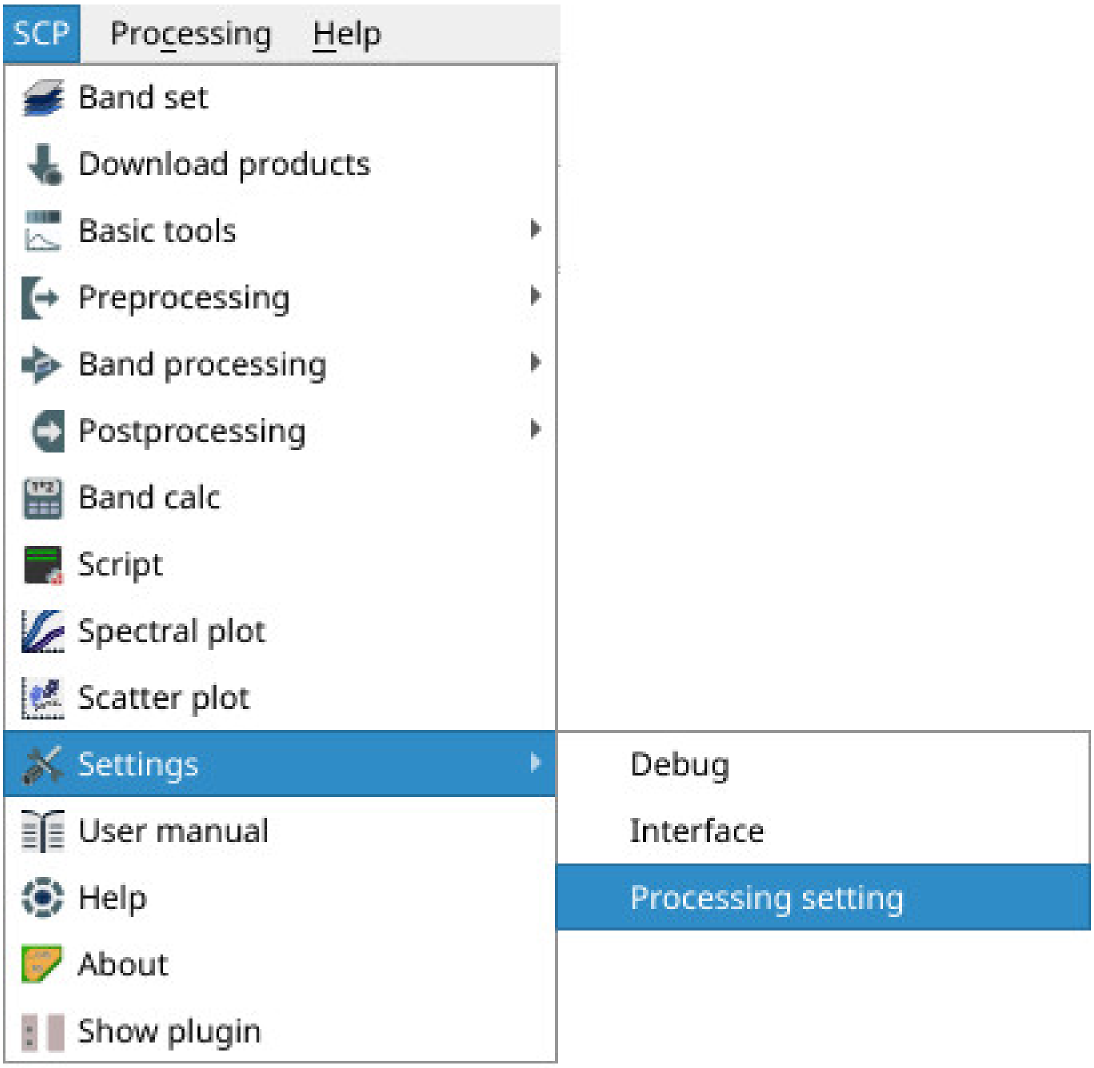


2.4.4 Configuration of the plugin

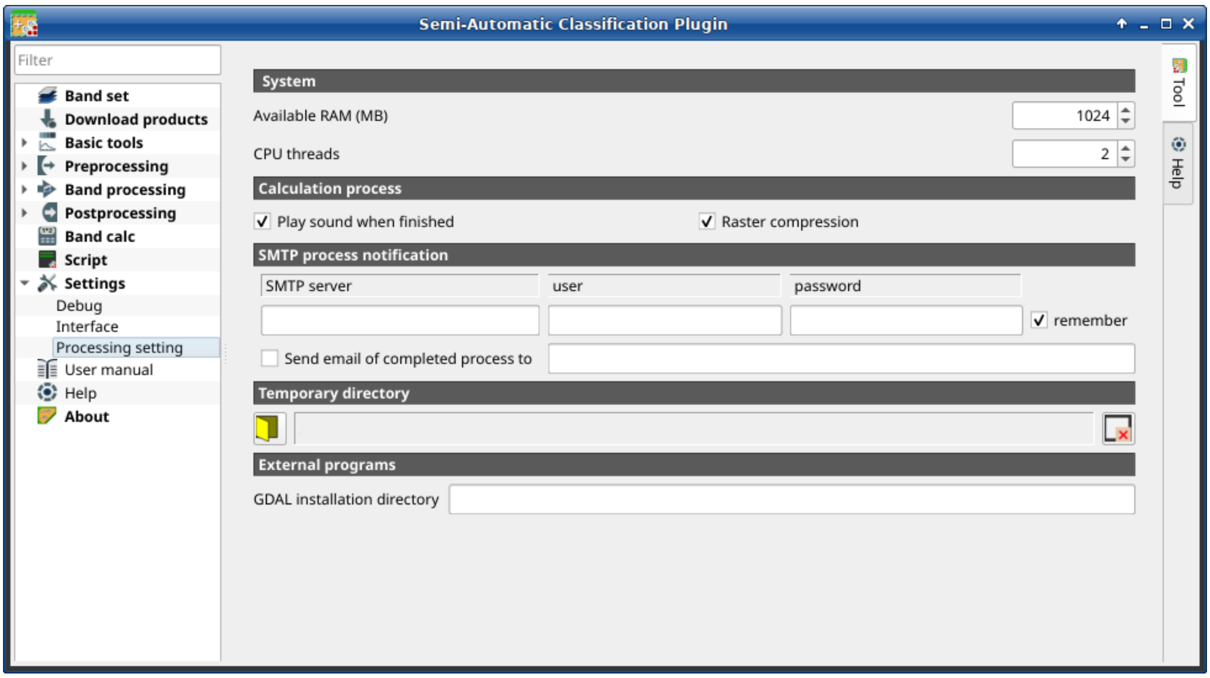
Now, the Semi-Automatic Classification Plugin is installed and a dock and a toolbar should be added to QGIS. Also, a SCP menu is available in the Menu Bar of QGIS. It is possible to move the toolbar and the dock according to your needs, as in the following image.



The configuration of available RAM is recommended in order to reduce the processing time. From the *SCP menu* (page 29) select `Settings > Processing` .

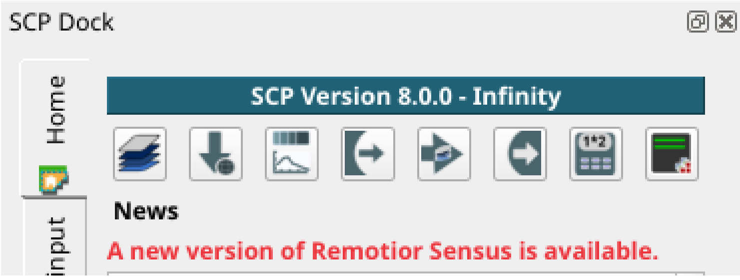


In the *Settings* (page 107), set the `Available RAM (MB)` to a value that should be half of the system RAM. For instance, if your system has 2GB of RAM, set the value to 1024MB.



2.4.5 Update of required dependencies

The dependency Remotior Sensus is frequently updated. The Semi-Automatic Classification Plugin can check automatically if a new version is available, and display a message in the *SCP dock* (page 31).



It is recommended to close QGIS and update Remotior Sensus following the same installation steps described in *Installation of required dependencies* (page 19) .

2.5 Advanced installation using Conda

2.5.1 QGIS download and installation with the dependencies

The Semi-Automatic Classification Plugin requires Remotior Sensus, GDAL, NumPy and SciPy for most functionalities.

QGIS and the dependencies can be installed using a *Conda* environment (if you don't know *Conda* please read https://conda-forge.org/docs). For instance, you can use Miniforge to create a *Conda* environment.

Once installed conda, open the terminal and run the following commands to create a new environment :

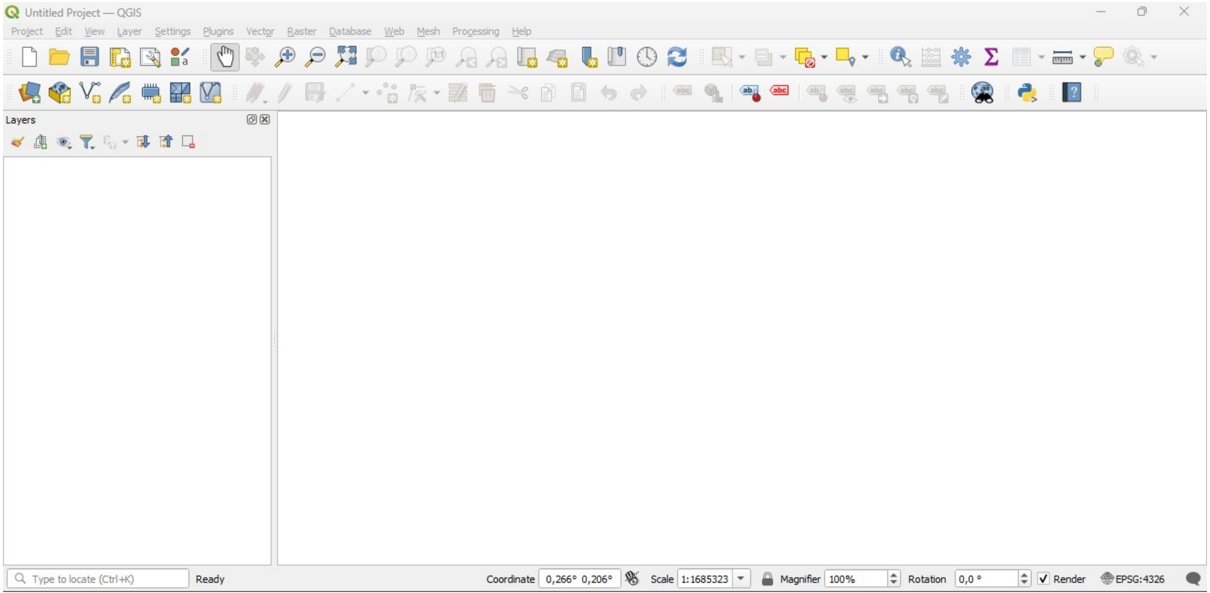
```
$ conda create -c conda-forge --name environment python=3.10
Proceed ([y]/n)? y
$ conda activate environment
```

Now install QGIS and the dependencies (it could take some time) :

```
$ conda install -c conda-forge qgis gdal remotior-sensus scikit-learn pytorch
```

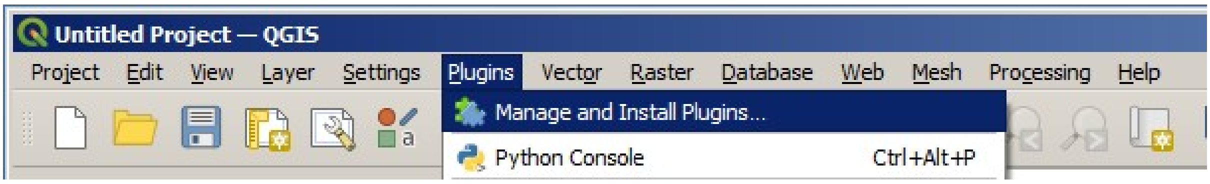
Now, QGIS is installed. To launch it run in the terminal :

```
$ qgis
```

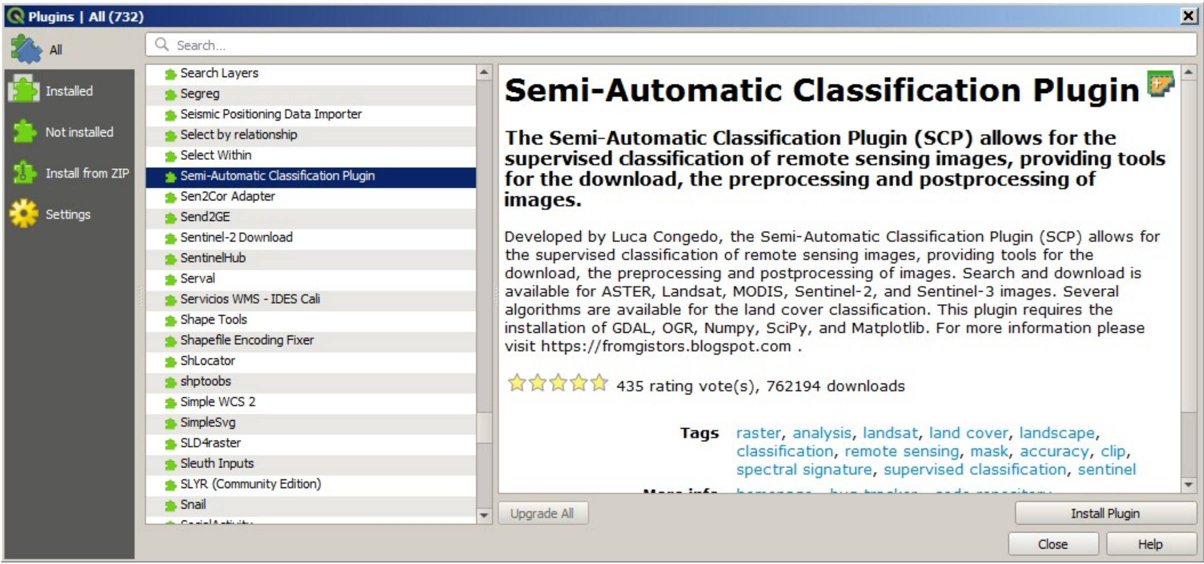


2.5.2 Semi-Automatic Classification Plugin installation

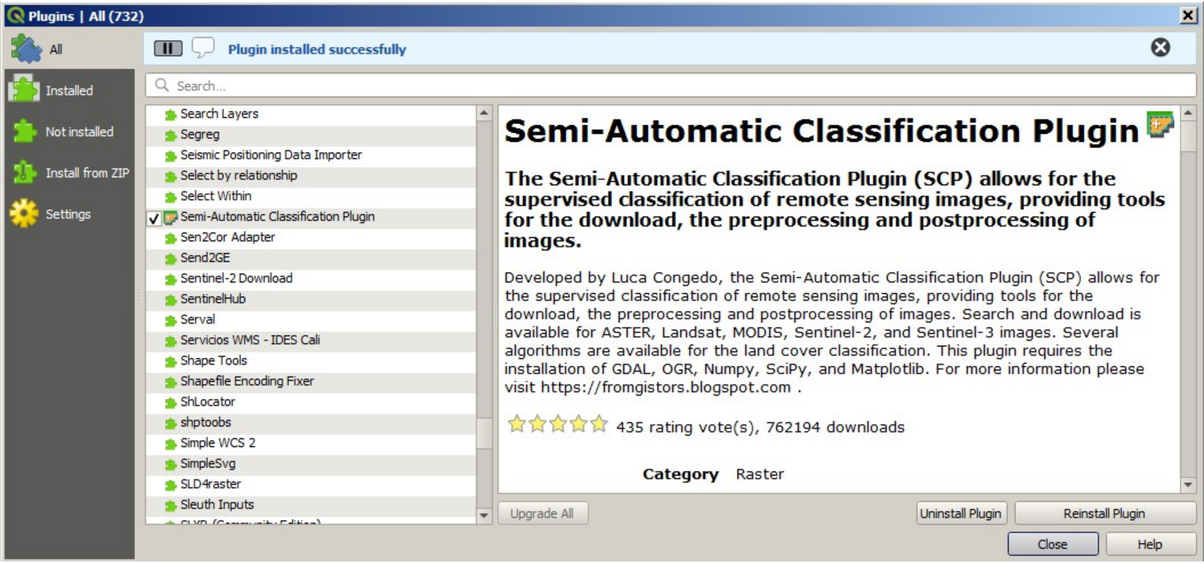
— Run QGIS ;
— From the main menu, select `Plugins` > `Manage and Install Plugins` ;



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

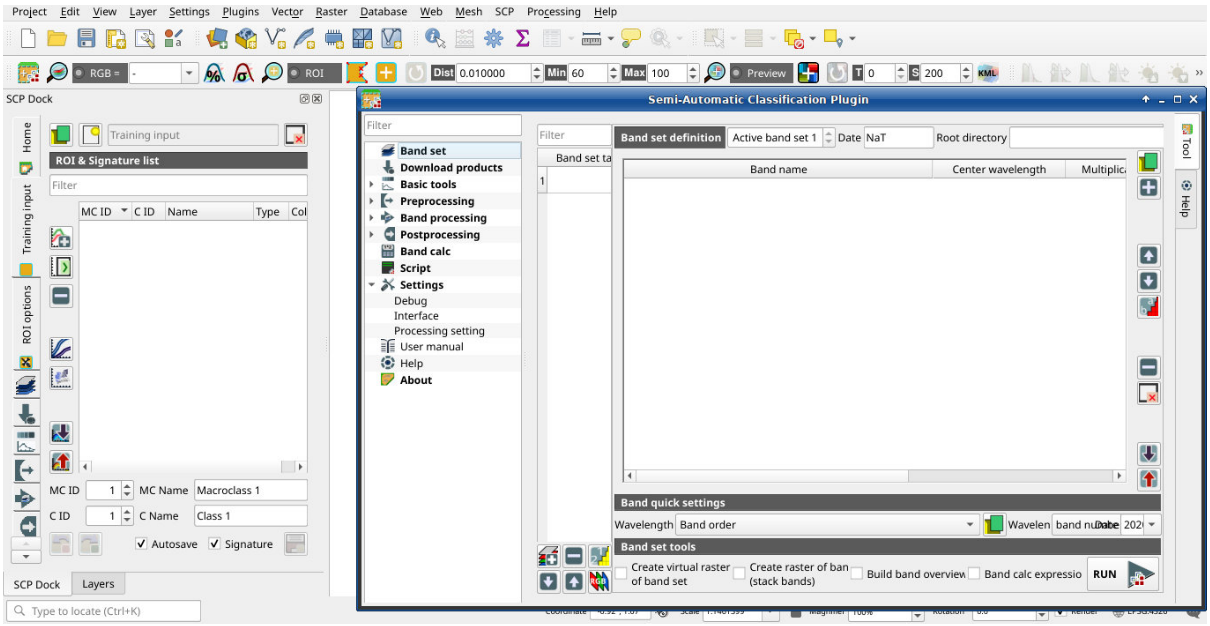


— The SCP should be automatically activated ; however, be sure that the Semi-Automatic Classification Plugin is checked in the menu `Installed` (the restart of QGIS could be necessary to complete the SCP installation) ;

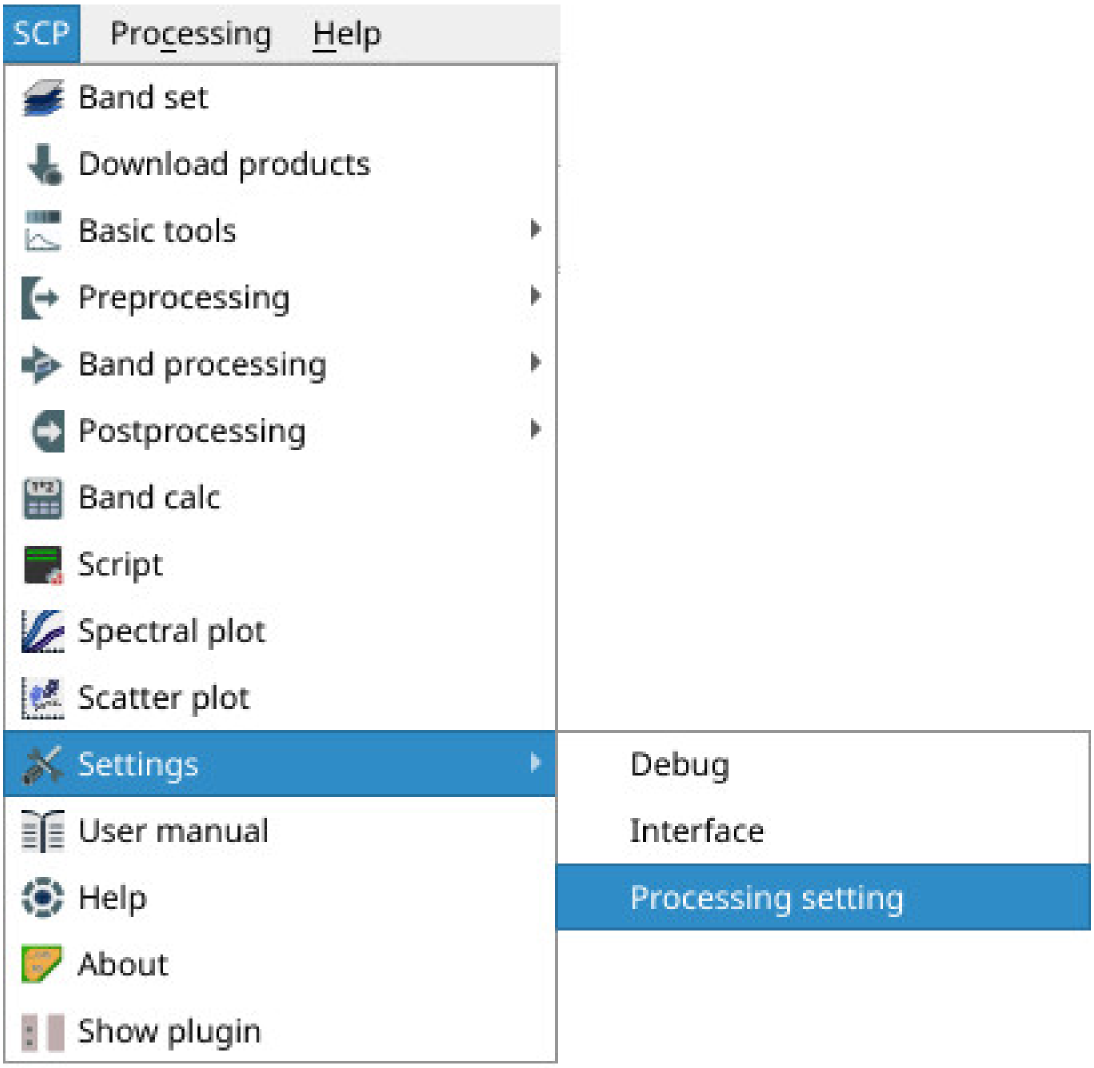


2.5.3 Configuration of the plugin

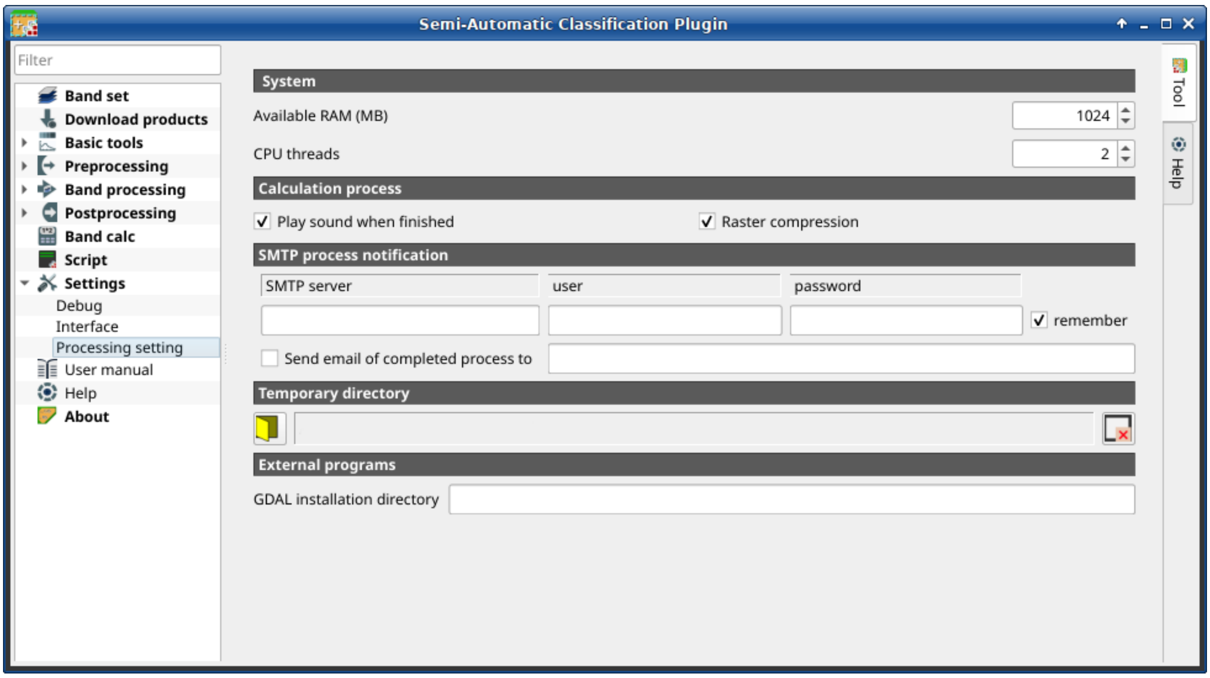
Now, the Semi-Automatic Classification Plugin is installed and a dock and a toolbar should be added to QGIS. Also, a SCP menu is available in the Menu Bar of QGIS. It is possible to move the toolbar and the dock according to your needs, as in the following image.



The configuration of available RAM is recommended in order to reduce the processing time. From the *SCP menu* (page 29) select  `Settings > Processing` .

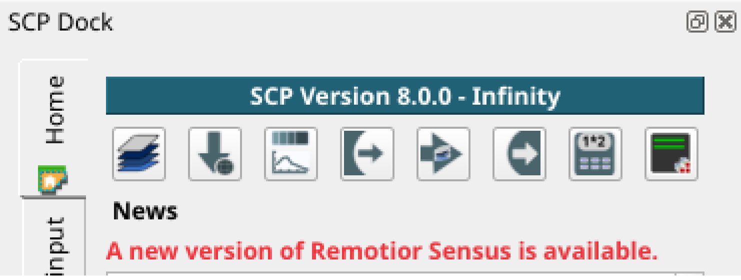


In the *Settings* (page 107), set the `Available RAM (MB)` to a value that should be half of the system RAM. For instance, if your system has 2GB of RAM, set the value to 1024MB.



2.5.4 Update of required dependencies

The dependency Remotior Sensus is frequently updated. The Semi-Automatic Classification Plugin can check automatically if a new version is available, and display a message in the *SCP dock* (page 31).



It is recommended to close QGIS and update Remotior Sensus using activating the conda environment and running the command :

```
$ conda update -c conda-forge remotior-sensus
```

CHAPITRE 3

The Interface of SCP

The *SCP* interface is composed of several parts that are described in detail in the following paragraphs. The following video provides a brief introduction to the tools.

https://www.youtube.com/watch?v=gvSSO5LPw8s

3.1 SCP menu

The *SCP menu* allows for the selection of the main functions of the *Main Interface Window* (page 45), the *Spectral Signature Plot* (page 113), and the *Scatter Plot* (page 116).

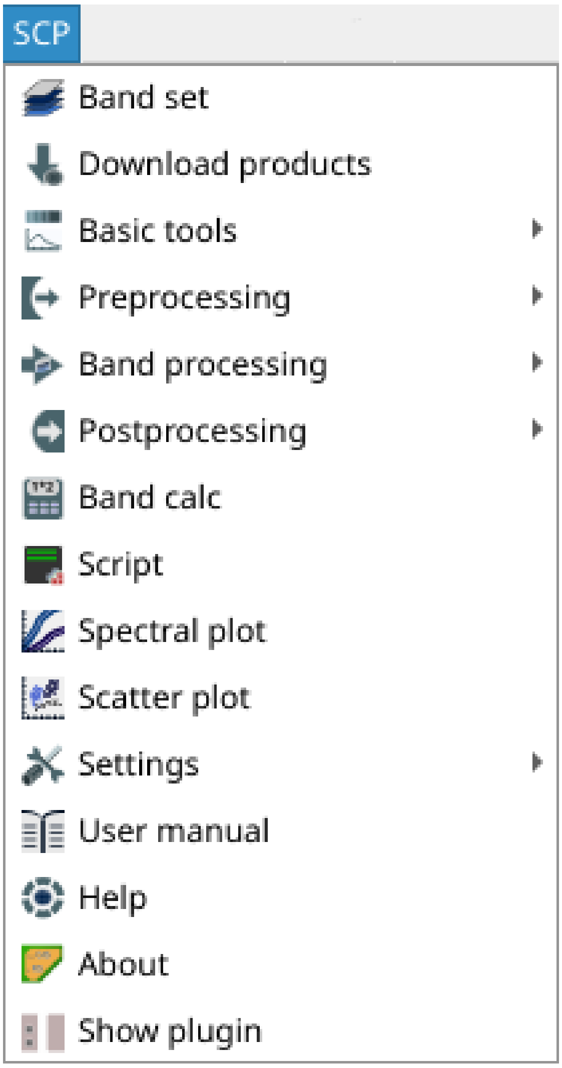


Fig. 1 – *SCP menu*

	Band set (page 45)
	Download products (page 48)
	Basic tools (page 53)
	Preprocessing (page 62)
	Band processing (page 74)
	Postprocessing (page 90)
	Band calc (page 98)
	Script (page 106)
	Settings (page 107)
	Spectral Signature Plot (page 113)
	Scatter Plot (page 116)
	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 45). The *Training input* (page 33), created with *SCP*, stores the ROI polygons and spectral signatures ; depending on the algorithm, the training could be performed using ROI polygons (e.g. *Random Forest* (page 140)) or spectral signatures (e.g. *Spectral Angle Mapping* (page 137)).

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 54)). 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 41). These are *temporary ROI polygons* because the ROI creation is an interactive process, and one can refine the geometry according to photointerpreation. Then, one can save *temporary ROI polygons* in the *Training input* (page 33) which is the actual input for classifications.

The *Training input* (page 33) is composed of a vector part that stores the geometries and a spectral signature part, which are managed by *SCP*. A temporary layer is added to QGIS but the actual 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 134)) 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 75). Using *Macroclass ID* instead of *Class ID* is useful to group materials that belong to the same land cover class but have spectral signatures that are distant enough to be considered as different materials (e.g., different types of vegetation).

FIG. 2 – *SCP dock*

The **classification** can be performed for the entire image (see *Algorithm* (page 75)) or for a part of it creating a *Classification preview* (page 44).

The *SCP dock* contains the following tabs :

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 45)
	*Basic tools* (page 53)
	*Download products* (page 48)
	*Preprocessing* (page 62)
	*Band processing* (page 74)
	*Postprocessing* (page 90)
	*Band calc* (page 98)
	*Script* (page 106)

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 *Settings* (page 107).

3.2.2 Training input

This tool allows for the creation of the training input file (`.scpx`) 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 45). 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.


SCP Dock
Home
Training input
ROI options
SCP Version 8.0.0 - Infinity
News
User manual
Support forum
To cite the Semi-Automatic Classification Plugin in your work:
Congedo, Luca, (2021). Semi-Automatic Classification Plugin: A Python tool for the download and processing of remote sensing images in QGIS. Journal of Open Source Software, 6(64), 3172, https://doi.org/10.21105/joss.03172
SCP Dock

FIG. 3 – *Home*

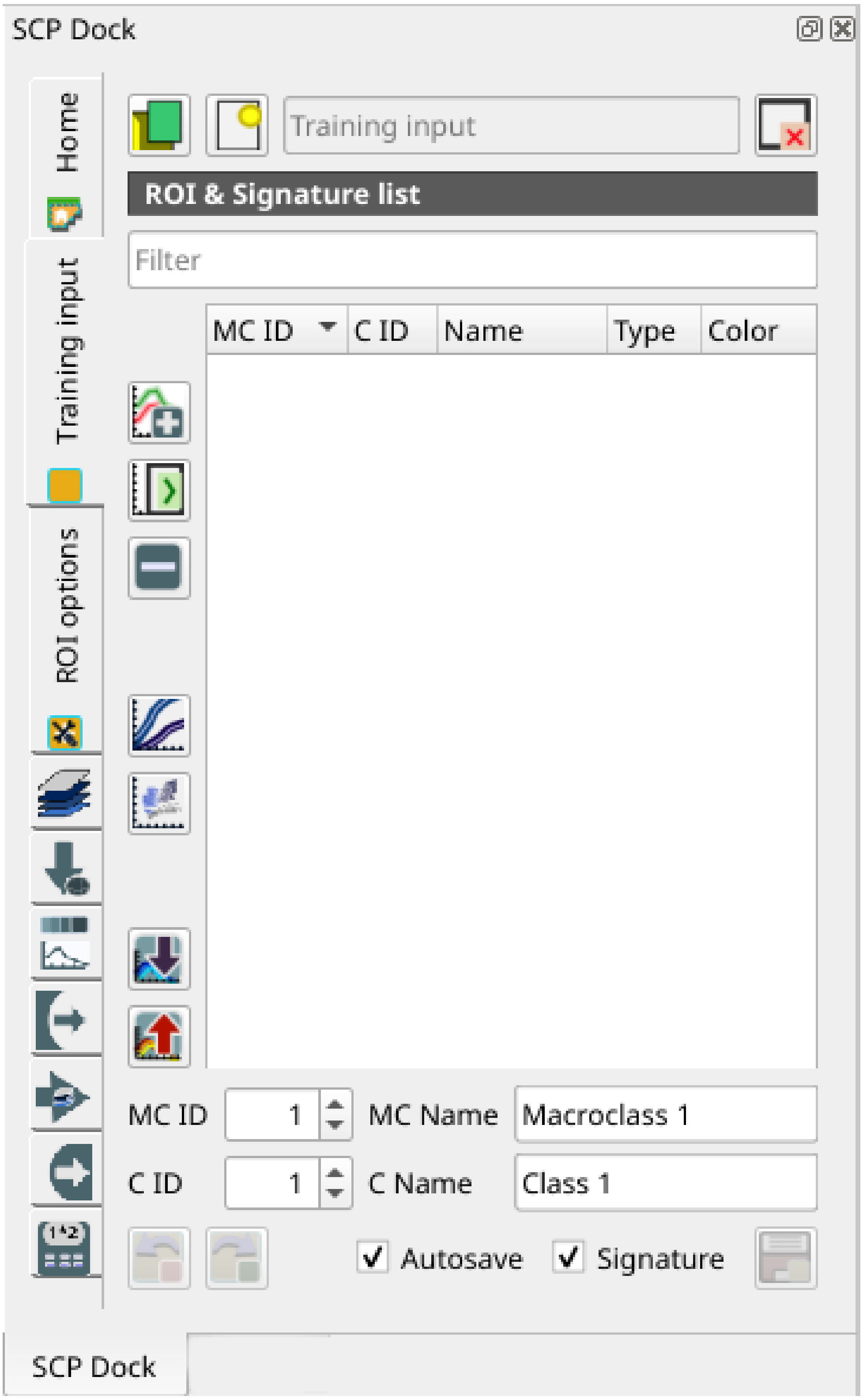


FIG. 4 – *Training input*

Tool symbol and name	Description
	open a training input file ; ROIs and spectral signatures are loaded in *ROI & Signature list* (page 36) ; the vector part of the training input is loaded in QGIS
	create an empty training input file (`.scpx`) ; the vector part of the training input is loaded in QGIS ; also a backup file is created (a file `.scpx.backup` in the same directory as the file `.scpx`) 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	it displays the path to the training input file
	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 36).

Avertissement : 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.

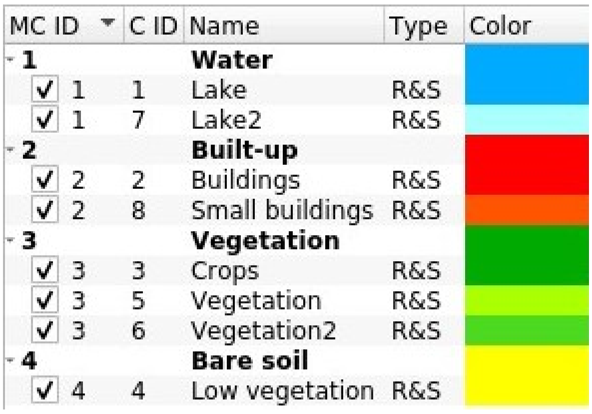
A filter for names can be defined in *Filter* .

The tree list *ROI & Signature list* has the following fields :

— *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 ;
  — *RS* = 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 ;

Changes in the *ROI & Signature list* are applied to the file *Training input* (page 33) only when the QGIS project is saved (but there is also the option *Autosave*). ROIs can be edited, deleted and merged from this list.

Astuce : According to *Algorithm* (page 75), classifications performed using *C ID* have the colors defined for classes in the *ROI & Signature list* (page 36) ; classifications performed using *MC ID* have the colors defined for



MC ID	C ID	Name	Type	Color
1		**Water**		
1	1	Lake	R&S	
1	7	Lake2	R&S	
2		**Built-up**		
2	2	Buildings	R&S	
2	8	Small buildings	R&S	
3		**Vegetation**		
3	3	Crops	R&S	
3	5	Vegetation	R&S	
3	6	Vegetation2	R&S	
4		**Bare soil**		
4	4	Low vegetation	R&S	

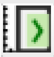
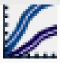
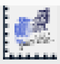
FIG. 5 – *ROI & Signature list example*

the macroclasses.

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.

Astuce : ROIs and spectral signatures can be imported from other sources (see *Import signatures* (page 54)) and exported (see *Export signatures* (page 53)).

The following tools are available.

Tool symbol and name	Description
	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 45)
	delete highlighted ROIs and signatures
	show the ROI spectral signature in the *Spectral Signature Plot* (page 113) ; spectral signature is calculated from the *Band set* (page 45)
	add highlighted ROIs to the *Scatter Plot* (page 116)
	open the tab *Import signatures* (page 54)
	open the tab *Export signatures* (page 53) and export highlighted items

ROI & Signature list is complementary to the *Working toolbar* (page 41) and it allows for saving ROIs to the *Training input* (page 33) defining classes and macroclasses. A *Band set* (page 45) must be defined before the ROI creation, and ROI polygons must be inside the area of the *Band set*.

Tool symbol and name	Description
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 33) ; it is possible to undo a maximum of 10 actions
	redo ROI creation in the *Training input* (page 33)
Autosave	if checked, automatically save the *ROI & Signature list* to the *Training input* (page 33) every time a ROI is saved
Signature	if checked, while saving a ROI, the spectral signature thereof is calculated (from *Band set* (page 45) pixels under ROI polygon) and saved to *Training input* (page 33) (calculation time depends on the band number of the *active band set* in *Band set* (page 45))
	save the temporary ROI to the *Training input* (page 33) using the defined classes and macroclasses ; ROI is displayed in the *ROI & Signature list* (page 36)

Right click menu

A right click on *ROI & Signature list* (page 36) allows for opening a menu containing several functions to manage ROIs and spectral signatures.

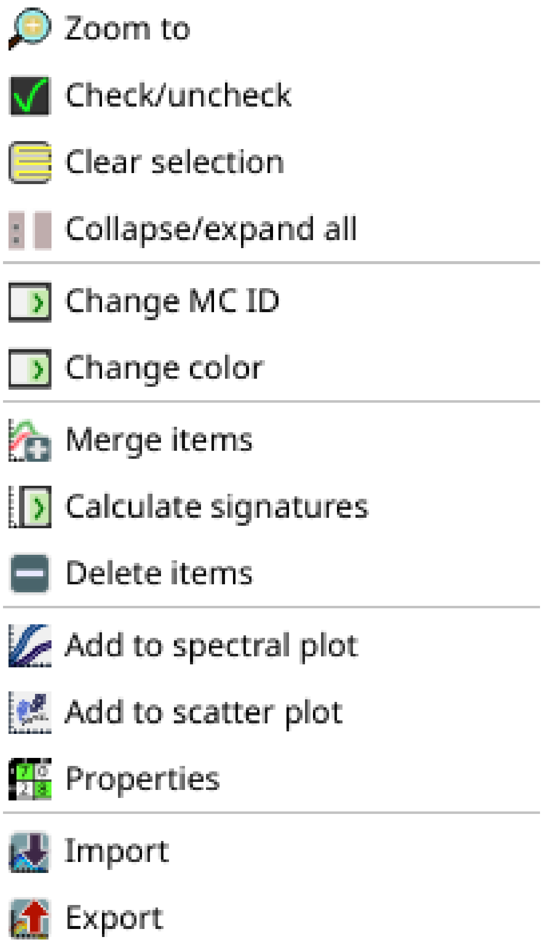


FIG. 6 – *Right click menu*

Tool symbol and name	Description
Zoom to	zoom to highlighted items (if ROI polygons) in the map
Check/unch	check or uncheck highlighted items
Clear selection	clear selection of highlighted items
Collapse/expan 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 36)) ; 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 45) ; 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 113) ; spectral signature is calculated from the *Band set* (page 45) ; 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 116) ; 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 54)
Export	open the tab *Export signatures* (page 53) and export highlighted items

3.2.3 ROI options

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

Tool symbol and name	Description
Display	if the ROI creation pointer is active (see *Working toolbar* (page 41)), the pixel value of selected vegetation index is displayed on the map; vegetation indices available in the combo box are : * 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 45); * Custom; use the custom expression defined in the following line
T	set a custom expression; expression is based on the *Band set* and bands such as band 1 is referred to as « b1 », band 2 as « b2 » and so on; also reference to band names such as « #NIR# » or « #RED# » can be used
Rapid ROI b. 1	if checked, temporary ROI is created with region growing using only one *Band set* (page 45) 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 113) (`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 41) are being changed
Maximum training buffer 1	defines the maximum number of action for undo and redo ROIs; the higher is the number, the more is the required memory

3.3 Working toolbar

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

The functions are described in detail in the following paragraphs.

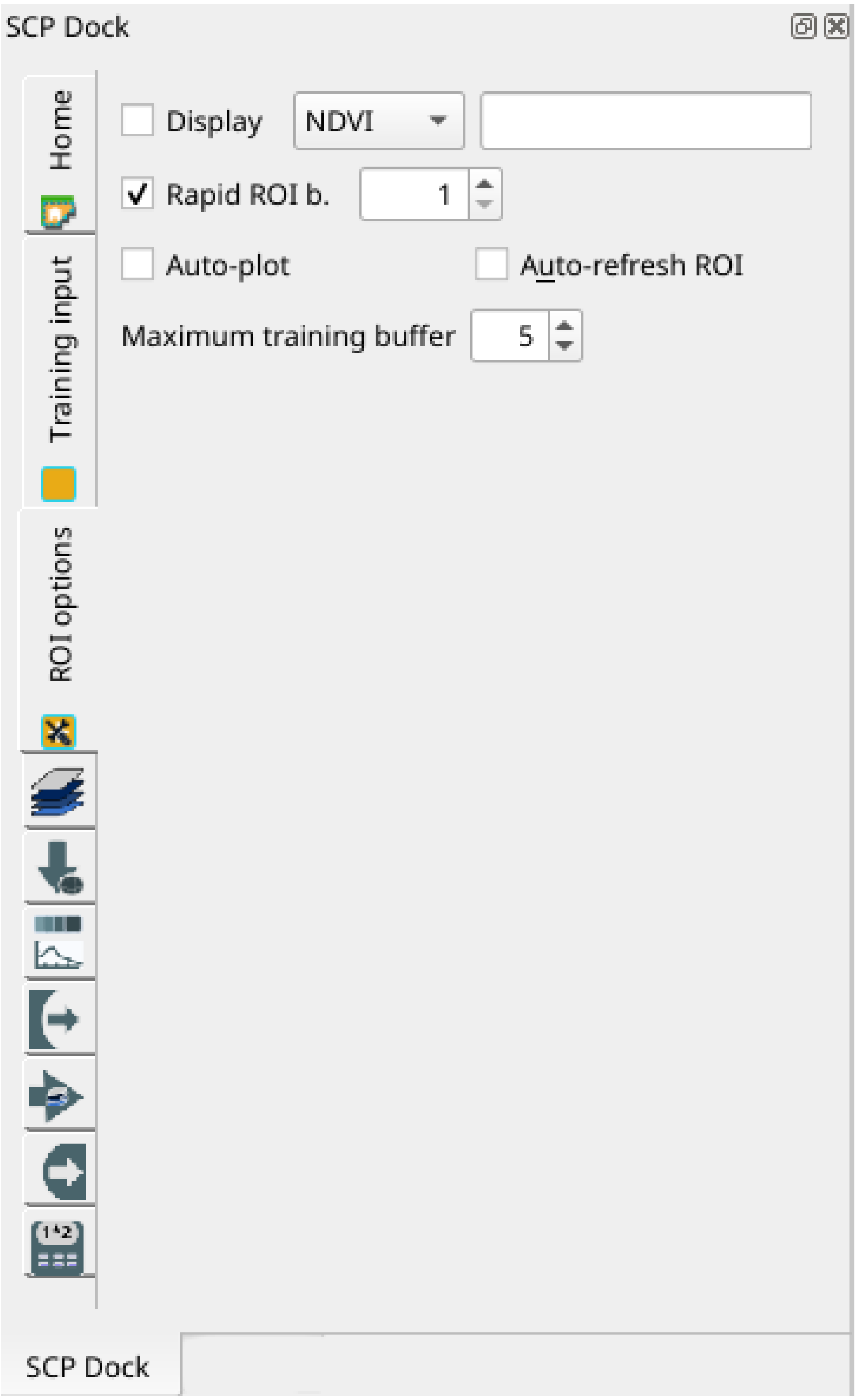


Fig. 7 – *ROI options*

Fig. 8 – *Working toolbar*

3.3.1 Image control

Tool symbol and name	Description
	show the *Main Interface Window* (page 45)
	zoom the map to the extent of the *active band set* in *Band set* (page 45) ;
RGB=	use the button to show/hide the *active band set* in *Band set* (page 45) in the map ; from the list select a *Color Composite* (page 133) that is applied to the *Band set* (page 45) ; 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

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 33). A *temporary ROI* can be drawn manually or using a *Region Growing Algorithm* (page 134) (i.e. the image is segmented around a pixel seed including spectrally homogeneous pixels).

Tool symbol and name	Description
	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 113) ; press the keyboard button `CTRL` and left click to add a multipart polygon (new parts are not created if overlapping to other parts) ; press the keyboard buttons `CTRL + Z` for removing the last multipart polygon ; press the keyboard button `CTRL` and right click to plot spectral signatures of the same pixel for all the *band sets*
	create a *temporary ROI* using the region growing algorithm at the same seed pixel as the previous one ; it is useful after changing the *region growing parameters*

Region growing parameters : the following parameters are required for the ROI creation using a region growing algorithm on the *Band set* (page 45) :

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

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 45), before classifying the entire image which can be time consuming.

Classification preview is performed according to the parameters defined in *Algorithm* (page 75).

Avertissement : ROIs and previews are performed on the active *Band set* (page 45).

After the creation of a new preview, old previews are placed in QGIS Layers inside a layer group named `Class_temp_group` and are deleted when the QGIS session is closed.

Avertissement : 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.

Tool symbol and name	Description
	zoom the map to the extent of the last *Classification preview* (page 44)
Preview	use the button to show/hide the last *Classification preview* (page 44) in the map
	activate the pointer for the creation of a *Classification preview* (page 44) ; left click the map to start the classification process and display the classification preview
	create a new *Classification preview* (page 44) centred at the same pixel as the previous one
T 1	change dynamically the classification preview transparency, which is useful for comparing the classification to other layers
S 1	size of the preview in pixel unit (i.e. the side length of a square, centred at the clicked pixel)
KML	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 29).

3.4.1 Band set

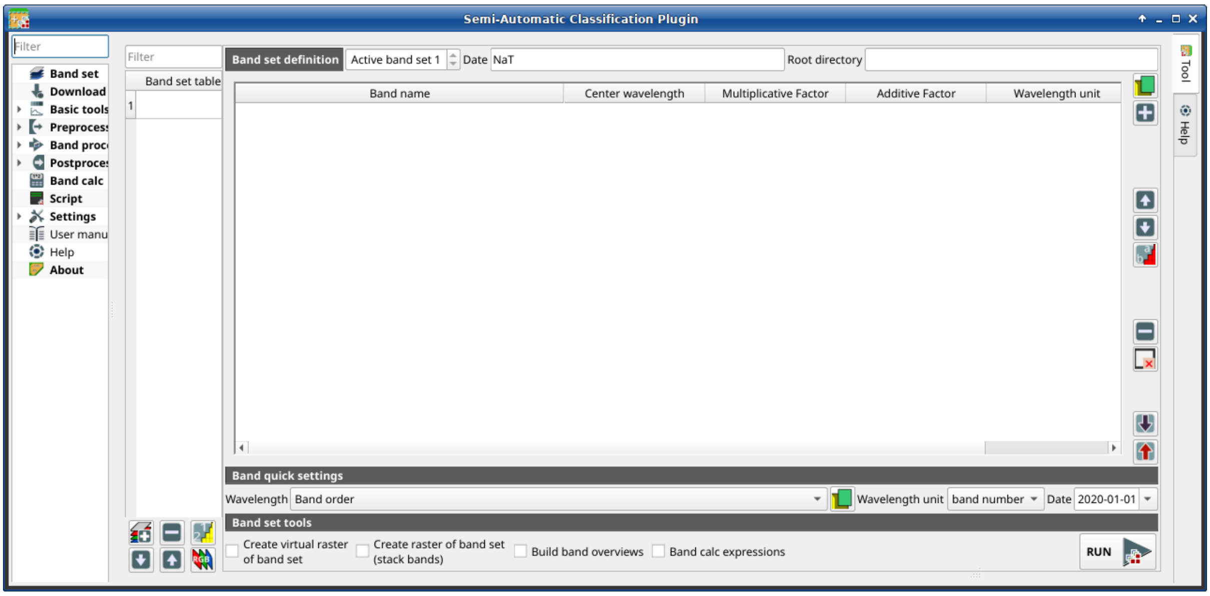


FIG. 9 – *Band set*

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

Band sets are identified by numbers. The *active band set* (i.e. the one selected in *Band set definition* (page 46)) is used as input for several tools in *SCP dock* (page 31) and the *Working toolbar* (page 41). Other *SCP* tools allow for the selection of *band set* numbers.

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

Astuce : Information about APIs of this tool in Remotior Sensus at this link .

Following a video tutorial about this tool.

https://www.youtube.com/watch?v=DQXfBPke2J4

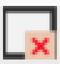
Band set definition

A *band set* is basically a list of bands defined as the following table.

Band name	Center wave-length	Multiplica-tive Factor	Additive Factor	Wave-length unit	Path	Date
name of the band (it cannot be edi-ted)	center of the wa-velength of the band	multiplicative rescaling factor	additive re-scaling fac-tor	wave-length unit	relative path of the raster	image ac-quisition date

It is possible to add to the *active band set* one or more bands already loaded in QGIS, or select files that are not loaded. A *Date* can be assigned to a *band set* which can be later used in other tools to select *band sets* by date. Also, a *Root directory* for band paths can be defined, which can be useful to create projects with relative paths.

The following tools are available.

Tool symbol and name	Description
	open file explorer and add raster files (preferably single band raster) to the *active band set*
	open a window to select rasters already loaded in QGIS and add them to the *active band set*
	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*
	import a previously saved *active band set* from file
	export the *active band set* to a file

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.

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.

Band quick settings

These tools allow for quickly set attributes of the *active band set*.

Tool symbol and name	Description
Wavelength	rapid definition of band center wavelength for the following satellite sensors : * Band order * 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
	open a csv file of wavelength values (center wavelength separated by comma or new line)
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

Band set table

The table on the left side is the *Band set table*. It includes the list of all the defined *band sets* (the names of the first bands are displayed), which can be selected with a left click. Double click on a table item can be used to define the *Active band set*.

A *Filter* can be used to display *band sets* in the table matching a name.

The following tools are available for managing *band sets*.

Tool symbol and name	Description
	add a new empty *band set*
	remove highlighted *band sets*
	sort *band sets* by date
	move highlighted *band sets* upward
	move highlighted *band sets* downward
	display the RGB color composite of selected *band sets* (a virtual raster is added in QGIS)

Band set tools

Band set tools are tools that can be executed directly on *Active band set*. Multiple tools can be selected by the corresponding check box. This can also be useful to automate the processing during image conversion.

Tool symbol and name	Description
Create virtual raster of band set	create a multiband virtual raster of *Active band set*
Create raster of band set (stack bands)	stack bands in a single multiband raster
Build band overview	build band overview of *Active band set*
Band calc expression	execute the expression defined in *Band calc* (page 98)
	execute selected tools

3.4.2 Download products

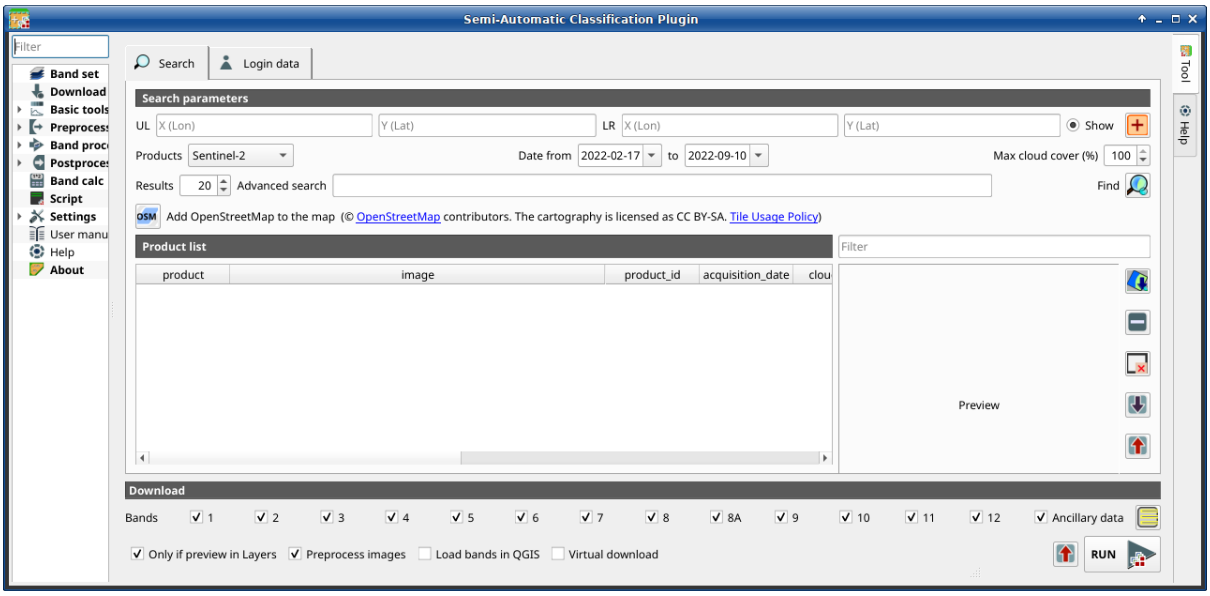


FIG. 10 – *Download products*

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

Astuce : Information about APIs of this tool in Remotior Sensus at this link .

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

Following a video tutorial about this tool.

https://www.youtube.com/watch?v=NwL2f5Nrn3U

Search

The *Search* tool allows for searching and downloading :

- *Sentinel-2* : Copernicus Sentinel-2 images (Level-1C and Level-2A) acquired from 2015 to present days ;
- *Landsat_MPC* : Landsat Collection images acquired from August 1982 to present days, such as Landsat 5, 7, 8, 9 (data retrieved from Microsoft Planetary Computer) ;
- *Sentinel-2_MPC* : Copernicus Sentinel-2 Level-2A acquired from 2015 to present days (data retrieved from Microsoft Planetary Computer) ;
- *Landsat_HLS* : Landsat from Harmonized Landsat Sentinel-2 by NASA which are surface reflectance data product (generated with Landsat 8, Landsat 9, and Sentinel-2 data acquired from 2013 to present days) with observations every two to three days at 30m spatial resolution (more information about the project) ;
- *Sentinel-2_HLS* : Sentinel-2 from Harmonized Landsat Sentinel-2 by NASA which are surface reflectance data product (generated with Landsat 8, Landsat 9, and Sentinel-2 data acquired from 2013 to present days) with observations every two to three days at 30m spatial resolution (more information about the project) ;
- *MODIS_09Q1_MPC* : MODIS Surface Reflectance 8-Day (250m) (data retrieved from Microsoft Planetary Computer) ;
- *MODIS_11A2_MPC* : MODIS Land Surface Temperature 8-Day (data retrieved from Microsoft Planetary Computer) ;
- *ASTER_MPC* : ASTER L1T (data retrieved from Microsoft Planetary Computer) ;
- *Copernicus_DEM_30_MPC* : Copernicus DEM GLO-30 (data retrieved from Microsoft Planetary Computer) ;

The download of *Harmonized Landsat Sentinel-2* requires credentials defined in *Login data* (page 52).

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 fewer the results, the faster is the query).

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

Tool symbol and name	Description
UL	set the UL longitude X (Lon) and the UL latitude Y (Lat)
LR	set the LR longitude X (Lon) and the LR latitude Y (Lat)
Show	show or hide the search area in the map ;
	define a search area by left click to set the UL point and right click to set the LR point ; the search area is displayed in the map
Products	set the search product
Date from 1980	set the starting date of acquisition
to 1980	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)
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 51) ; results are added to previous results
OSM Add OpenStreet-Map 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)

Astuce : 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).

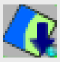
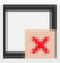
Product list

The table *Product list* contains the results of the search. Click on any item (highlight the item) to display the image preview thereof (not all the products include image previews). Resulting products are saved with the QGIS project.

The table includes the following fields.

product	imag	product_	acquisition_	cloud_	zone_p	row	min_	min_	max_	max_	collection	size	preview	uid	ref_url
the product name (e.g., Senti 2)	the imag name	the ID of the product	the acquisition date of the product	percentage of cloud cover in the product	the zone or WRS path depending on the product type	the WRS row	minimum latitude of the product	minimum longitude of the product	maximum latitude of the product	maximum longitude of the product	collection code	product size	URL of the product preview	identifier of the item	reference URL

The following tools are available.

Tool symbol and name	Description
	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 an XML file
	export the product list to an XML file

Download

Download the products in the *Product list* (page 51). During the download it is recommended not to interact with QGIS.

Depending on the download service, it is possible to select single bands for download.

Tool symbol and name	Description
Band X	select bands for download
Ancillary data	if checked, the metadata files are selected for download
	select or deselect all bands
Only if preview in Layers	if checked, download only those images listed in *Product list* (page 51) which are also listed in the QGIS layer panel
Preprocess images	if checked, bands are automatically converted after the download
Load bands in QGIS	if checked, bands are loaded in QGIS after the download
	export the download links to a text file (.csv)
RUN	start the download process of all the products listed in *Product list* (page 51)

Login data

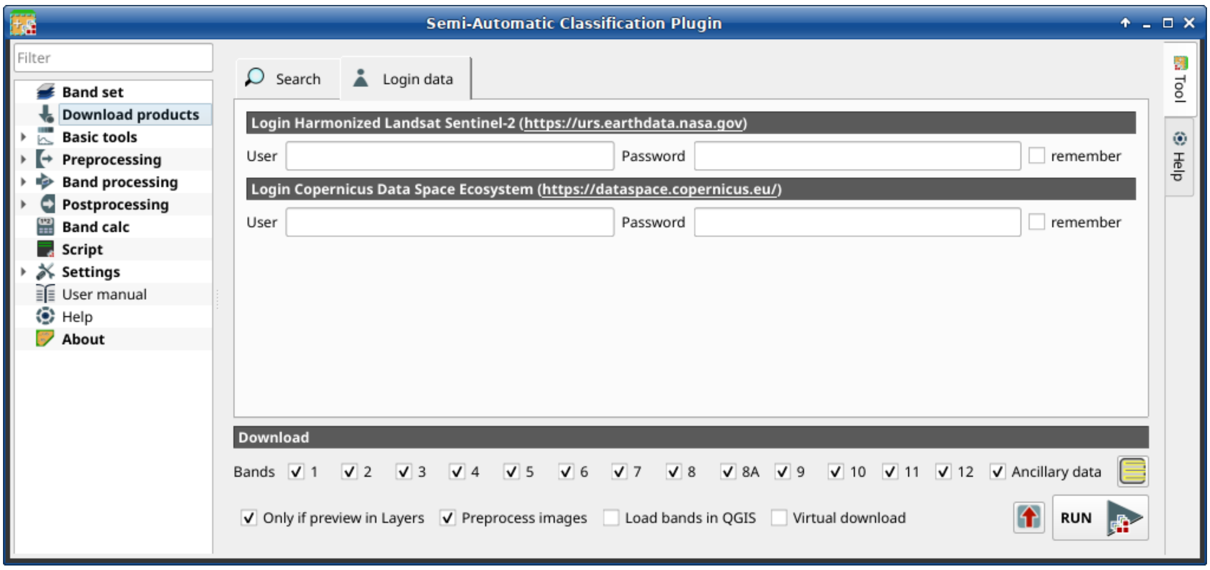


FIG. 11 – *Login data*

Login Harmonized Landsat Sentinel-2

The download of Harmonized Landsat Sentinel-2 requires to login using *EOSDIS Earthdata* credentials (https://urs.earthdata.nasa.gov) One can register for free at https://urs.earthdata.nasa.gov/users/new .

Tool symbol and name	Description
User	enter the user name
Password	enter the password
remember	if checked, remember user name and password locally in QGIS

Avertissement : If *remember* is checked, the password is stored unencrypted in QGIS registry.

Login Copernicus Data Space Ecosystem

The download of Sentinel-2 is available also using *Copernicus Data Space Ecosystem* credentials (https://dataspace.copernicus.eu). One can register for free at https://dataspace.copernicus.eu .

Tool symbol and name	Description
User	enter the user name
Password	enter the password
remember	if checked, remember user name and password locally in QGIS

Avertissement : If *remember* is checked, the password is stored unencrypted in QGIS registry.

3.4.3 Basic tools

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

Export signatures

This tool allows for exporting the signatures highlighted in the *ROI & Signature list* (page 36).

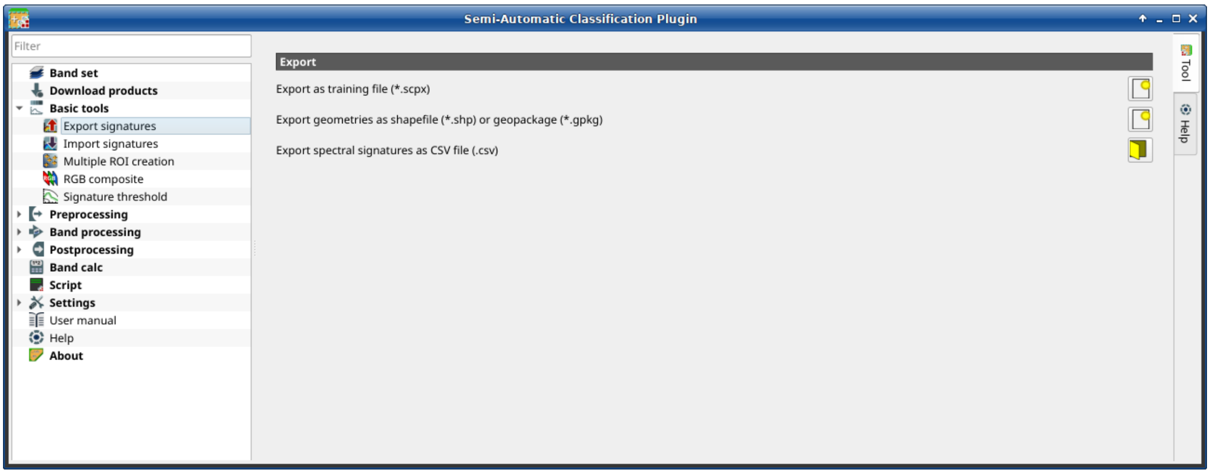


FIG. 12 – *Export signatures*

Tool symbol and name	Description
Export as SCP file	create a new .scp file and export highlighted ROIs and spectral signatures as *SCP* file (.scpx)
Export as shapefile or geopackage	export highlighted ROIs (spectral signature data excluded) as a new shapefile (.shp) or geopackage (.gpkg)
Export spectral signatures as CSV file	open a directory, and export highlighted spectral signatures as individual CSV files (.csv) separated by semicolon (;)

Import signatures

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

Import library file

This tool allows for importing spectral signatures from various sources : a previously saved *Training input* (page 33) (`.scpx` 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 45), and added to the *ROI & Signature list* (page 36) ;

Tool symbol and name	Description
Select a file	open a file to be imported in the *Training input* (page 33)

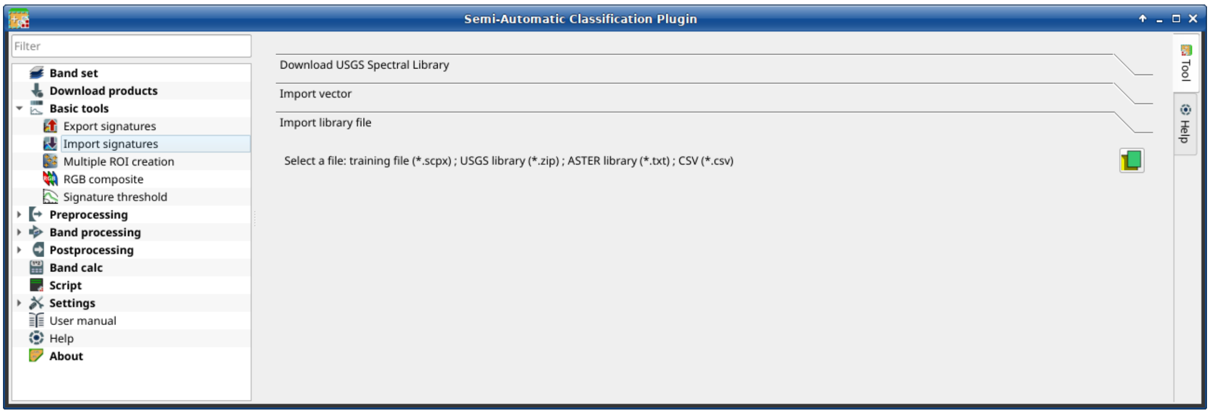


FIG. 13 – *Import library file*

Import vector

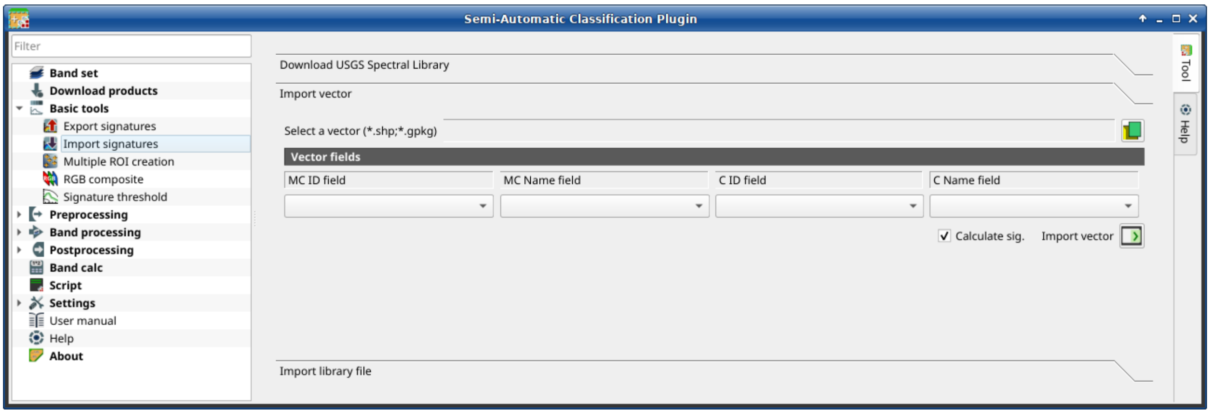


FIG. 14 – *Import vector*

This tool allows for importing a vector (shapefile or geopackage), selecting the corresponding fields of the *Training input* (page 33).

Tool symbol and name	Description
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 33)
Import vector	import all the vector polygons as ROIs in the *Training input* (page 33)

Download USGS Spectral Library

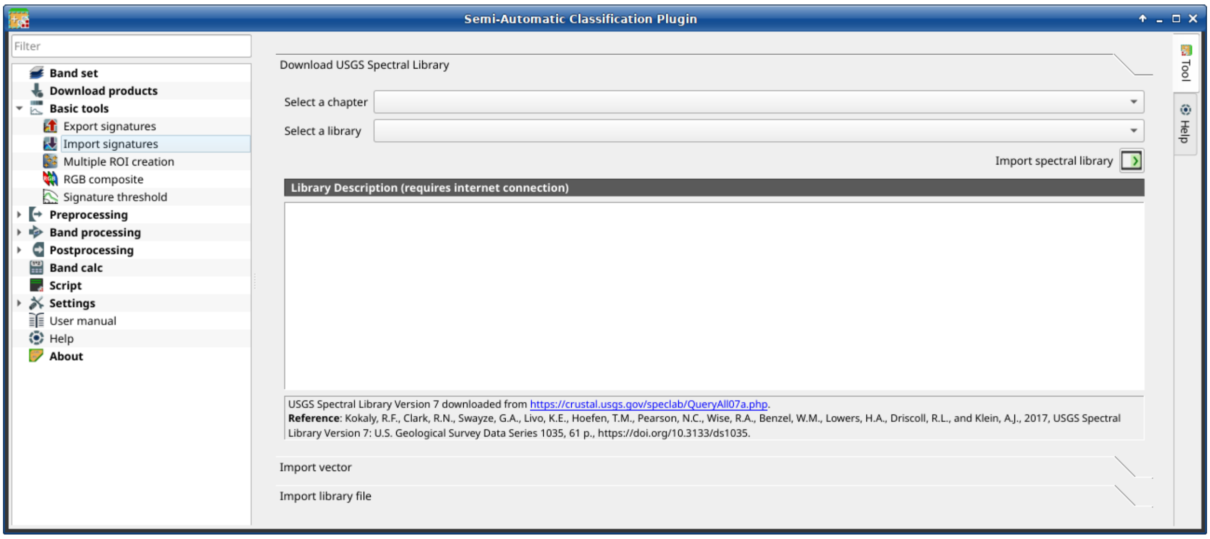


FIG. 15 – *Download USGS Spectral Library*

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.

Tool symbol and name	Description
Select a chapter	select one of the library chapters ; after the selection, chapter libraries are shown in *Select a library*
Select a library	select one of the libraries ; the library description is displayed in the frame *Library description*
Import spectral library	download the library and add the sampled spectral signature to the *ROI & Signature list* (page 36) 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 45), and added to the *ROI & Signature list* (page 36)

Astuce : 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.

Multiple ROI Creation

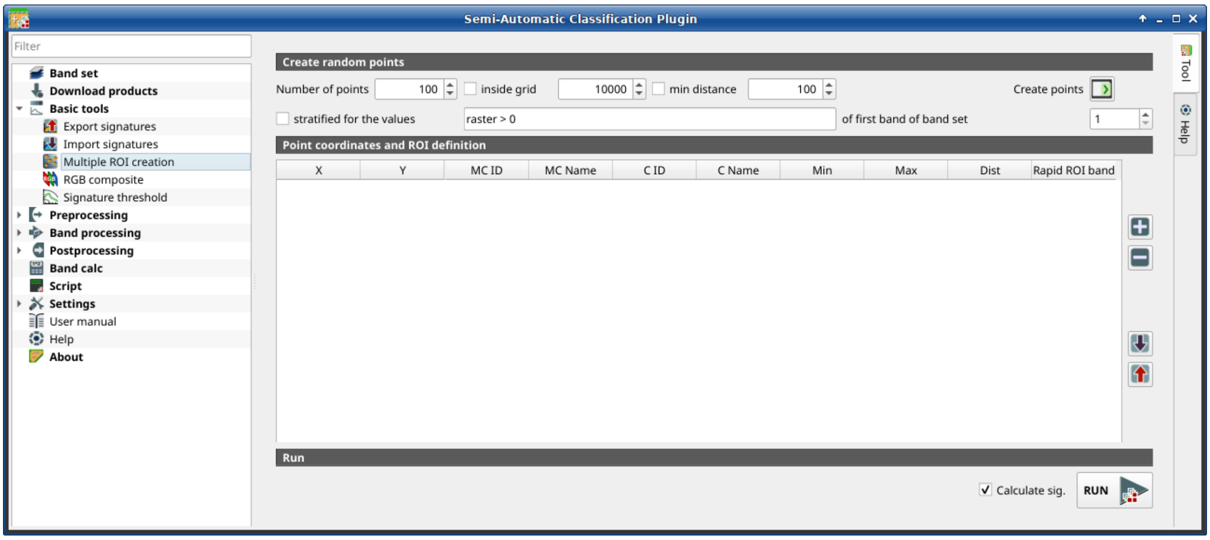


FIG. 16 – *Multiple ROI Creation*

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 33). The *active band set* in *Band set* (page 45) is used for calculations.

Create random points

Tool symbol and name	Description
Number of points 1	set a number of points that will be created when *Create points* is clicked
inside grid 1	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 1	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 T	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*
of the first band of band set 1	defines the *band set* in *stratified for the values*

Point coordinates and ROI definition

The table *Point coordinates and ROI definition* contains the following fields.

X	Y	MC ID	MC Name	C ID	C Nam	Min	Max	Dist	Rapid ROI band
point X coordinate (float)	point Y coordinate (float)	ROI Macroclass ID (int)	ROI Macroclass Name (text)	ROI Class ID (int)	ROI Class Name (text)	the minimum area of a ROI (in pixel unit)	the maximum width of a ROI (in pixel unit)	the interval which defines the maximum spectral distance between the seed pixel and the surrounding pixels (in radiometry unit)	if a band number is defined, ROI is created only using the selected band, similarly to *Rapid ROI band* in *ROI & Signature list* (page 36)

The following tools are available.

Tool symbol and name	Description
	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 33)
RUN	start the ROI creation process for all the points and save ROIs to the *Training input* (page 33)

RGB composite

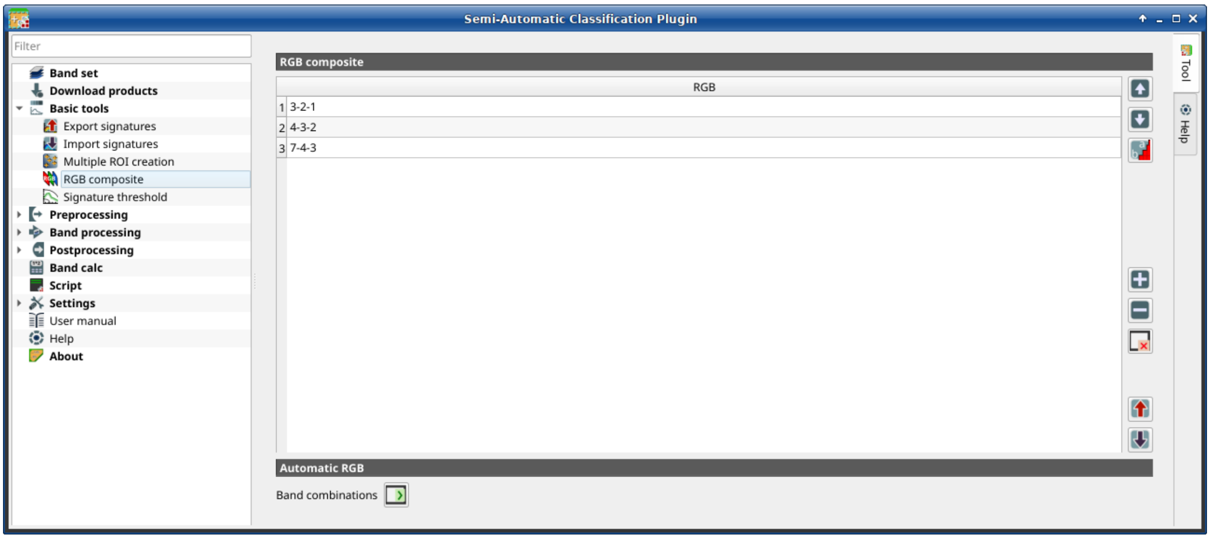


FIG. 17 – *RGB composite*

This tab allows for managing the RGB *Color Composite* (page 133) used in the list *RGB=* of the *Image control* (page 43).

RGB composite

The table *RGB composite* contains the field *RGB* that allows for entering an RGB combination.

Tool symbol and name	Description
	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

Tool symbol and name	Description
Band combinations	add the combinations of all bands (i.e. permutation) to the *RGB composite* (page 60) (e.g. 1-2-3, 1-2-4, ..., 3-2-1)

Signature threshold

This tab allows for the definition of a classification threshold (only for Minimum Distance, Maximum Likelihood, and Spectral Angle Mapping algorithms) for each spectral signature. All the signatures contained in the *Training input* (page 33) are listed. Thresholds defined in this tool are applied to classification only if *Threshold* value in *Algorithm* (page 75) 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 33).

If threshold is 0 then no threshold is applied and all the image pixels are classified. Depending on the selected *Algorithm* (page 75) 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).

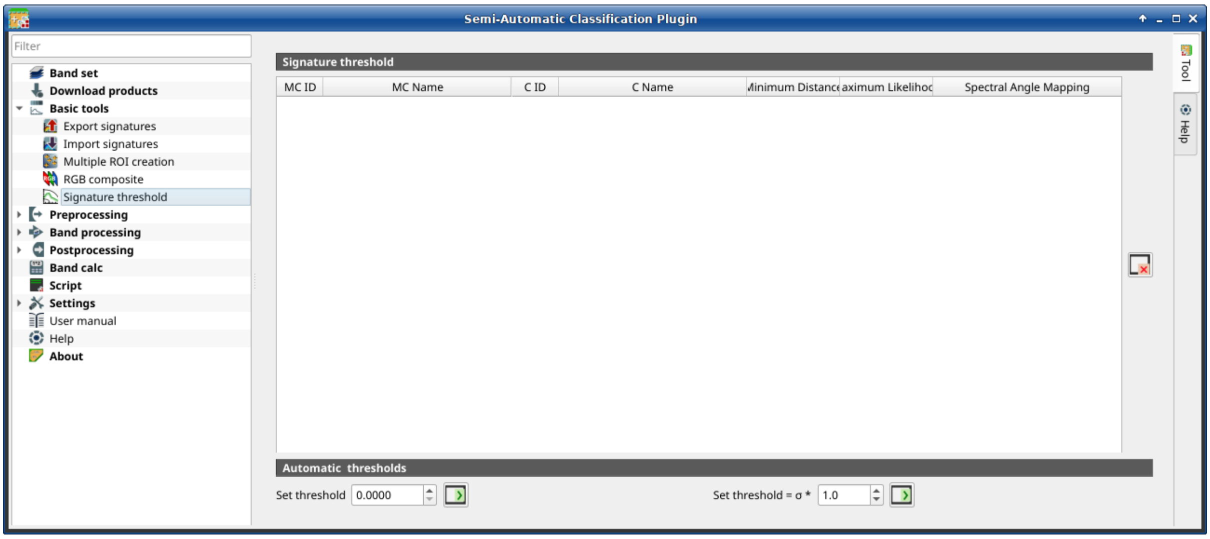


FIG. 18 – *Signature threshold*

Signature threshold

The table *Signature threshold* contains the following fields.

MC ID	MC Name	C ID	C Name	MD Threshold	ML Threshold	SAM Threshold
signature Macroclass ID	signature Macroclass Name	signature Class ID	signature Class Name	Minimum Distance threshold ; this value can be edited	Maximum Likelihood threshold ; this value can be edited	Spectral Angle Mapping threshold ; this value can be edited

— : reset all signatures thresholds to 0 (i.e. no threshold used) ;

Automatic thresholds

Tool symbol and name	Description
Set threshold	set the defined value as threshold for all the highlighted signatures in the table
*Set threshold = **	for all the highlighted signatures, set an automatic threshold calculated as the distance (or angle) between mean signature and (mean signature + (* v)), where is the standard deviation and v is the defined value ; currently works for Minimum Distance and Spectral Angle Mapping

3.4.4 Preprocessing

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

Clip raster bands

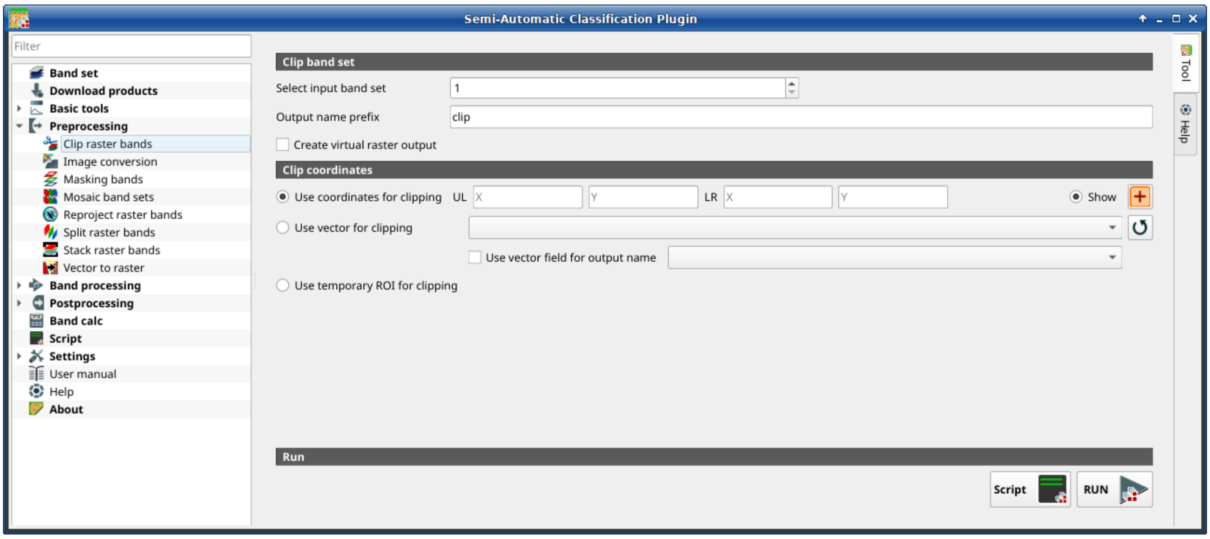


Fig. 19 – *Clip multiple rasters*

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

Astuce : Information about APIs of this tool in Remotior Sensus at this link .

Clip band set

Tool symbol and name	Description
Select input band set	select the input *Band set* (page 45) to be clipped
Use value as NoData	if checked, set the value for `NoData` pixels (e.g. pixels outside the clipped area)
Output name prefix	set the prefix for output file names (default is `clip`)

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.

Tool symbol and name	Description
Use coordinates for clipping	if checked, use defined coordinates for clipping bands
UL X	set the UL X coordinate
UL Y	set the UL Y coordinate
LR X	set the LR X coordinate
LR Y	set the LR Y coordinate
Show	show or hide the clip area drawn in the map
	define a clip area by drawing a rectangle in the map ; left click to set the UL point and right click to set the LR point ; the area is displayed in the map
Use vector for clipping	if checked, use the selected vector (already loaded in QGIS) for clipping ; UL and LR coordinates are ignored
Use vector field for output name	if checked, a vector field is selected for clipping while iterating through each vector polygon and the corresponding field value is added to the output name
Use temporary ROI for clipping	if checked, use a *Temporary ROI* (page 43) for clipping ; UL and LR coordinates are ignored
	refresh layer list
Script	add this function to the *Script* (page 106)
RUN	run this function

Image conversion

This tool allows for the conversion of several products to reflectance. Depending on the processing level of the source product, the conversion can be 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 147)). In case the source product is already provided as surface reflectance level, the rescaling factors are applied to convert the DN to decimal values.

The following products can be processed :

— **Sentinel-2** images Level-1C ;
— **Sentinel-2** images Level-2A ;
— **Landsat 1, 2, 3 MSS, 4, 5, 7, 8, 9** images Collection 2 Level-2 ;
— **Harmonized Landsat Sentinel-2**.

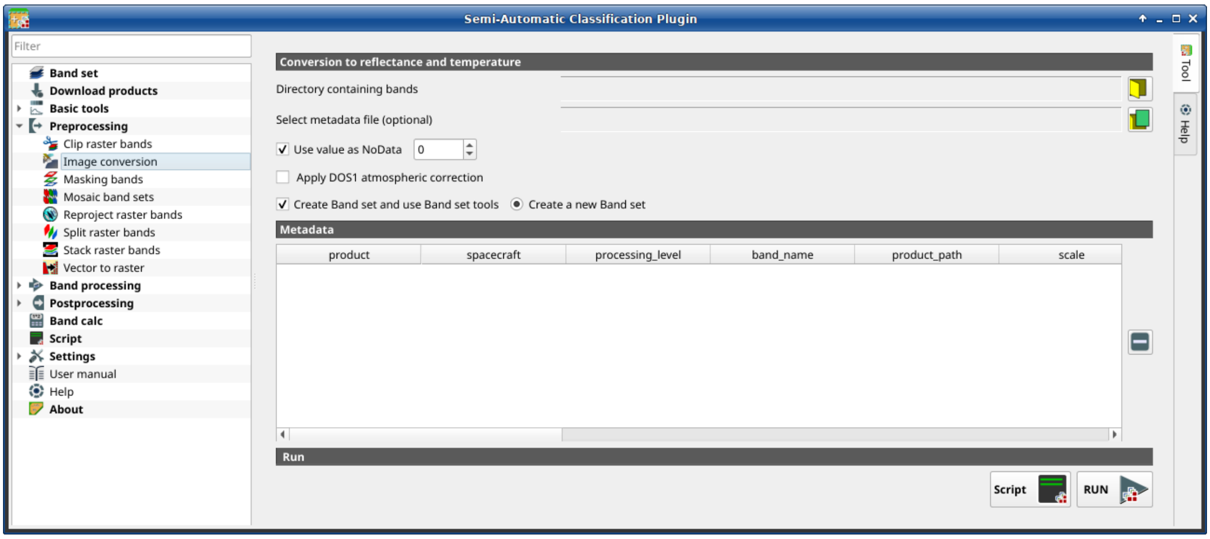


FIG. 20 – *Image conversion*

Astuce : Information about APIs of this tool in Remotior Sensus at this link .

Image conversion

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

Tool symbol and name	Description
Directory containing bands	open a directory containing product bands ; names of bands must end with the corresponding number ; if the metadata file is included in this directory then *Metadata* (page 65) is automatically filled
Select metadata file	select the metadata file if not included in the *Directory containing bands* ; for Sentinel-2, the metadata file is a .xml file whose name contains `MTD_MSIL1C`.
Use value as NoData 1	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)
Apply DOS1 atmospheric correction	if checked, the *DOS1 Correction* (page 148) is applied to all the 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 45)
Add bands in a new Band set	if checked, bands are added to a new empty *Band set* after the conversion

Astuce : For the best spectral precision one should download Surface Reflectance products (e.g., for Sentinel-2 the Level-2A Products).

Avertissement : For Sentinel-2 L2A images downloaded as .zip file, all the .jp2 files must be moved inside the same directory and renamed according to the band number in the ending (e.g. from name_02_10m.jp2 to name_02.jp2).

Metadata

Metadata are required for the process to identify the product. If the *Metadata* file is not inside the input directory, one can define the file path in *Select metadata file*. In the *Metadata*, all the bands found in are listed.

The table *Metadata* contains the following fields.

product	spacecraft	processing_lev	band	product_	scale	offset	nodata	date	k1	k2	band	e_su	earth_sun_distance
product name (e.g., Sentinel-2)	spacecraft name (e.g., Sentinel-2)	processing level of the product (e.g., Level-2)	name of the band	path of the band	scale of the band	offset of the band	nodata value of the band	date of acquisition of the product	k1 parameter for Landsat thermal conversion	k2 parameter for Landsat thermal conversion	band number	solar irradiance of band	Earth-Sun distance

It is possible to remove bands from the table, to exclude these bands from the conversion.

Tool symbol and name	Description
	remove highlighted bands from the table *Metadata*

Bands having different spatial resolution are not resampled at this stage. However, when using these bands in a classification process, all the bands are resampled on the fly to the highest spatial resolution with nearest neighbor.

Tool symbol and name	Description
Script	add this function to the *Script* (page 106)
RUN	run this function

Astuce : To reduce file size, output files are saved as data type UInt16 with scale 0.0001, which are interpreted as Float32 type by GDAL.

Masking bands

— *Mask of band set* (page 67)

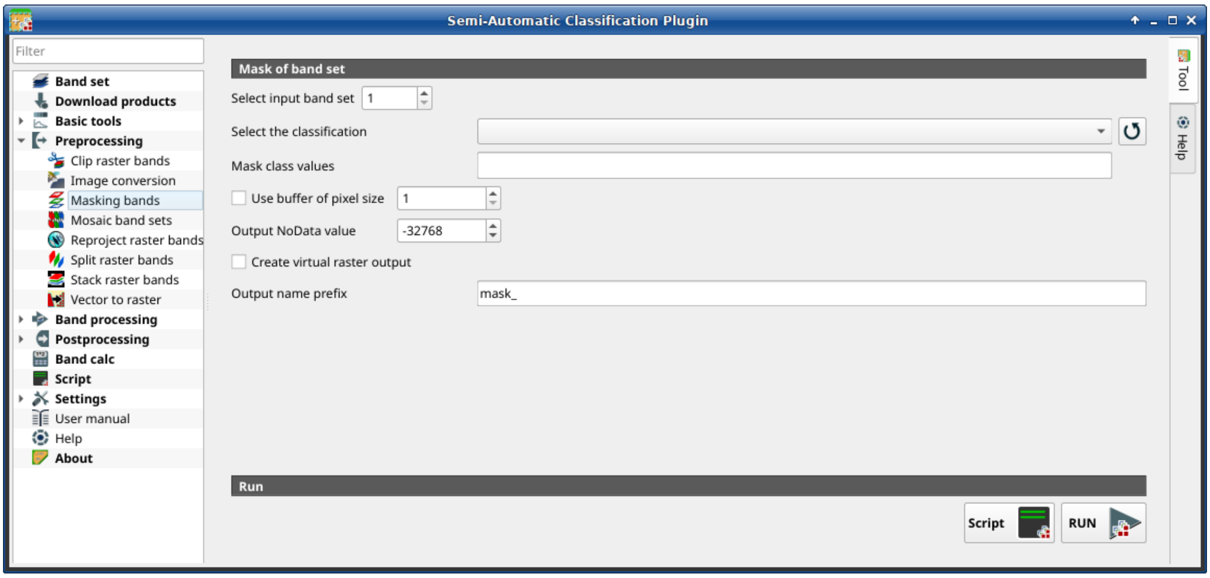


FIG. 21 – *Masking bands*

This tool allows for masking bands, based on the values of a raster mask, creating an output masked band for each band of the *Band set* (page 45). `NoData` is set in all the bands of the *Band set* (page 45) for pixels corresponding to the mask.

Astuce : Information about APIs of this tool in Remotior Sensus at this link .

Mask of band set

Tool symbol and name	Description
Select input band set	select the input *Band set* (page 45) to be masked
Select the classification	select a classification raster (already loaded in QGIS) which contains a mask class
	refresh layer list
Mask class values	set the class values to be masked ; class values must be separated by `,` and `-` can be used to define a range of values (e.g. `1, 3-5, 8` will select classes 1, 3, 4, 5, 8) ; if the text is red then the expression contains errors
Use buffer of pixel size	if checked, a buffer is created for masked area, corresponding to the defined number of pixels ; this can be useful to dilate masked area
Output NoData value	set the value of `NoData` pixels corresponding to the mask
Output name prefix	set the prefix for output file names (default is `mask_`)
Script	add this function to the *Script* (page 106)
RUN	run this function

Mosaic of band sets

— *Mosaic of band sets* (page 68)

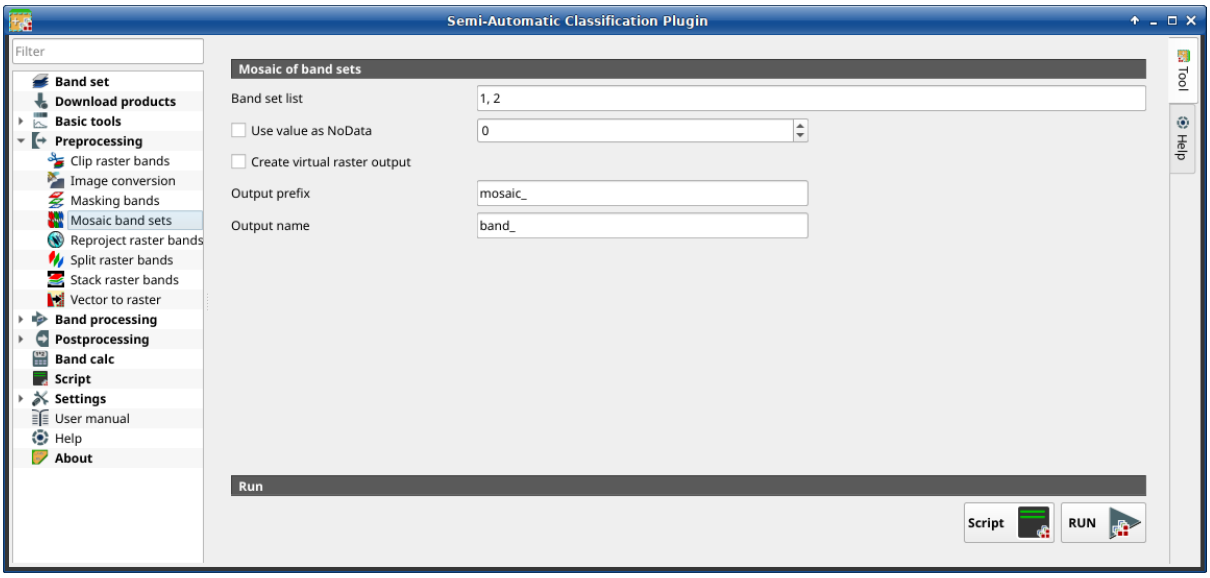


FIG. 22 – *Mosaic band sets*

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 45). 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.

Astuce : Information about APIs of this tool in Remotior Sensus at this link .

Mosaic of band sets

Tool symbol and name	Description
Band set list	list if band sets defined in the *Band set* (page 45) ; in case of overlapping images, the pixel values of the first band set in the list are assigned
Use value as NoData	if checked, set the value of `NoData` pixels, ignored during the calculation
Create virtual raster output	if checked, output is created as virtual raster `.vrt` composed of as many `.tif` files as the number of threads defined in *System* (page 110) ; for large rasters this can speed up the process
Output name prefix	set the prefix for output file names (default is `mosaic`)
Script	add this function to the *Script* (page 106)
RUN	run this function

Reproject raster bands

— *Reproject raster bands* (page 69)

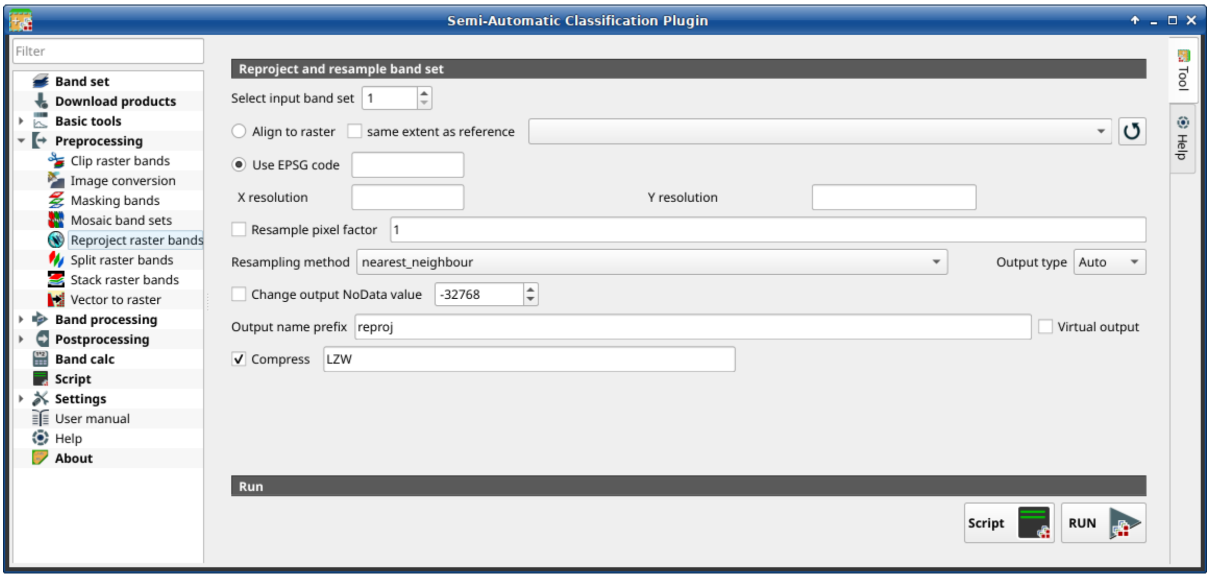


FIG. 23 – *Reproject raster bands*

This tab allows for reprojecting bands in a *Band set* (page 45) and perform other raster operations.

Astuce : Information about APIs of this tool in Remotior Sensus at this link .

Reproject raster bands

Tool symbol and name	Description
Select input band set	select the input *Band set* (page 45) to be reprojected
Align to raster	if checked, use the same coordinate reference system and pixel size as the selected reference
same extent as reference	if checked, the output extent will be the same as the reference
	refresh layer list
Use EPSG code	if checked, use the EPSG code for defining the output coordinate reference system
X resolution	set X pixel resolution
Y resolution	set Y pixel resolution
Resample pixel factor	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	set the prefix for output file names (default is `reproj`)
Compress	if checked, set the compression method (e.g., LZW, DEFLATE)
Script	add this function to the *Script* (page 106)
RUN	run this function

Split raster bands

— *Raster list* (page 70)

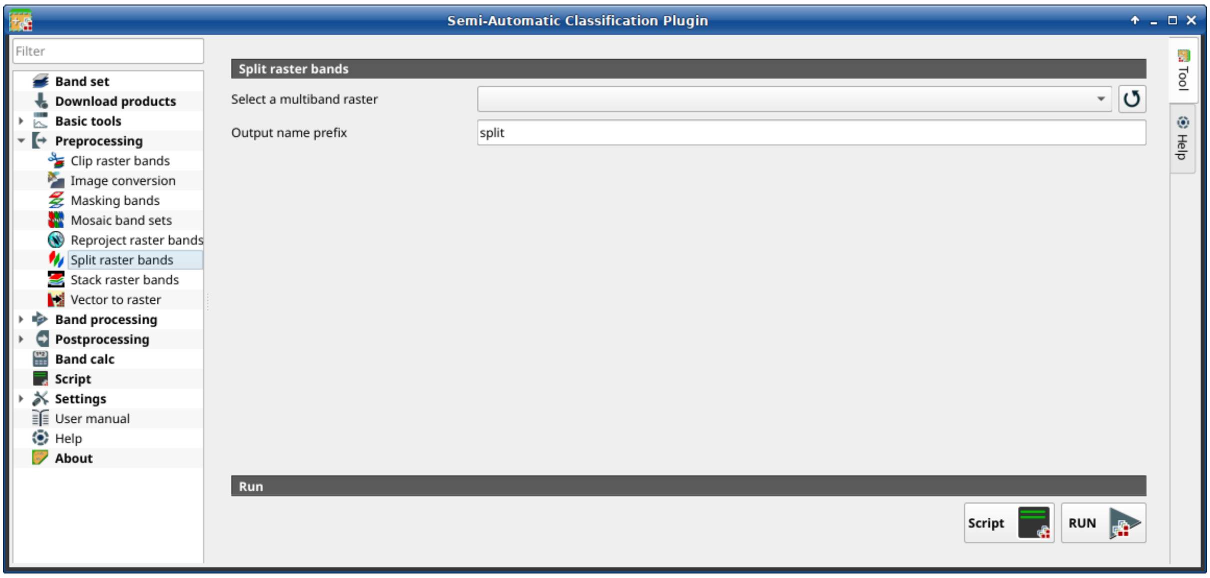


Fig. 24 – *Split raster bands*

Split a multiband raster to single bands.

Astuce : Information about APIs of this tool in Remotior Sensus at this link .

Raster list

Tool symbol and name	Description
Select a multiband raster	select the input raster
	refresh layer list
Output name prefix	set the prefix for output file names (default is `split`)
Script	add this function to the *Script* (page 106)
RUN	run this function

Stack raster bands

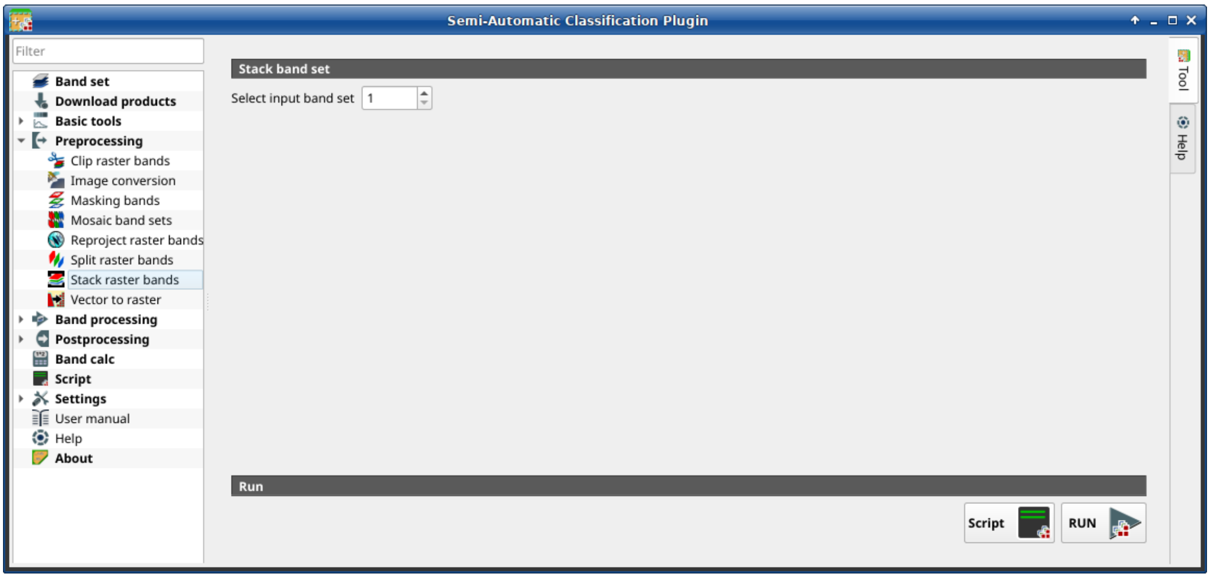


FIG. 25 – *Stack raster bands*

Stack all the bands in a *Band set* (page 45) into a multiband raster.

Astuce : Information about APIs of this tool in Remotior Sensus at this link .

Stack band set

Tool symbol and name	Description
Select input band set 1	select the input *Band set* (page 45) to be stacked
Script	add this function to the *Script* (page 106)
RUN	run this function

Vector to raster

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

Astuce : Information about APIs of this tool in Remotior Sensus at this link .

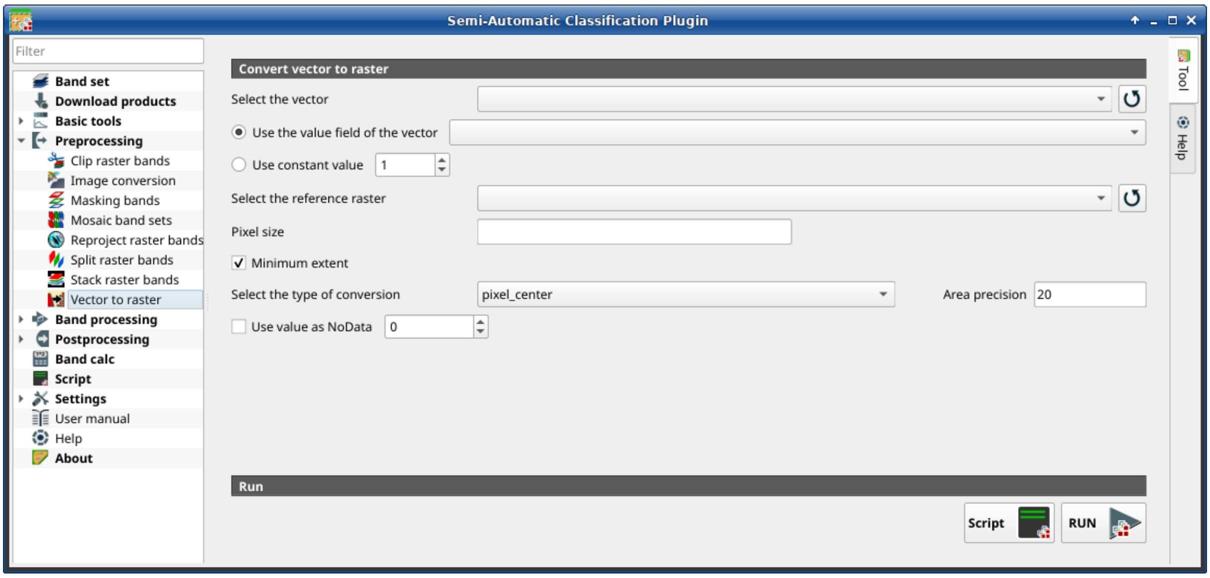


Fig. 26 – *Vector to raster*

Convert vector to raster

Tool symbol and name	Description
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 reference raster	select a reference raster ; pixels of the output raster have the same size and alignment as the reference raster
	refresh layer list
Pixel size T	set the size of pixel of output raster
Minimum extent	if checked, the output raster has the minimum vector extent ; otherwise, output extent is the same as the *Select the reference raster*
Select the type of conversion	**select the type of conversion among :** — *pixel_center* : 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_touched* : during the conversion, vector is compared to the reference raster ; output raster pixels are attributed to a polygon if pixel touches that polygon — *area_based* : during the conversion, output raster pixels are attributed based on area proportion of polygons
Area precision T	for *area_based* method, the higher the value, the higher is the precision in the calculation of area proportion (and the time required for calculation)
Use value as NoData 1	if checked, set a value for `NoData` pixels
Script	add this function to the *Script* (page 106)
RUN	run this function

3.4.5 Band processing

The tab  *Band processing* provides several functions that can be applied to the *Band set* (page 45).

Classification

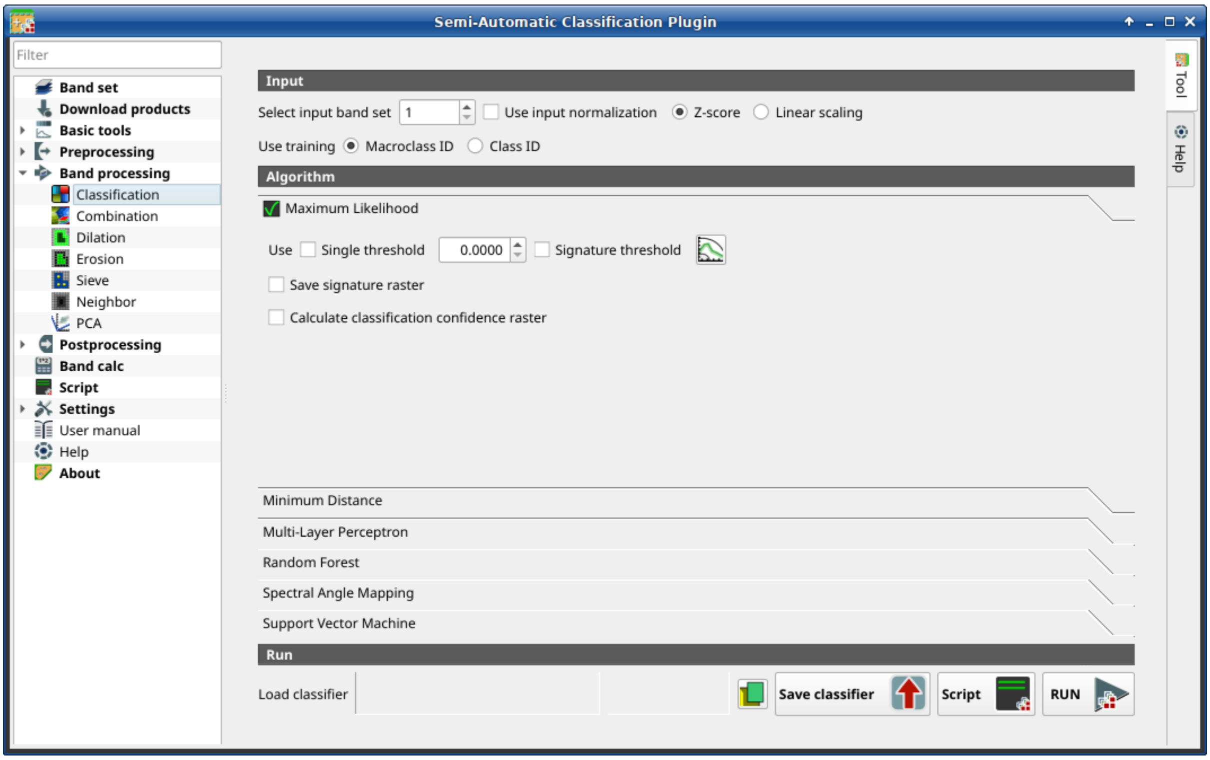


FIG. 27 – *Classification*

This tab allows for the classification of the *Band set* (page 45) using the spectral signatures checked in *ROI & Signature list* (page 36). Several classification options are set in this tab which affect the classification process also during the *Classification preview* (page 44).

This tool allows for the selection of one the following algorithms :
— *Maximum Likelihood* (page 75)
— *Minimum Distance* (page 76)
— *Multi-layer Perceptron* (page 77)
— *Random Forest* (page 79)
— *Spectral Angle Mapping* (page 80)
— *Support Vector Machine* (page 81)
Also, it is possible to save and load a trained classifier.

Astuce : Information about APIs of this tool in Remotior Sensus at this link .

Input

Tool symbol and name	Description
Select input band set	select the input *Band set* (page 45) to be classified
Use input normalization	if checked, normalize the input based on the selected method
Z-score	if checked with *Use input normalized*, Z-score normalization of input is performed
Linear scaling	if checked with *Use input normalized*, Linear scaling normalization of input is performed
Use training *Macroclass ID*	if checked, the classification is performed using
Use training *Class ID* the Macroclass ID (code *MC ID* of the signature)	if checked, the classification is performed using the Class ID (code *C ID* of the signature)

Algorithm

This tool allows for the selection of the classification algorithm. The algorithm tab includes the available parameters.

Maximum Likelihood

Use the *Maximum Likelihood* (page 136) algorithm.

Tool symbol and name	Description
Use single threshold	if checked, it allows for the definition of a classification threshold (applied to all the spectral signatures) ; pixels are unclassified if probability is less than threshold value (max 100)
Signature threshold	if checked, thresholds *Signature threshold* (page 60) are evaluated
	open the *Signature threshold* (page 60) for the definition of signature thresholds
Save signature raster	if checked, in addition to the classification raster, for each spectral signature a raster is saved in the same output directory, which represents the distance between pixel and signature
Calculate classification confidence raster	if checked, calculate classification confidence raster

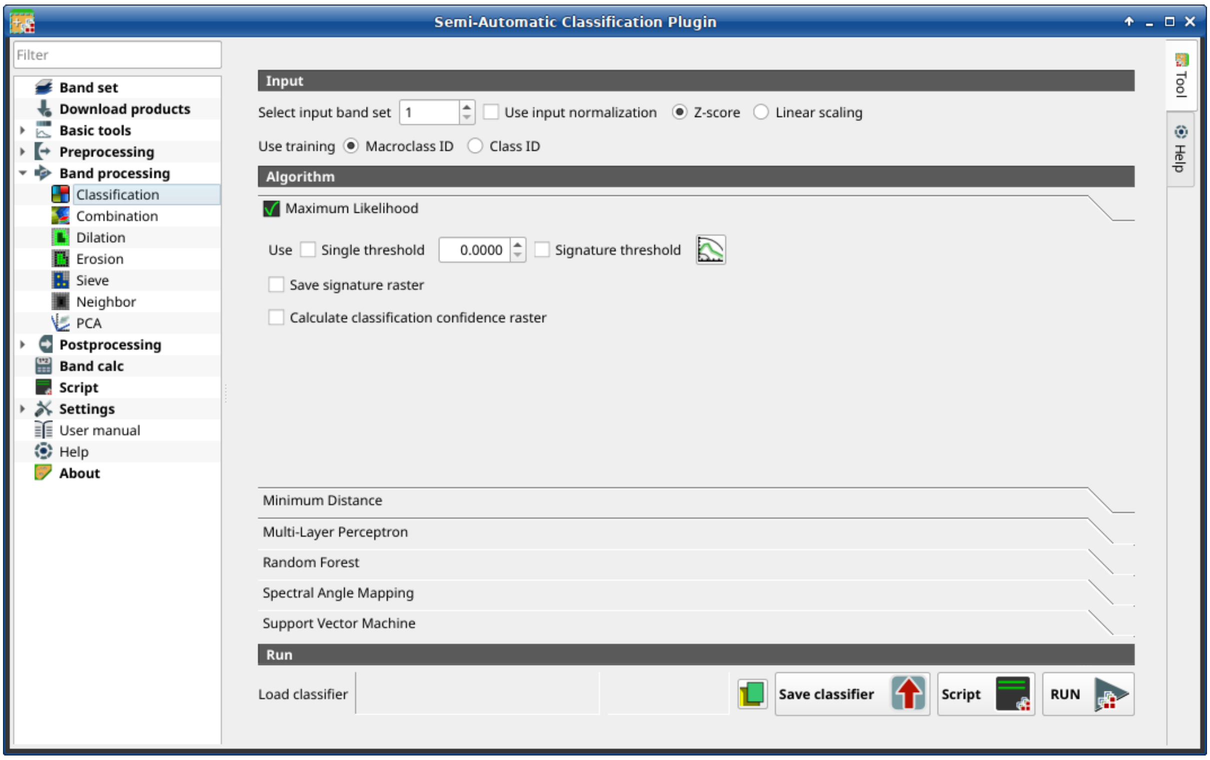


Fig. 28 – *Maximum Likelihood*

Minimum Distance

Use the *Minimum Distance* (page 135) algorithm.

Tool symbol and name	Description
Use single threshold	if checked, it allows for the definition of a classification threshold (applied to all the spectral signatures) ; pixels are unclassified if distance is greater than threshold value
Signature threshold	if checked, thresholds *Signature threshold* (page 60) are evaluated
	open the *Signature threshold* (page 60) for the definition of signature thresholds
Save signature raster	if checked, in addition to the classification raster, for each spectral signature a raster is saved in the same output directory, which represents the distance between pixel and signature
Calculate classification confidence raster	if checked, calculate classification confidence raster

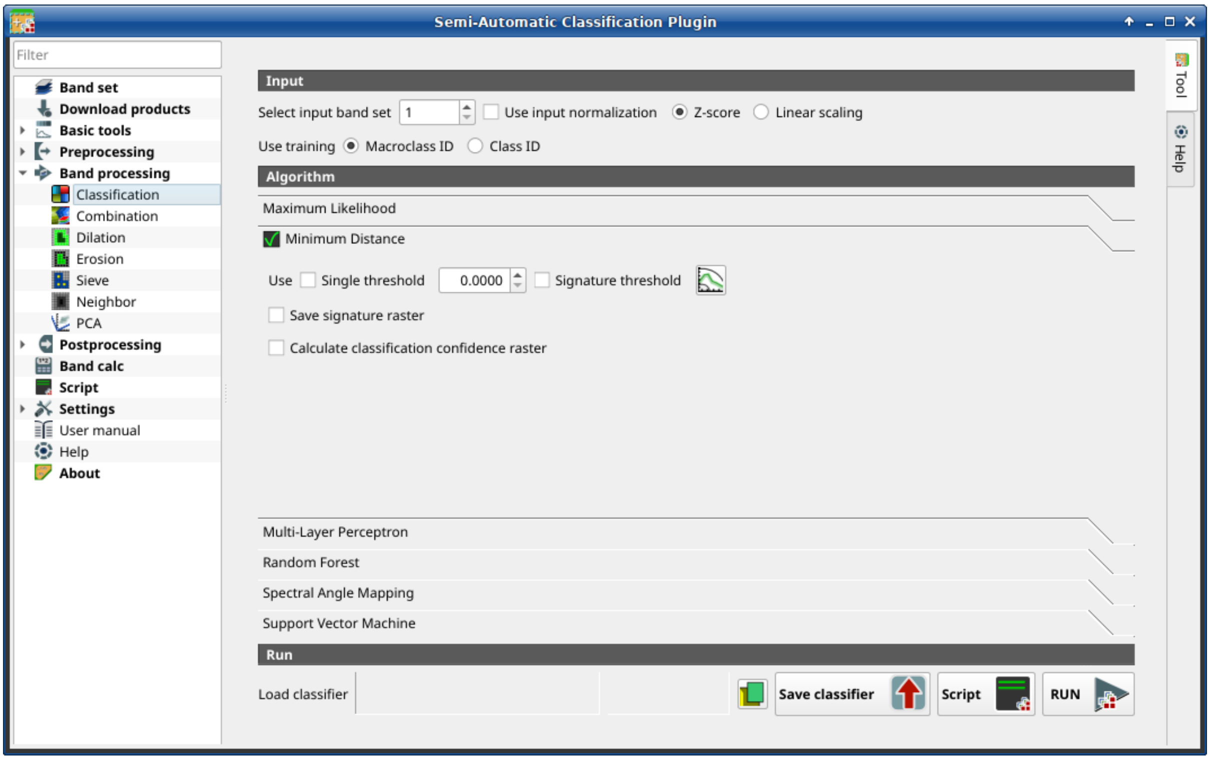


FIG. 29 – *Minimum Distance*

Multi-layer Perceptron

Use the *Multi-Layer Perceptron* (page 141) algorithm.

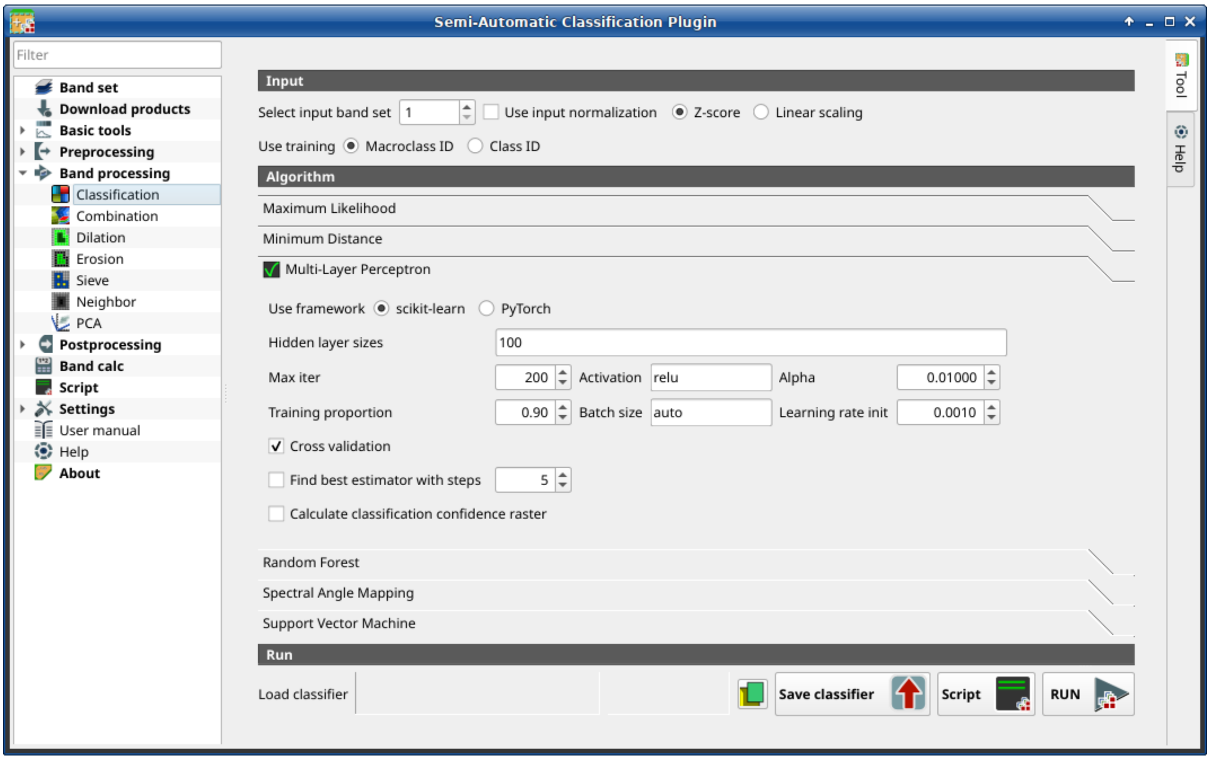


FIG. 30 – *Multi-layer Perceptron*

Tool symbol and name	Description
Use framework scikit-learn	if checked, use scikit-learn framework (read this)
Use framework PyTorch	if checked, use PyTorch framework (read about this)
Hidden layer sizes	list of values separated by comma, where each value defines the number of neurons in a hidden layer (e.g. : 200, 100 for two hidden layers of 200 and 100 neurons respectively)
Max iter	set the maximum number of iterations
Activation	set the activation function (default : relu)
Alpha	set the weight decay (also L2 regularization term) for Adam optimizer
Training proportion	set the proportion of data to be used as training and the remaining part as test
Batch size	set the number of samples per batch for optimizer ; if auto, the batch is the minimum value between 200 and the number of samples
Learning rate init	set initial learning rate
Cross validation	if checked, perform cross validation
Find best estimator with steps	if checked, find the best estimator iteratively with a number of steps
Calculate classification confidence raster	if checked, calculate classification confidence raster

Random Forest

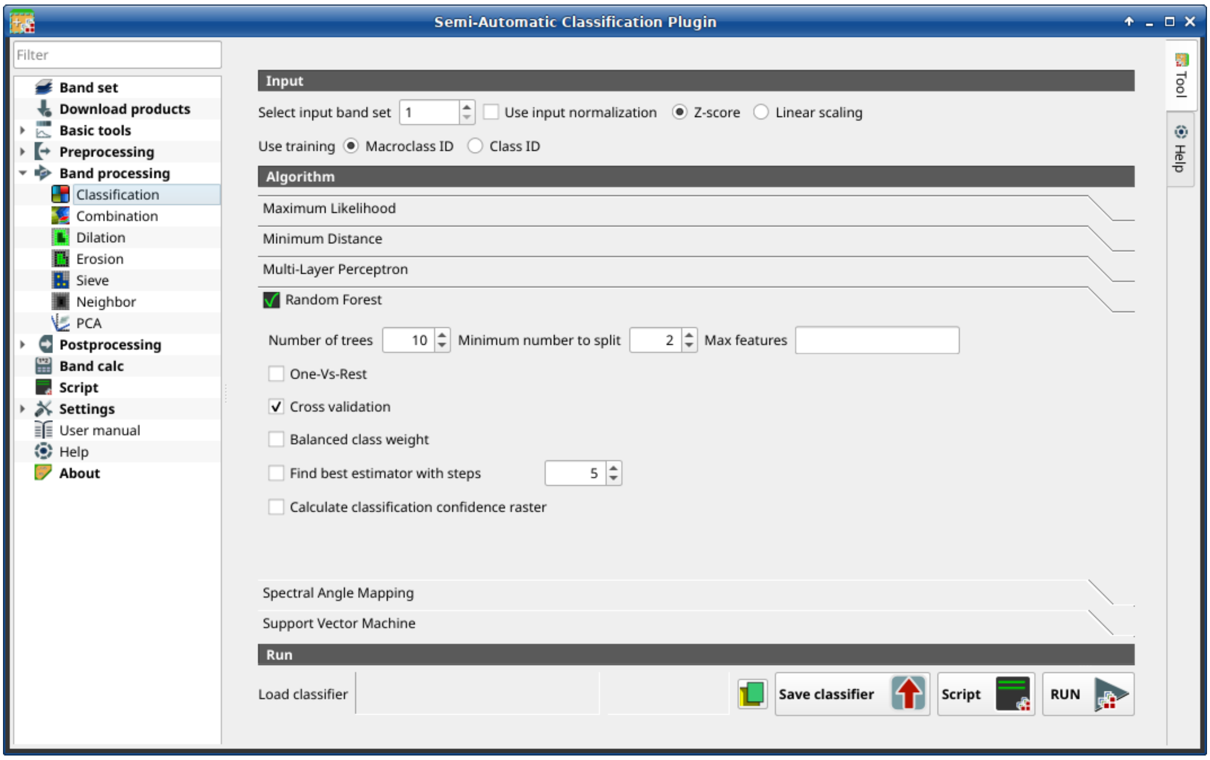


FIG. 31 – *Random Forest*

Use the *Random Forest* (page 140) algorithm.

Tool symbol and name	Description
Number of trees	set the number of trees
Minimum number to split	set the minimum number of samples required to split an internal node
Max features	for node splitting, if empty all features are considered ; if sqrt the square root of all the features, if integer number the number of features ; if float number a fraction of all the features
One-Vs-Rest	if checked, perform One-Vs-Rest classification (read more)
Cross validation	if checked, perform cross validation
Balanced class weight	if checked, balanced weight is computed inversely proportional to class frequency
Find best estimator with steps	if checked, find the best estimator iteratively with a number of steps
Calculate classification confidence raster	if checked, calculate classification confidence raster

Spectral Angle Mapping

Use the *Spectral Angle Mapping* (page 137) algorithm.

Tool symbol and name	Description
Use single threshold	if checked, it allows for the definition of a classification threshold (applied to all the spectral signatures) ; pixels are unclassified if spectral angle distance is greater than threshold value (max 90)
Signature threshold	if checked, thresholds *Signature threshold* (page 60) are evaluated
	open the *Signature threshold* (page 60) for the definition of signature thresholds
Save signature raster	if checked, in addition to the classification raster, for each spectral signature a raster is saved in the same output directory, which represents the distance between pixel and signature
Calculate classification confidence raster	if checked, calculate classification confidence raster

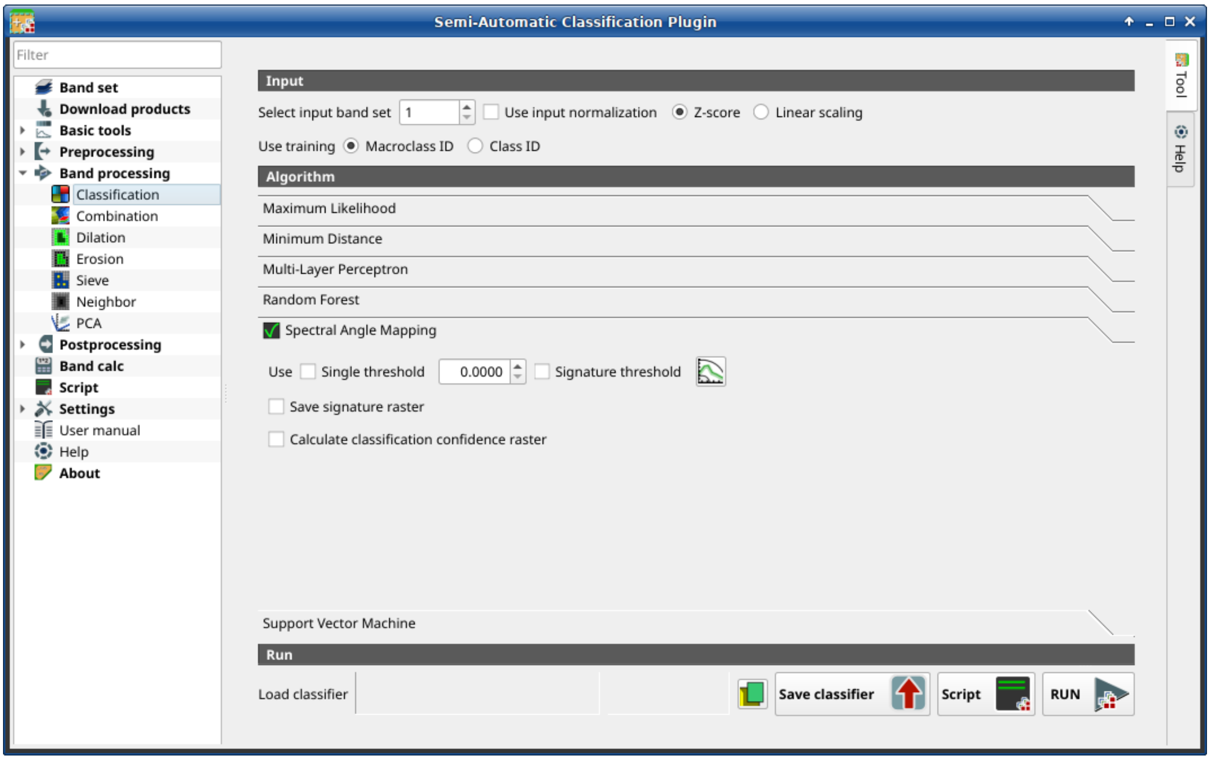


FIG. 32 – *Spectral Angle Mapping*

Support Vector Machine

Use the *Support Vector Machine* (page 141) algorithm.

Tool symbol and name	Description
Regularization parameter C	set the regularization parameter C
Kernel	set the kernel (default : rbf)
Gamma	set the kernel coefficient gamma (default : scale)
Cross validation	if checked, perform cross validation
Balanced class weight	if checked, balanced weight is computed inversely proportional to class frequency
Find best estimator with steps	if checked, find the best estimator iteratively with a number of steps
Calculate classification confidence raster	if checked, calculate classification confidence raster

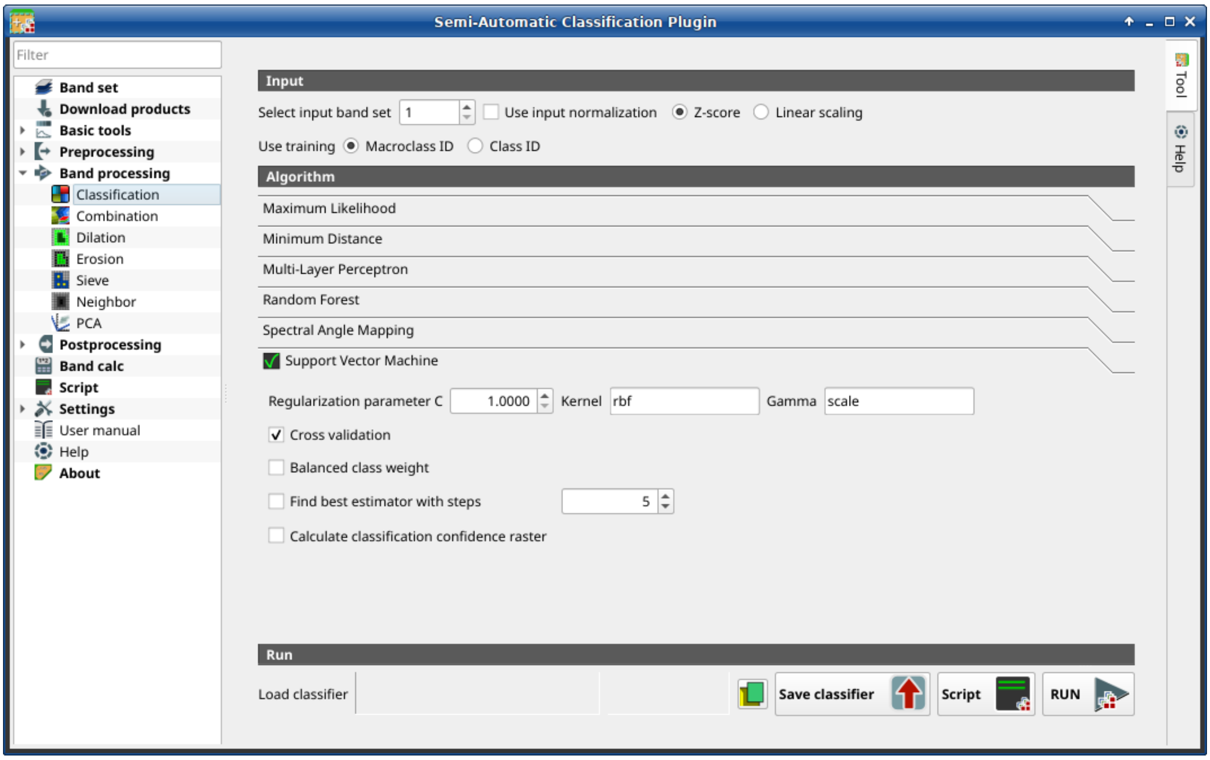
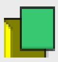


FIG. 33 – *Support Vector Machine*

Run

It is possible to run the classification, or save and load a trained classifier.

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.

Tool symbol and name	Description
Load classifier 	open an already save classifier file (.rsmo)
Save classifier 	save the classifier to file (.rsmo), in order to be loaded later
RUN 	run this function

Combination

— *Combination of band values* (page 83)

This tab allows for the combination of bands loaded in a *Band set* (page 45). This tool is intended for combining classifications in order to get a raster where each value corresponds to a combination of class values. Raster values must be integer type. A combination raster is produced as output and the area of each combination is reported in a `.csv` file.

This tool supports `virtual raster output` ; if the output file name ends with `.vrt` then the output is created as virtual raster composed of as many `.tif` files as the number of CPU threads defined in *System* (page 110) ; for large rasters this can speed up the process.

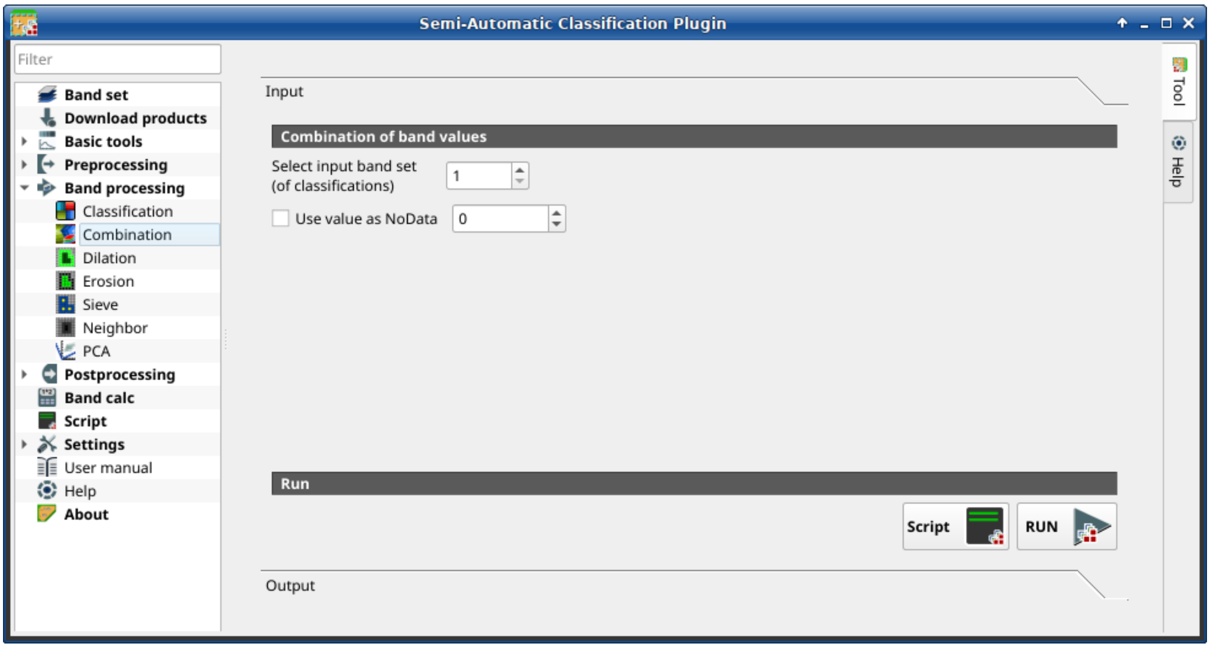


Fig. 34 – *Combination*

Astuce : Information about APIs of this tool in Remotior Sensus at this link .

Combination of band values

Tool symbol and name	Description
Select input band set (of classifications) 1	select the input *Band set* (page 45)
Use value as NoData 1	if checked, set the value of `NoData` pixels, ignored during the calculation
Script	add this function to the *Script* (page 106)
RUN	run this function

The list of combinations and the area thereof will be displayed in the tab `Output`.

Dilation

— *Dilation* (page 84)

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.

Astuce : Information about APIs of this tool in Remotior Sensus at this link .

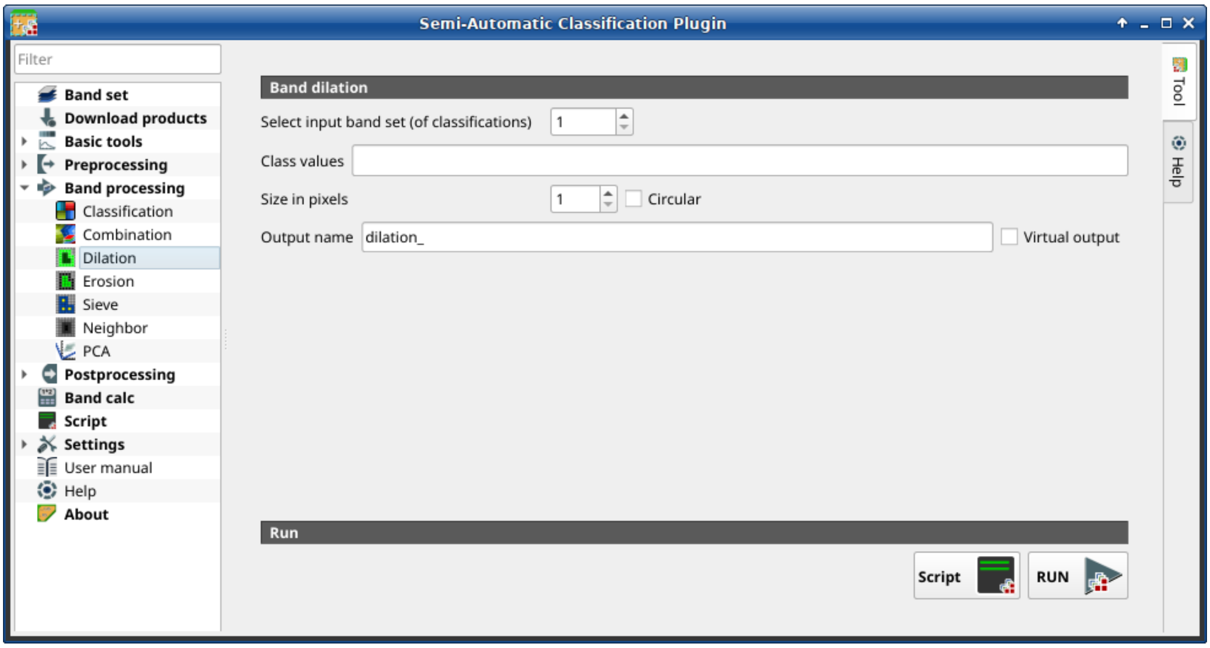


Fig. 35 – *Dilation*

Dilation

Tool symbol and name	Description
Select input band set (of classifications)	select the input *Band set* (page 45)
Class values	set the class values to be dilated ; class values must be separated by `,` and `-` can be used to define a range of values (e.g. `1, 3-5, 8` will select classes 1, 3, 4, 5, 8) ; if the text is red then the expression contains errors
Size in pixels	number of pixels to be dilated from the border
Circular	if checked, the dilation will be circular, similar to a buffer
Output name	set the name prefix for output files
Virtual output	if checked, the output is created as virtual raster composed of as many `.tif` files as the number of CPU threads defined in *System* (page 110)
Script	add this function to the *Script* (page 106)
RUN	run this function

Erosion

— *Erosion* (page 86)

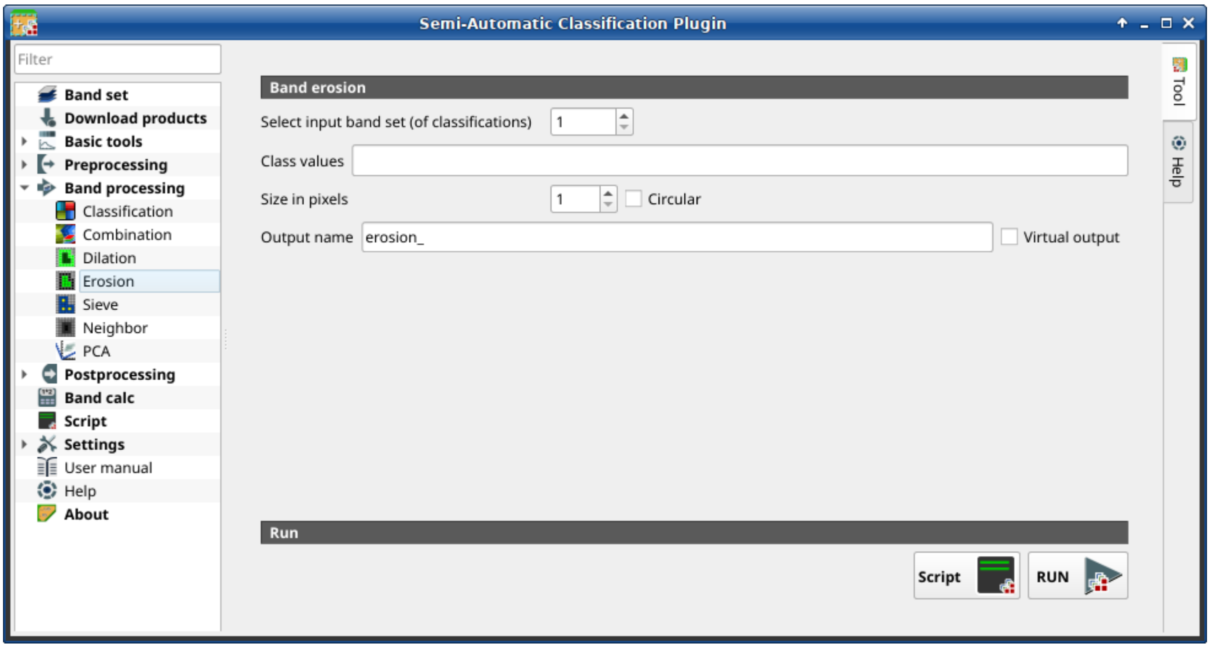


FIG. 36 – *Erosion*

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

Astuce : Information about APIs of this tool in Remotior Sensus at this link .

Erosion

Tool symbol and name	Description
Select input band set (of classifications)	select the input *Band set* (page 45)
Class values	set the class values to be eroded ; class values must be separated by `,` and `-` can be used to define a range of values (e.g. `1, 3-5, 8` will select classes 1, 3, 4, 5, 8) ; if the text is red then the expression contains errors
Size in pixels	number of pixels to be eroded from the border
Circular	if checked, the erosion will be circular, similar to a buffer
Output name	set the name prefix for output files
Virtual output	if checked, the output is created as virtual raster composed of as many `.tif` files as the number of CPU threads defined in *System* (page 110)
Script	add this function to the *Script* (page 106)
RUN	run this function

Sieve

— *Sieve* (page 87)

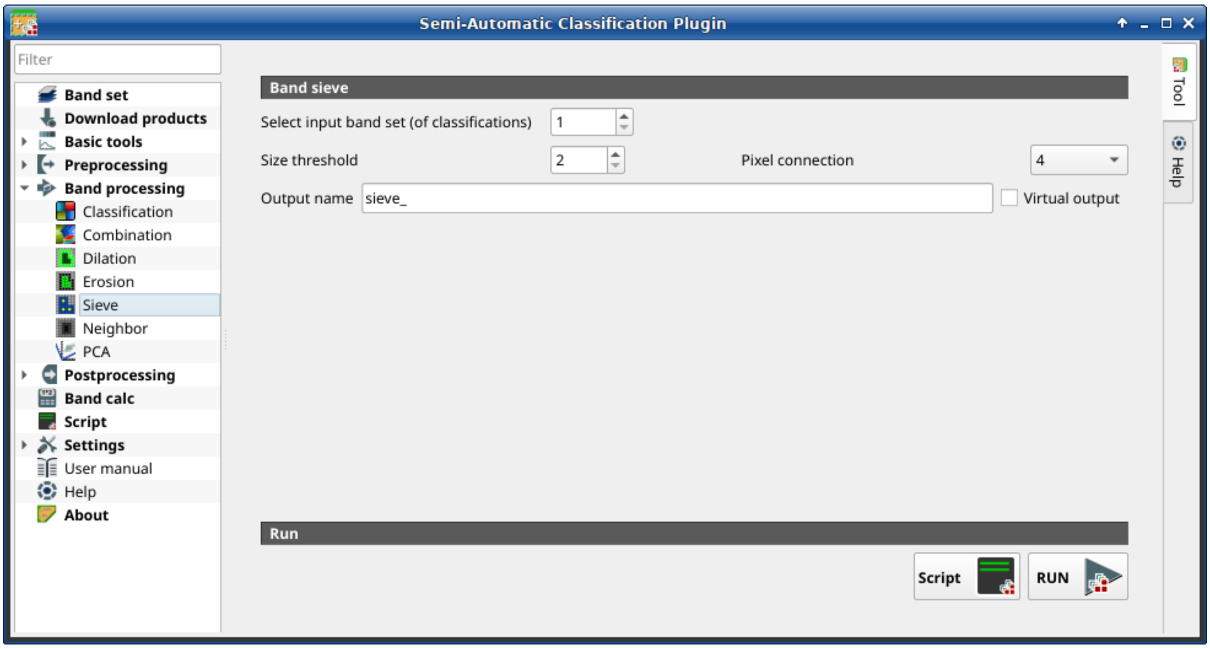


FIG. 37 – *Sieve*

This tab allows for the replacement of isolated pixel values with the value of the largest neighbour patch. It is useful for removing small patches from a classification.

It is possible to chose `4 pixel connection` (in a 3x3 window, diagonal pixels are not considered connected) or `8 pixel connection` (in a 3x3 window, diagonal pixels are considered connected).

Astuce : Information about APIs of this tool in Remotior Sensus at this link .

Sieve

Tool symbol and name	Description
Select input band set (of classifications)	select the input *Band set* (page 45)
Size threshold	size of threshold in number of pixels
Pixel connection	select between 4 pixel connection or 8 pixel connection
Output name	set the name prefix for output files
Virtual output	if checked, the output is created as virtual raster composed of as many `.tif` files as the number of CPU threads defined in *System* (page 110)
Script	add this function to the *Script* (page 106)
RUN	run this function

Neighbor

This tool allows for the calculation of several neighbor pixels statistics for every band of a band set defined in the *Band set* (page 45).

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 of a band set for photointerpretation.

Astuce : Information about APIs of this tool in Remotior Sensus at this link .

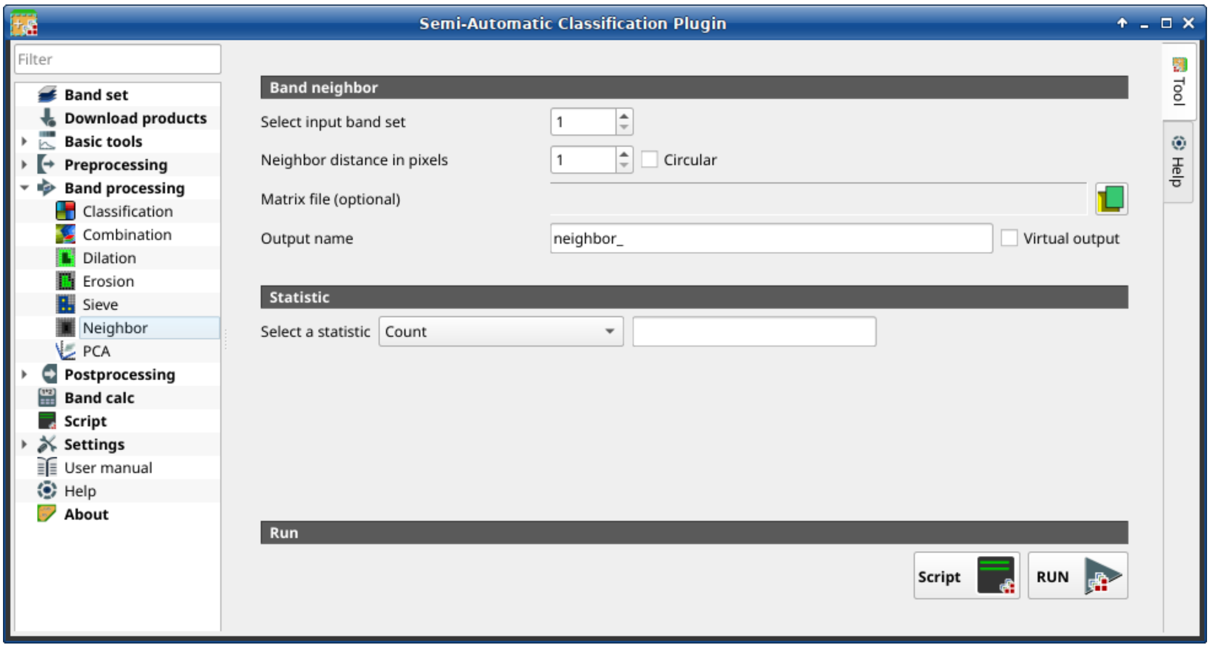


Fig. 38 – *Neighbor*

Neighbor

Tool symbol and name	Description
Select input band set	select the input *Band set* (page 45)
Neighbor distance in pixels	create a window defining the size based on the distance from the center (in number of pixels)
Circular	if checked, the window will be circular
Matrix file (optional)	select a `.csv` file containing the structure of the window
Output name	set the name prefix for output files
Virtual output	if checked, the output is created as virtual raster composed of as many `.tif` files as the number of CPU threads defined in *System* (page 110)

Statistic

Tool symbol and name	Description
Select a statistic	select a statistic among : Count, Max, Mean, Median, Min, Percentile, StandardDeviation, Sum. For Percentile statistic it is possible to enter the percentile value.

Run

— — *Script*
    — add this function to the *Script* (page 106)

— — *RUN*
    — run this function

PCA

— *PCA* (page 90)

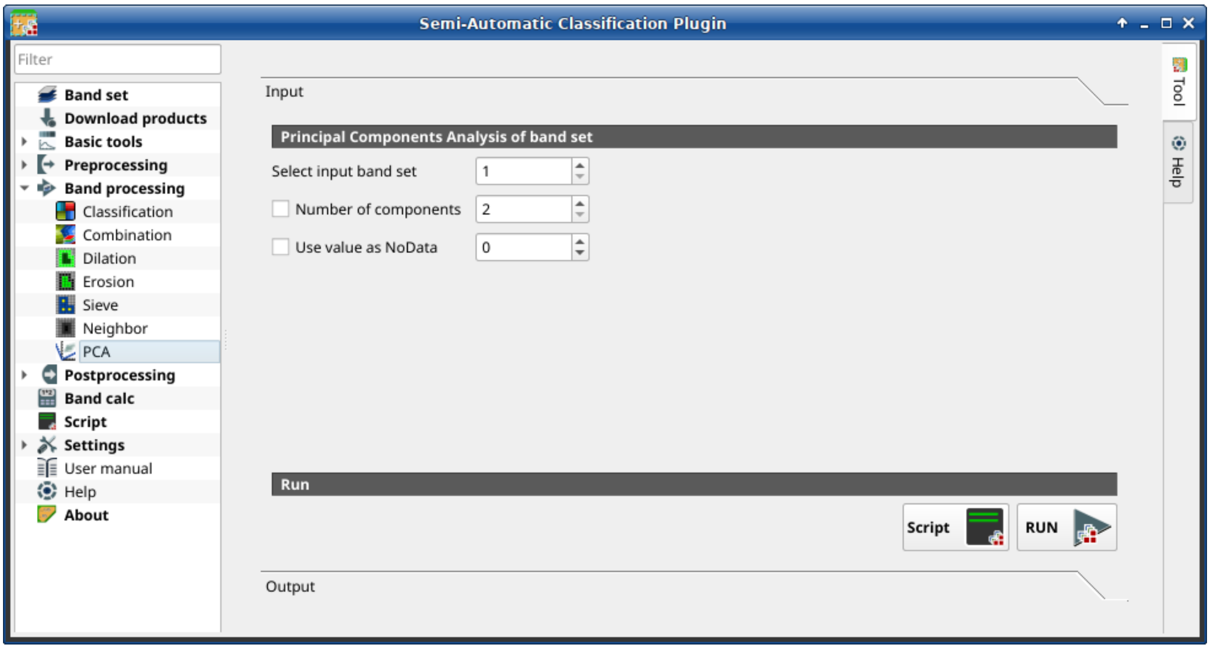


Fig. 39 – *PCA*

This tab allows for the PCA (*Principal Component Analysis* (page 144)) 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.

Astuce : Information about APIs of this tool in Remotior Sensus at this link .

PCA

Tool symbol and name	Description
Select input band set	select the input *Band set* (page 45)
Number of components	set the number of components to be calculated
Use value as NoData	if checked, set the value of `NoData` pixels, ignored during the calculation
Script	add this function to the *Script* (page 106)
RUN	run this function

The `Output` tab will display the Principal Components Analysis details (Covariance matrix, Correlation matrix, Eigenvectors, and Eigenvalues).

3.4.6 Postprocessing

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

Accuracy

— *Accuracy* (page 91)

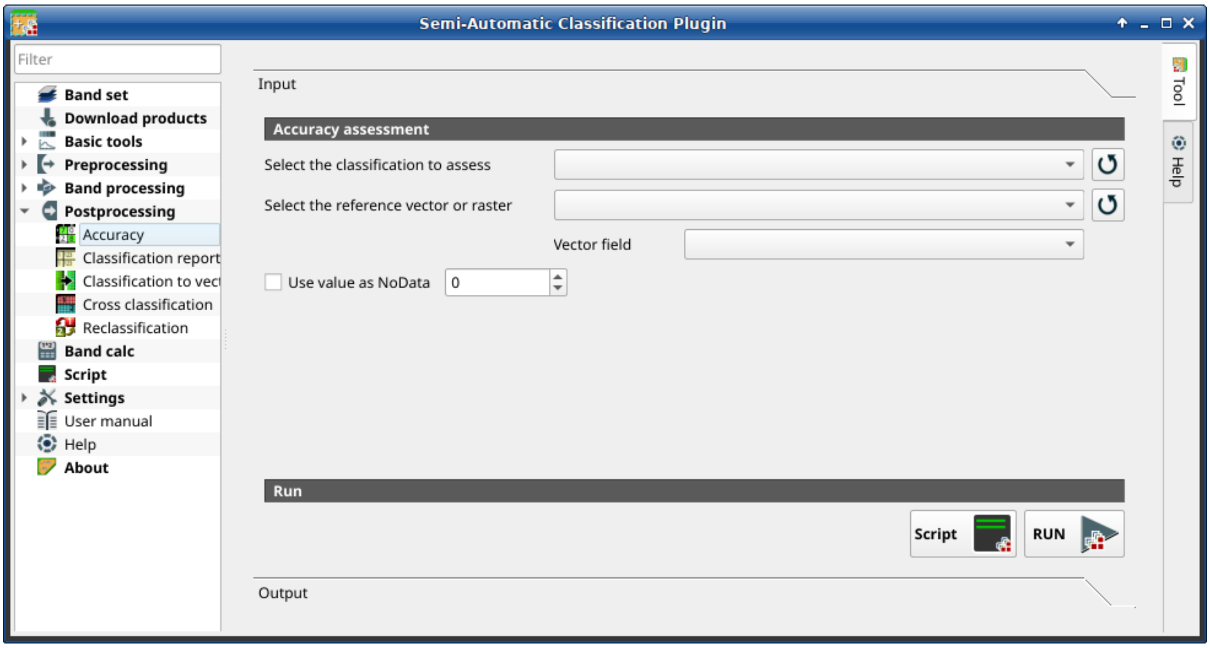


FIG. 40 – *Accuracy*

This tab allows for the validation of a classification (read *Accuracy Assessment* (page 143)).

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.

This tool supports `virtual raster output`; if the output file name ends with `.vrt` then the output is created as virtual raster composed of as many `.tif` files as the number of CPU threads defined in *System* (page 110); for large rasters this can speed up the process.

Astuce : Information about APIs of this tool in Remotior Sensus at this link .

Accuracy

Tool symbol and name	Description
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, set the value of `NoData` pixels, ignored during the calculation
Script	add this function to the *Script* (page 106)
RUN	run this function

Classification report

— *Classification report* (page 92)

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).

Astuce : Information about APIs of this tool in Remotior Sensus at this link .

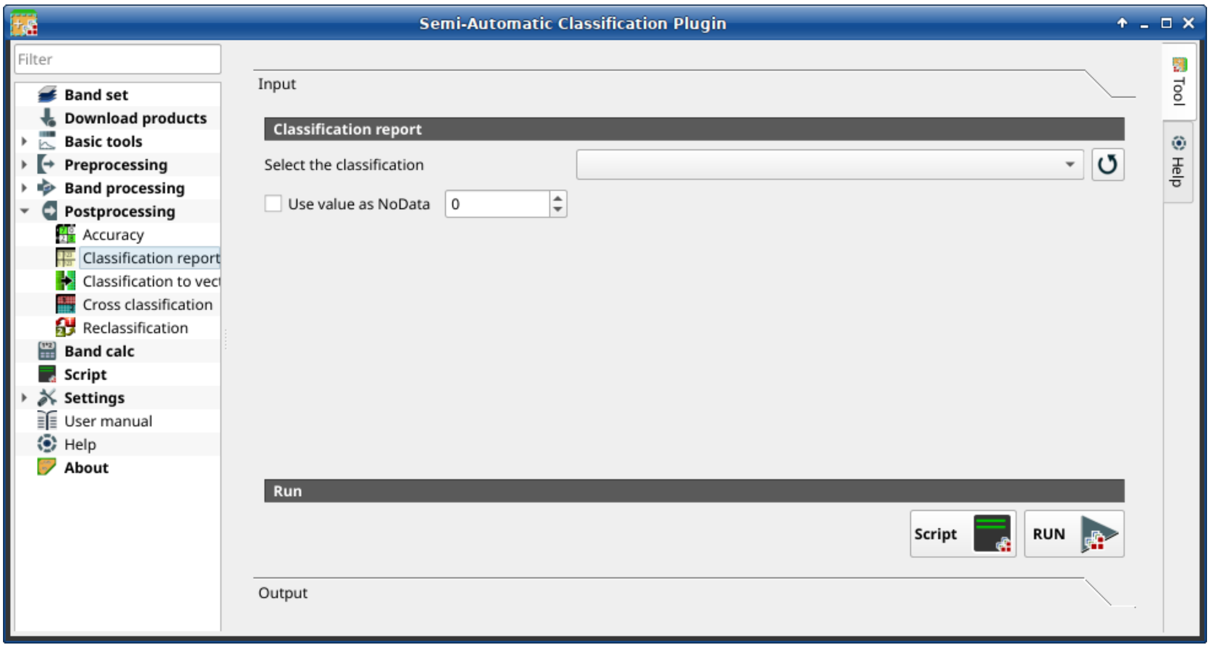


FIG. 41 – *Classification report*

Classification report

Tool symbol and name	Description
Select the classification	select a classification raster (already loaded in QGIS)
	refresh layer list
Use value as NoData	if checked, set the value of `NoData` pixels, ignored during the calculation
Script	add this function to the *Script* (page 106)
RUN	run this function

The tab `Output` will display the report.

Classification to vector

This tab allows for the conversion of a classification raster to vector GeoPackage (`.gpkg`) . Parallel processes are used for the conversion, resulting in a vector output which is split in as many portions as the process numbers. The argument dissolve allows for merging these portions, but it requires additional processing time depending on vector size.

Astuce : Information about APIs of this tool in Remotior Sensus at this link .

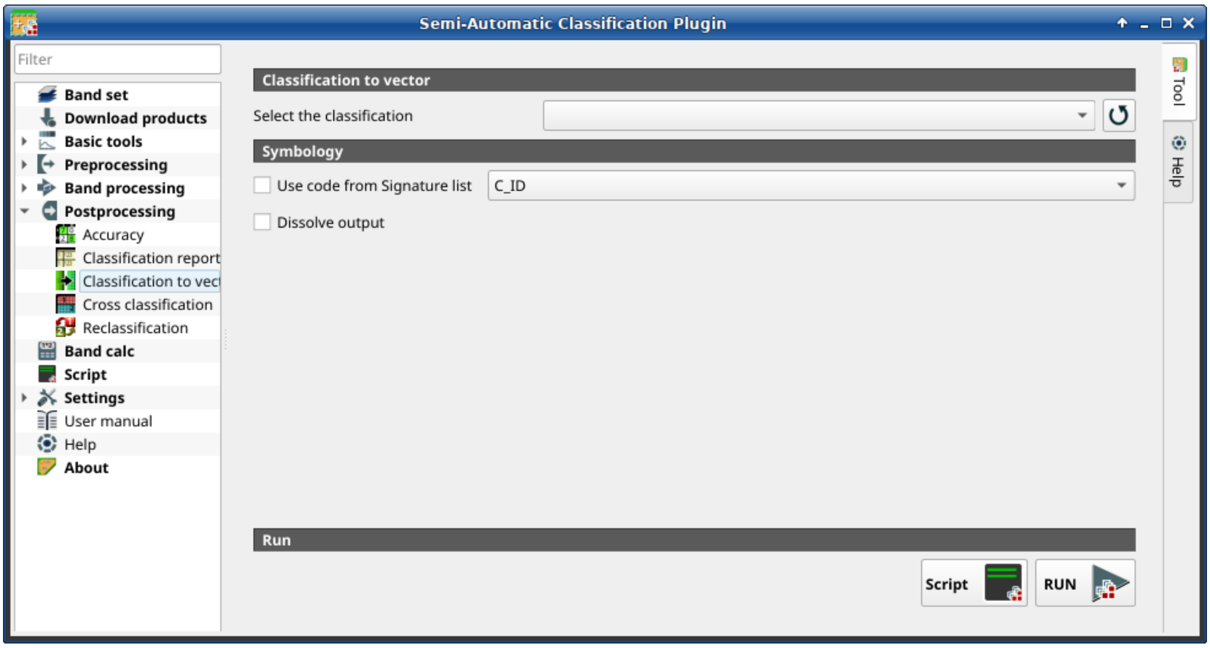


Fig. 42 – *Classification to vector*

Classification to vector

Tool symbol and name	Description
Select the classification	select a classification raster (already loaded in QGIS)
	refresh layer list

Symbology

Tool symbol and name	Description
— *Use code from Signature list*	if checked, color and class information are defined from *ROI & Signature list* (page 36) * MC ID : use the ID of macroclasses * C ID : use the ID of classes
— *Dissolve output*	if checked, dissolve adjacent polygons having the same values

Run

- — *Script* 
  - add this function to the *Script* (page 106)
- — *RUN* 
  - run this function

Cross classification

— *Cross classification* (page 95)

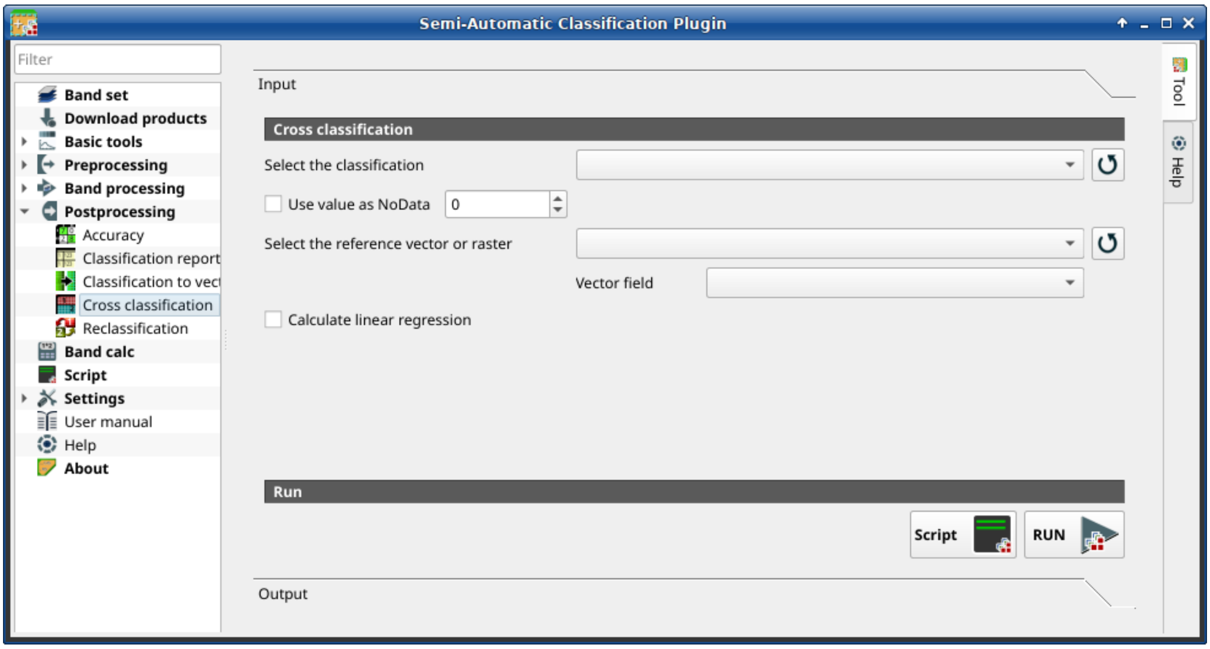


FIG. 43 – *Cross classification*

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

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

This tool supports `virtual raster output`; if the output file name ends with `.vrt` then the output is created as virtual raster composed of as many `.tif` files as the number of CPU threads defined in *System* (page 110); for large rasters this can speed up the process.

Astuce : Information about APIs of this tool in Remotior Sensus at this link .

Cross classification

Tool symbol and name	Description
Select the classification	select a classification raster (already loaded in QGIS)
	refresh layer list
Use value as NoData	if checked, set the value of `NoData` pixels, ignored during 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
Calculate linear regression	if checked, calculate linear regression between the two input layers
Script	add this function to the *Script* (page 106)
RUN	run this function

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.

This tool supports `virtual raster output`; if the output file name ends with `.vrt` then the output is created as virtual raster composed of as many `.tif` files as the number of CPU threads defined in *System* (page 110); for large rasters this can speed up the process.

Astuce : Information about APIs of this tool in Remotior Sensus at this link .

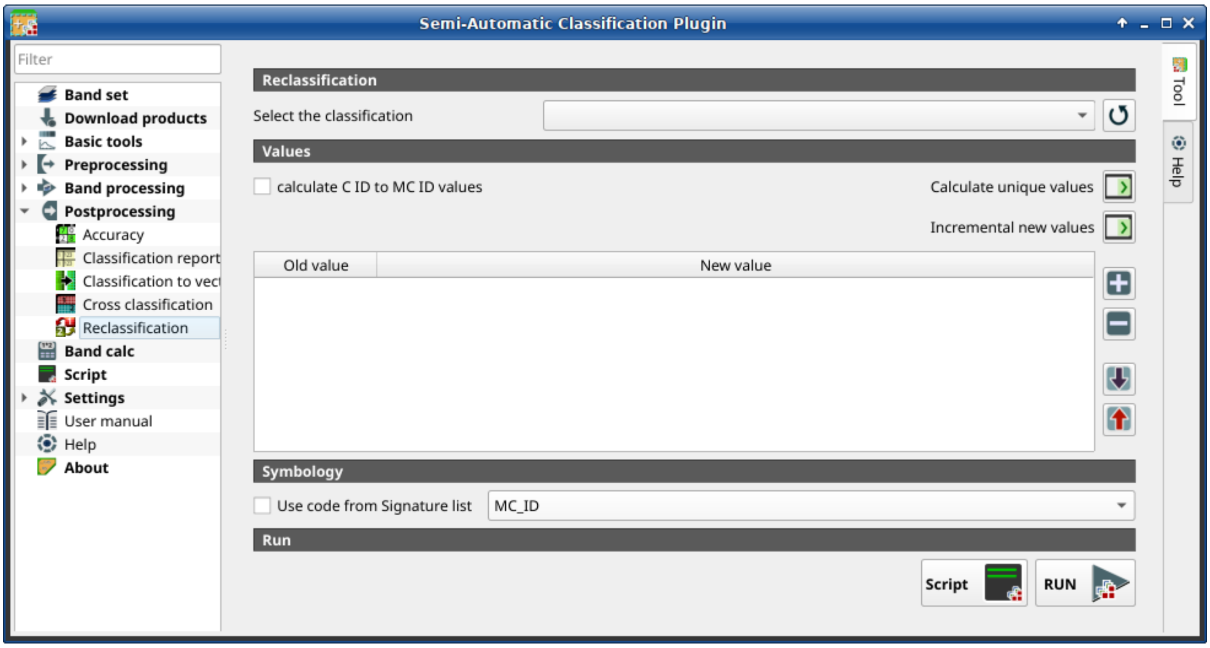


FIG. 44 – *Reclassification*

Cross classification

Tool symbol and name	Description
Select the classification	select a classification raster (already loaded in QGIS)
	refresh layer list

Values

Tool symbol and name	Description
calculate C ID to MC ID values	if checked, the reclassification table is filled according to the *ROI & Signature list* (page 36) 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
	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

The reclassification table is structured with the following fields.

Old value	New value
value or expression defining old values to be reclassified	integer value for the corresponding `Old value`

`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 109)), following Python operators (e.g. :

- `raster > 3` select all pixels having value > 3 ;
- `(raster > 5) | (raster < 2)` select all pixels having value > 5 or < 2 ;
- `(raster >= 2) & (raster <= 5)` select all pixel values between 2 and 5.

Symbology

Tool symbol and name	Description
Use code from Signature list	**if checked, color and class information are defined from *ROI & Signature list* (page 36) :** — `MC ID` : use the ID of macroclasses — `C ID` : use the ID of classes

Run

Tool symbol and name	Description
Script	add this function to the *Script* (page 106)
RUN	run this function

3.4.7 Band calc

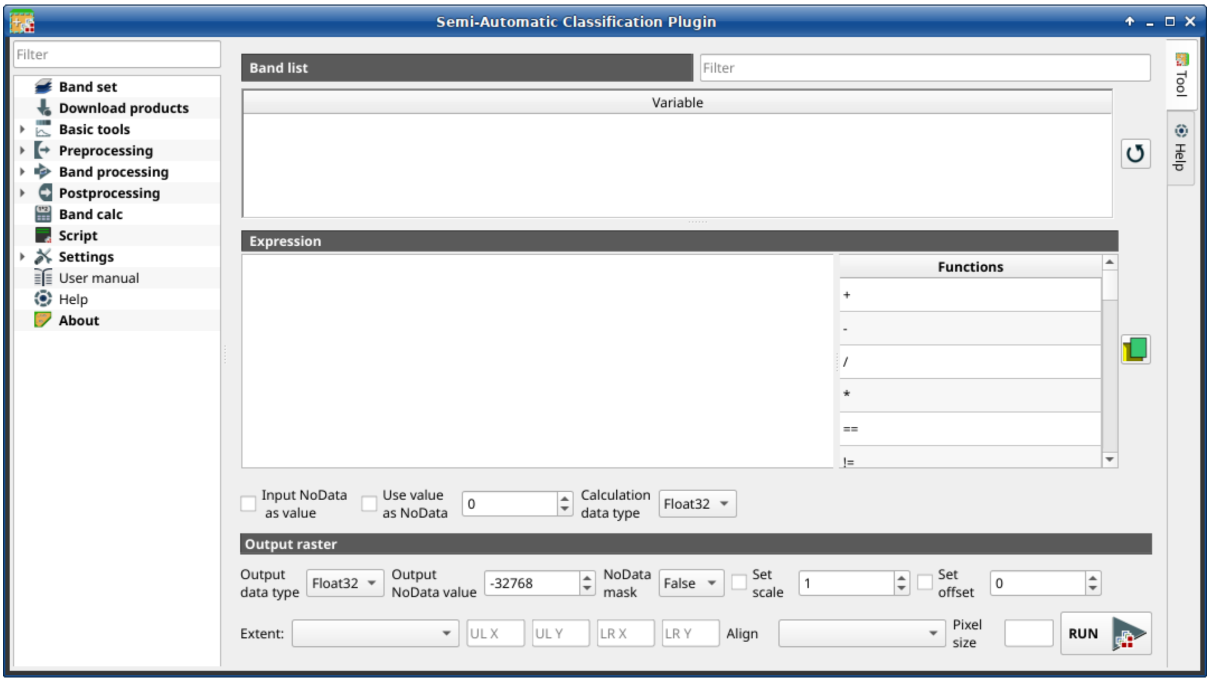


FIG. 45 – *Band calc*

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 multiple expression lines to perform multiple calculation at a time ; several iteration functions are available for *Band sets* allowing for performing multi-temporal calculations.

This tool supports `virtual raster output` ; if the output file name ends with `.vrt` then the output is created as virtual raster composed of as many `.tif` files as the number of CPU threads defined in *System* (page 110) ; for large rasters this can speed up the process.

Raster bands must be already loaded in QGIS. Input rasters can also be in different projection, but the output will have the projection of the reference raster.

Astuce : Information about APIs of this tool in Remotior Sensus at this link .

Band list

Tool symbol and name	Description
Band list	table containing a list of single band rasters (already loaded in QGIS) and *Input variables* (page 101) defined from *Band set*
Filter	filter the variable list
	refresh band 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 *Variable* between `"`. Double click on any item in the *Band list* (page 99) 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 variables (page 101) and *Output variables* (page 102) can be used in the expression.

Tool symbol and name	Description
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
Calculation data type	select the data type used during calculation as Float32 (default), Int32, Int16, UInt32, UInt16, Byte ; for instance, if Int32 is selected, input float values will be evaluated as integer
Functions	list of *Functions* (page 103) names (double click to copy one in the expression) such as mathematical, conditional, logical, statistics, indices, and custom
	open a text file (.txt) containing custom expressions to be listed in *Functions*

A text file can be loaded for adding expressions to the *Functions*. The text 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*. Opening an empty text file will remove custom expressions from the *Functions*. 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
```

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.

Astuce : 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.

Tool symbol and name	Description
Output data type	select the output data type as Float32 (default), Int32, Int16, UInt32, UInt16, Byte ; it can be different from *Calculation data type*
Output NoData value	set the value of `NoData` pixels in output raster
NoData mask	manage NoData at pixel level ; if True, then output is NoData if any input is NoData ; if False, then output is NoData if all the inputs are NoData ; if None, then NoData is not applied to output
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)
Extent *UL X UL Y LR X LR Y*	**set the extent of the output raster among :** — *"Union"* : the extent union of input rasters — *"Map extent"* : the extent of the map currently displayed — *"Intersection"* : the extent intersection of input raster extents (i.e. minimum extent) — *"Custom"* : coordinates defined in *UL X UL Y LR X LR Y* — *Layer name* : the extent of the selected layer
Align	align the output raster to a specific *Layer name* or *"Default"* for automatic alignment to input rasters
Pixel size	set pixel size
RUN	run this function ; it is disabled if the expression syntax is not correct

Input variables

The following variables related to the *Band set* (page 45) 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 46) ; 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*.

Avertissement : 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 45) ;
— *#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.

Avertissement : 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.

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 101) 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 `forbandsinbandset`), for instance :

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

During the iteration, the *Input variables* (page 101) 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
```

Also, *forbandsets* : allows for the iteration over *Band sets* dates (format yyyy-mm-dd, defined in *Band set definition* (page 46)) between square brackets, such as the following examples :

Iterating over a range of dates :

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

Iterating over a list of dates :

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

Iterating over a list of ranges of dates :

```
forbandsets[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 101) 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` :

```
forbandsets[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`) ; 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#* :
— *#BANDSET#* : the name of the first band in the *Band set* (page 45) ;
— *#DATE#* : the current date and time (e.g. 20161110_113846527764) ;
— @ : character @ ;

3.4.8 Script

This tab displays the output of the *Script* buttons that are available in several tools, which ease the creation of Python scripts using Remotior Sensus.

It is possible to edit or copy the Python code and run it in a Python shell. New code is appended to the existing one, when using the *Script* buttons.

Script

Tool symbol and name	Description
	clear the content of the script
Copy	copy the content of the script to the clipboard
Save to file	save the script to file `.py`

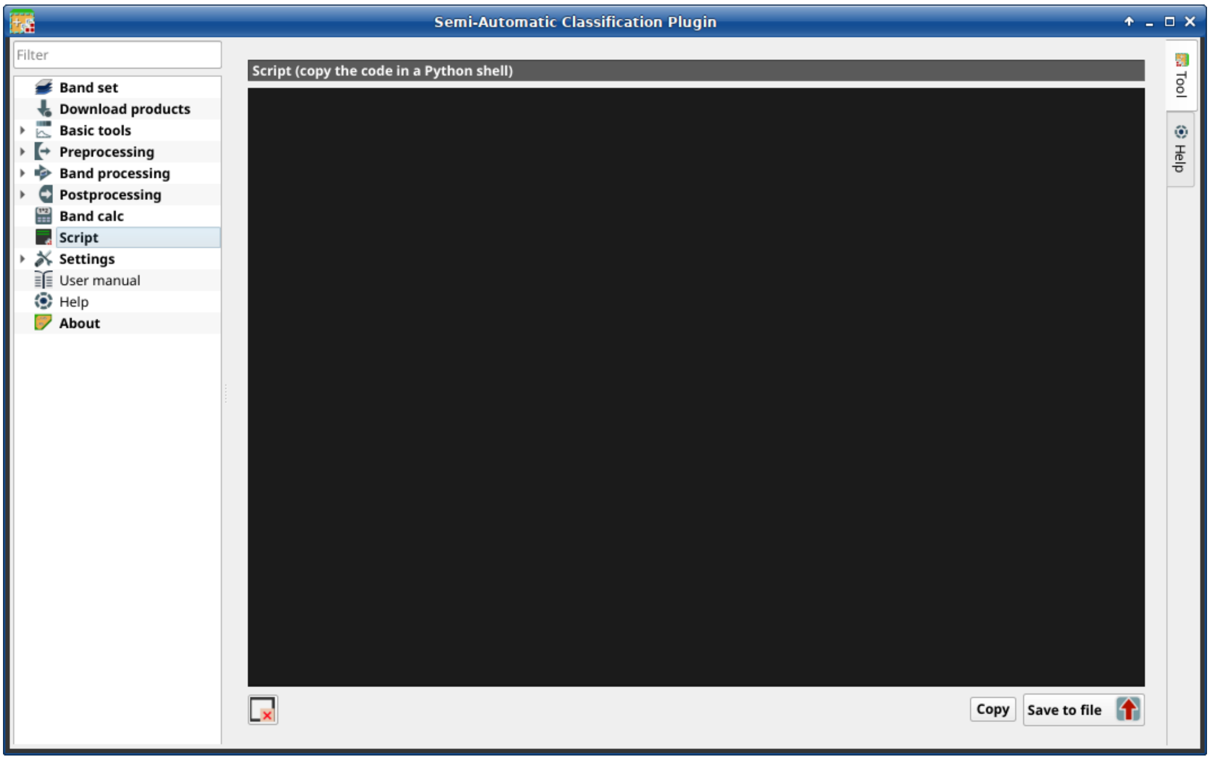


FIG. 46 – *Script*

3.4.9 Settings

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

Debug

This tab allows for the debug of *SCP* in case of issues, and the check of *SCP* dependencies.

Log file

Tool symbol and name	Description
Record detailed events in a Log file 	if checked, start recording detailed events in a Log file
	export the Log file to a .txt file

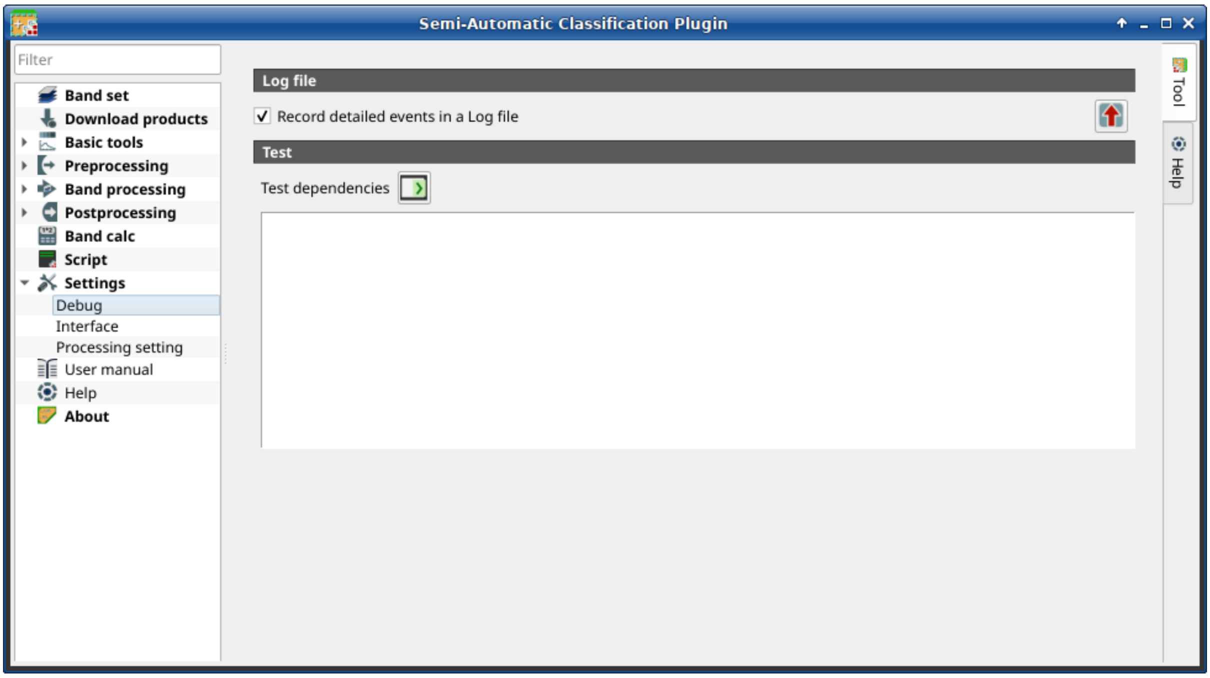


Fig. 47 – *Debug*

Test

Tool symbol and name	Description
Test dependencies	test *SCP* dependencies (NumPy, SciPy, Matplotlib, GDAL, PyTorch, scikit-learn, Remotior Sensus, Multiprocess, Internet connection)

Interface

This tab includes a few advanced settings of the *SCP* interface.

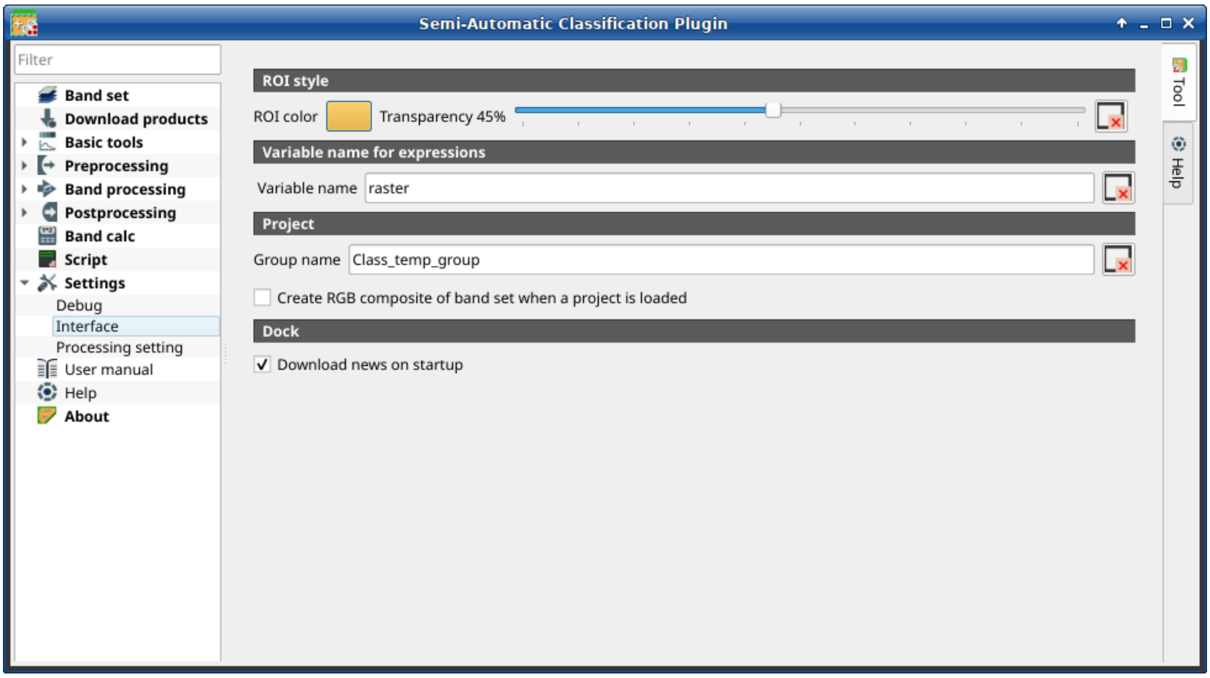


Fig. 48 – *Interface*

ROI style

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

Tool symbol and name	Description
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 95).

Tool symbol and name	Description
Variable name	set variable name (default is `raster`)
	reset variable name to default

Temporary group name

Tool symbol and name	Description
Group name	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

Tool symbol and name	Description
Download news on startup	if checked, news about the *SCP* and related services are downloaded on startup and displayed in *Dock* ; also, it checks for updates of Remotior Sensus

Processing setting

System

Tool symbol and name	Description
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)
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)

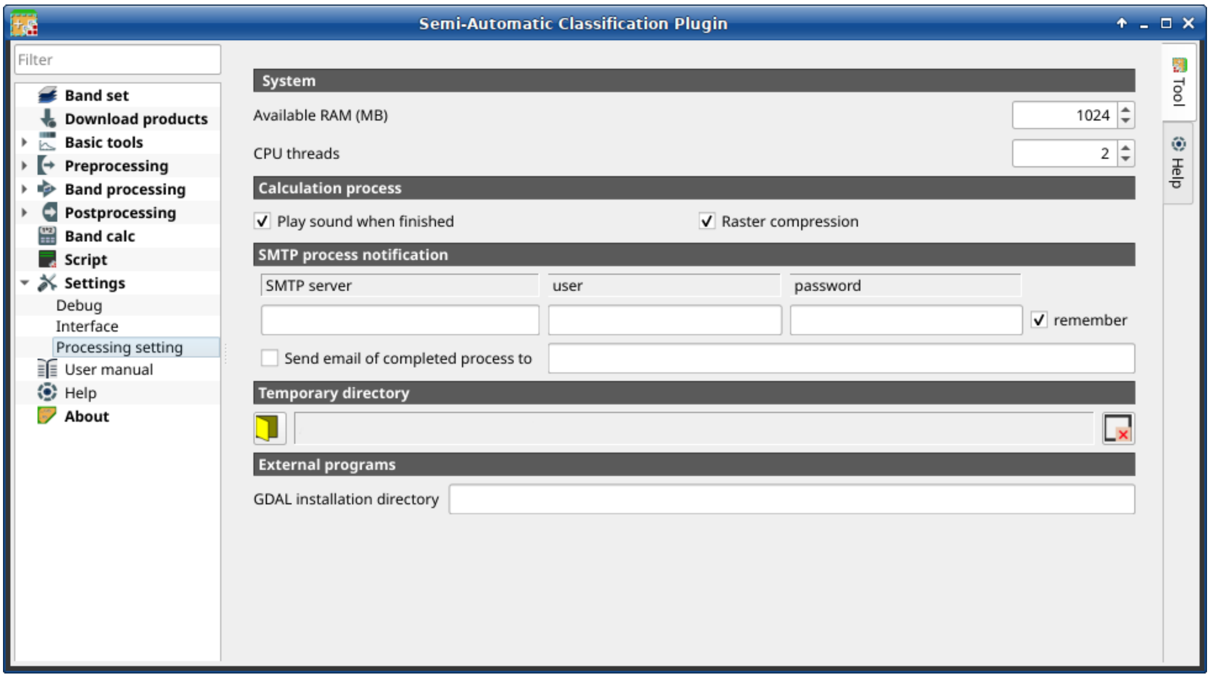


Fig. 49 – *Processing*

Calculation process

Tool symbol and name	Description
Play sound when finished	if checked, play a sound when the process is completed
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 to save disk space, or uncheck to faster the calculation

SMTP process notification

Tool symbol and name	Description
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

Avertissement : If *remember* is checked, the password is stored unencrypted in QGIS registry.

Temporary directory

Tool symbol and name	Description
	select a new temporary directory where temporary files are saved during the processing ; the path to the current temporary directory is displayed ; default is a system temporary directory
	reset to default temporary directory

External programs

Some tools require external programs to perform the processing.

Tool symbol and name	Description
GDAL installation directory	enter the path to the GDAL directory containing tools such as gdal_translate and gdalwarp (e.g. `/usr/bin`) ; this parameter is usually not required

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

Overlapping signatures (belonging to different classes or macroclasses) are highlighted in orange in the table *Signature list* (page 113) ; the overlapping check is performed considering *MC ID* or *C ID* according to the setting *Use* *MC ID* *C ID* in *Classification* (page 74). Overlapping signatures sharing the same *ID* are not highlighted.

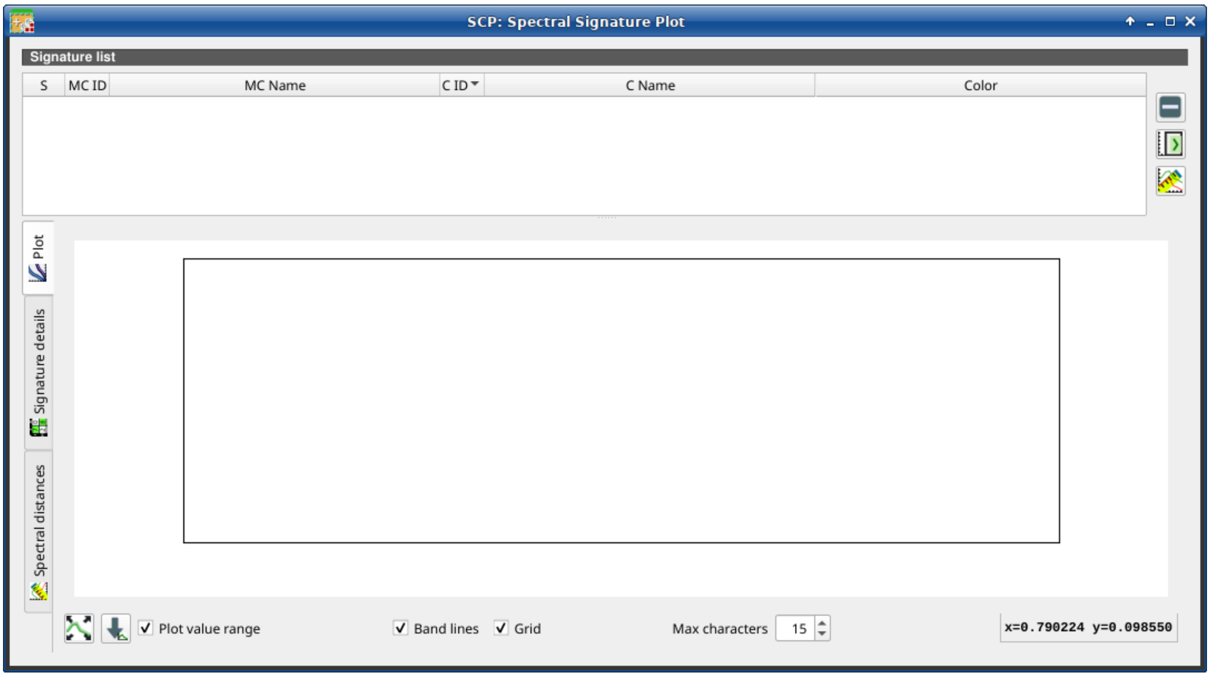


Fig. 50 – *Spectral Signature Plot*

3.5.1 Signature list

The *Signature list* is a table that includes the spectral signatures added from the *SCP dock* (page 31).

S	MC ID	MC Name	C ID	C Name	Color
checkbox field ; if checked, the spectral signature is displayed in the plot	signature Macroclass ID	signature Macroclass Name	signature Class ID	signature Class Name	signature color ; also, the combination *MC ID-C ID* is displayed in case of overlap with other signatures

The following tools are available.

Tool symbol and name	Description
	remove highlighted signatures from this list
	add highlighted spectral signatures to *ROI & Signature list* (page 36)
	calculate the spectral distances of spectral signatures displayed in the plot ; distances are reported in the tab *Spectral distances* (page 114)

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.

The following tools are available.

Tool symbol and name	Description
	automatically fit the plot to data
	save the plot image to file (available formats are `.jpg`, `.png`, and `.pdf`)
Plot value range	if checked, plot the value range for each signature with a 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

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 *Signature list* (page 113)), which are useful for assessing ROI separability (see *Spectral Distance* (page 141)).

The following spectral distances are calculated :

— *Spectral Angle* (page 141) : range [0 = identical, 90 = different] ; useful in particular for *Spectral Angle Mapping* (page 137) classifications
— *Euclidean Distance* (page 142) : useful in particular for *Minimum Distance* (page 135) classifications
— *Bray-Curtis Similarity* (page 142) : range [0 = different, 100 = identical] ; useful in general

Values are displayed in red if signatures are particularly similar.

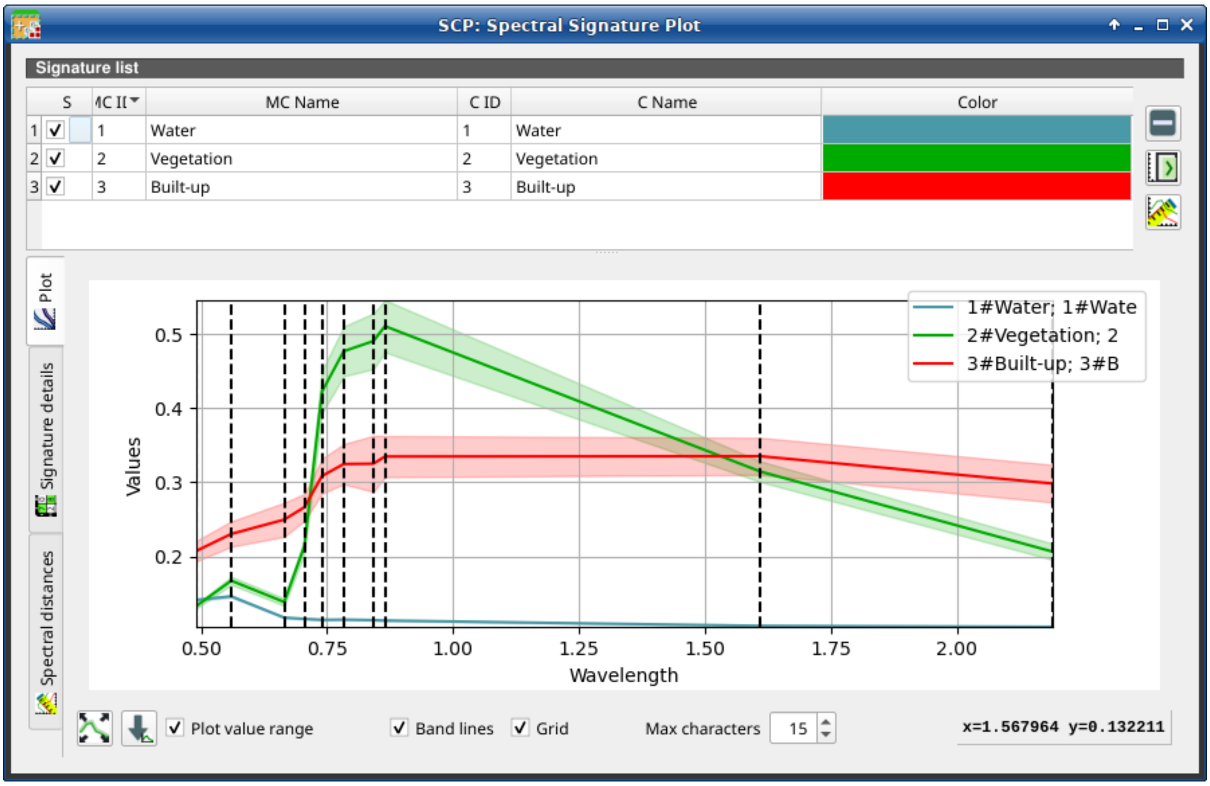


FIG. 51 – *Spectral Signature : Example of plot*

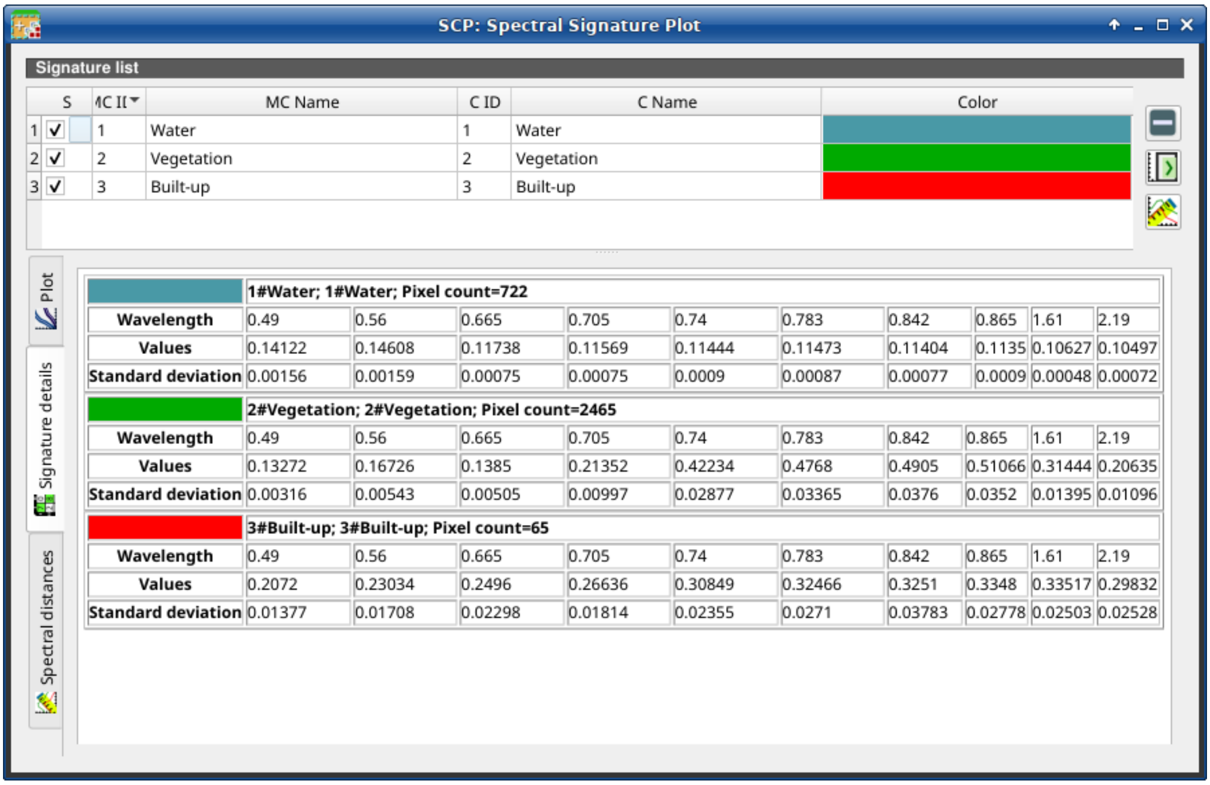


FIG. 52 – *Spectral Signature : Example of signature details*

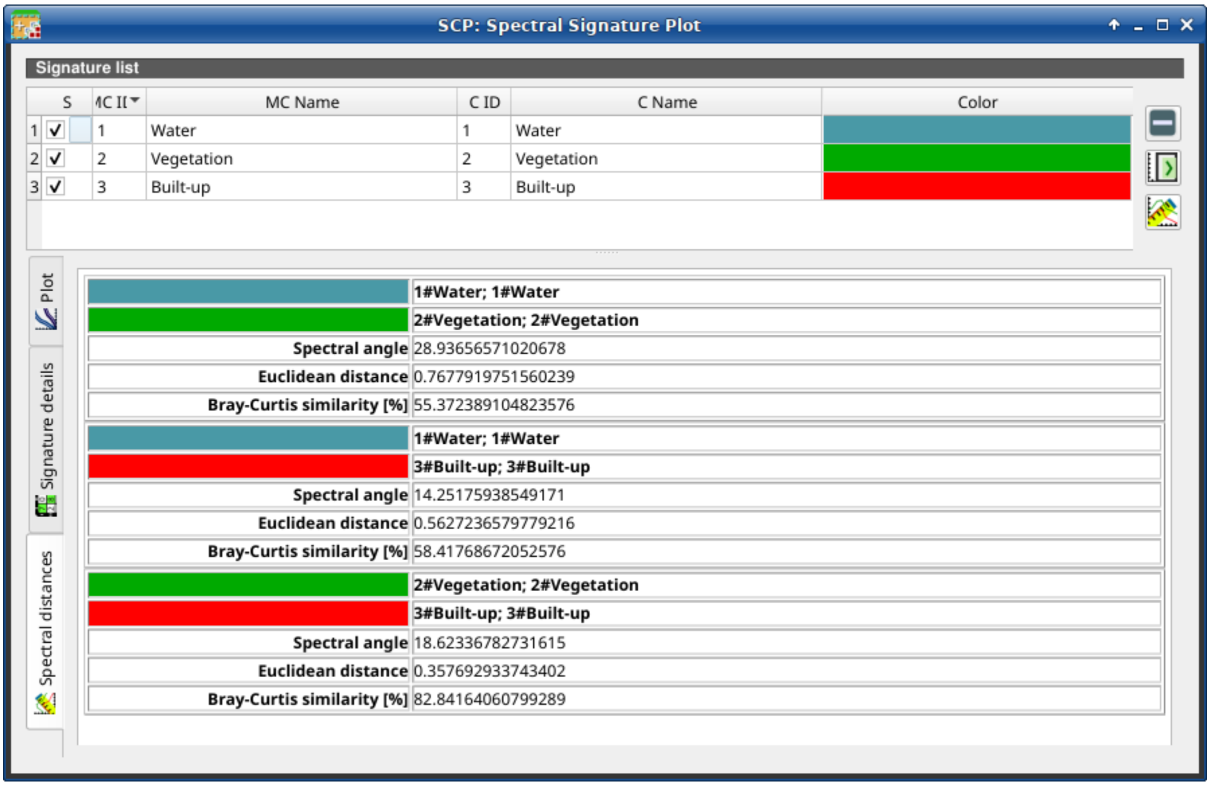


FIG. 53 – *Spectral Signature : Example of spectral distances*

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.

The functions are described in detail in the following paragraphs.

3.6.1 Scatter list

The *Scatter list* is a table that includes the spectral signatures added from the *SCP dock* (page 31).

S	MC ID	MC Name	C ID	C Name	Color
checkbox field ; if checked, the spectral signature is displayed in the plot	signature Macroclass ID	signature Macroclass Name	signature Class ID	signature Class Name	signature color

The following tools are available.

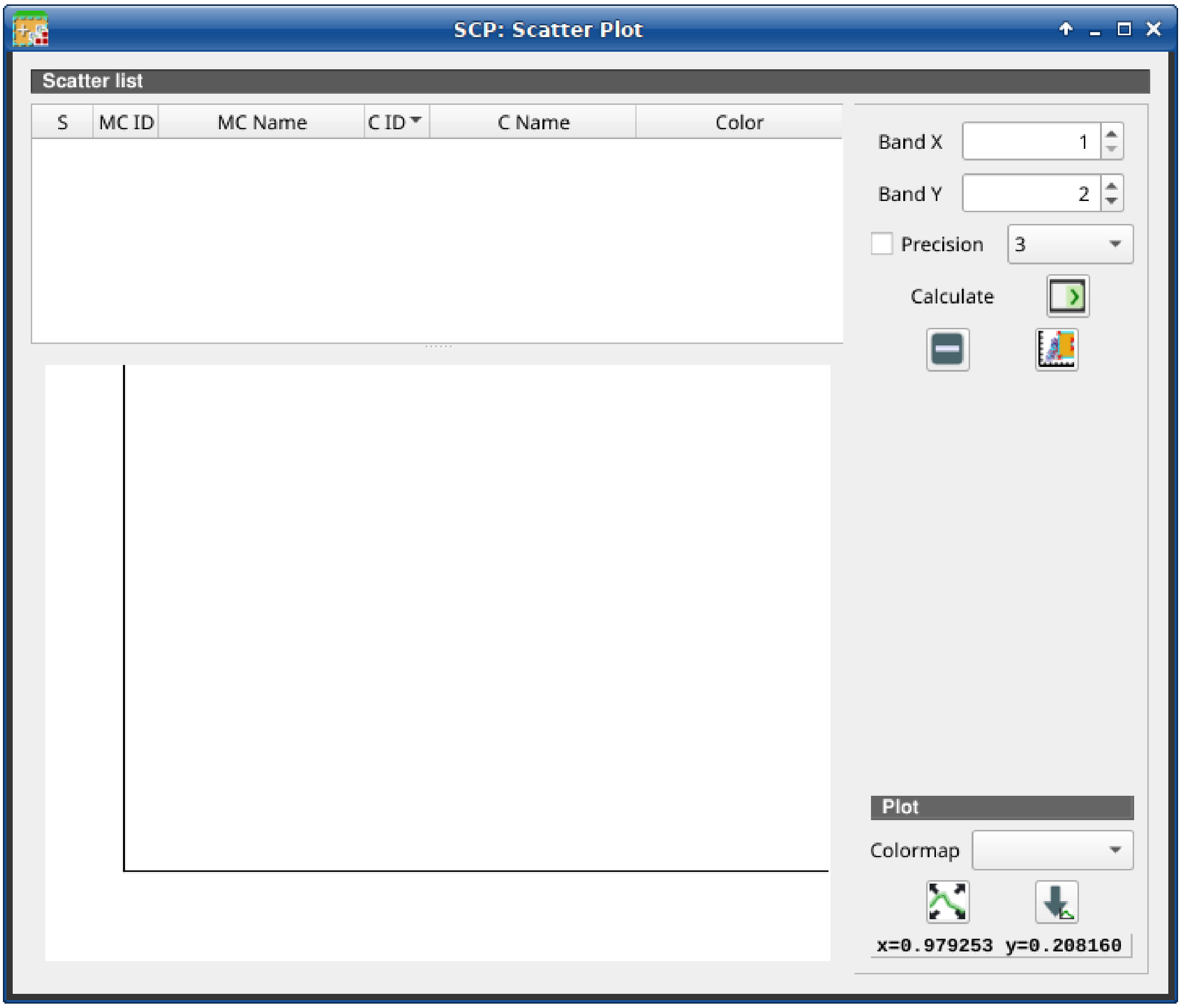


FIG. 54 – *Scatter Plot*

Tool symbol and name	Description
Band X	X band of the plot
Band Y	Y band of the plot
	remove highlighted signatures from this list
	add highlighted spectral signatures to *ROI & Signature list* (page 36)
Precision	use custom precision for calculation (precision should be selected according significant digits) : * 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 41))

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

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.

Tool symbol and name	Description
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

3.7 Integration in QGIS Processing

Several *SCP* tools can be accessed from the QGIS Processing Toolbox, and can be used to create models. The tools are available in the menu *Semi-Automatic Classification Plugin*.

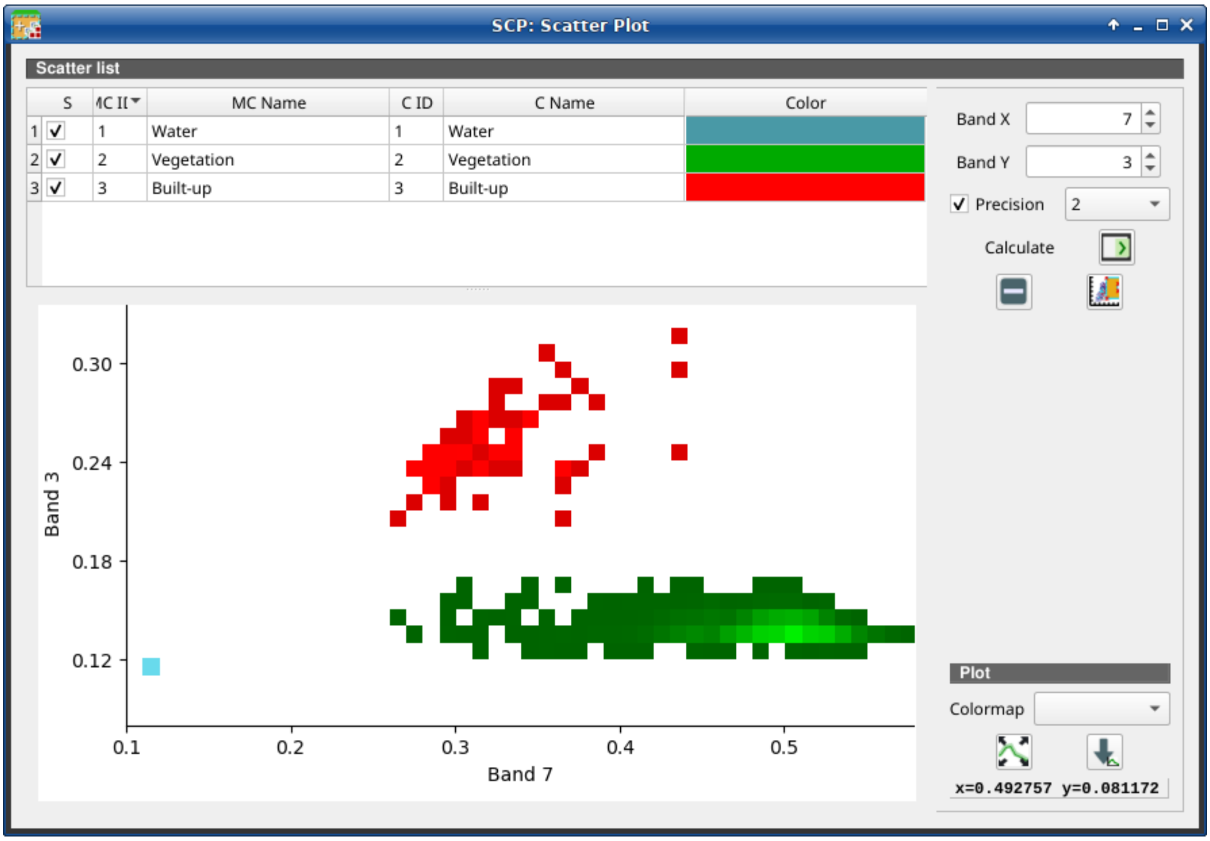
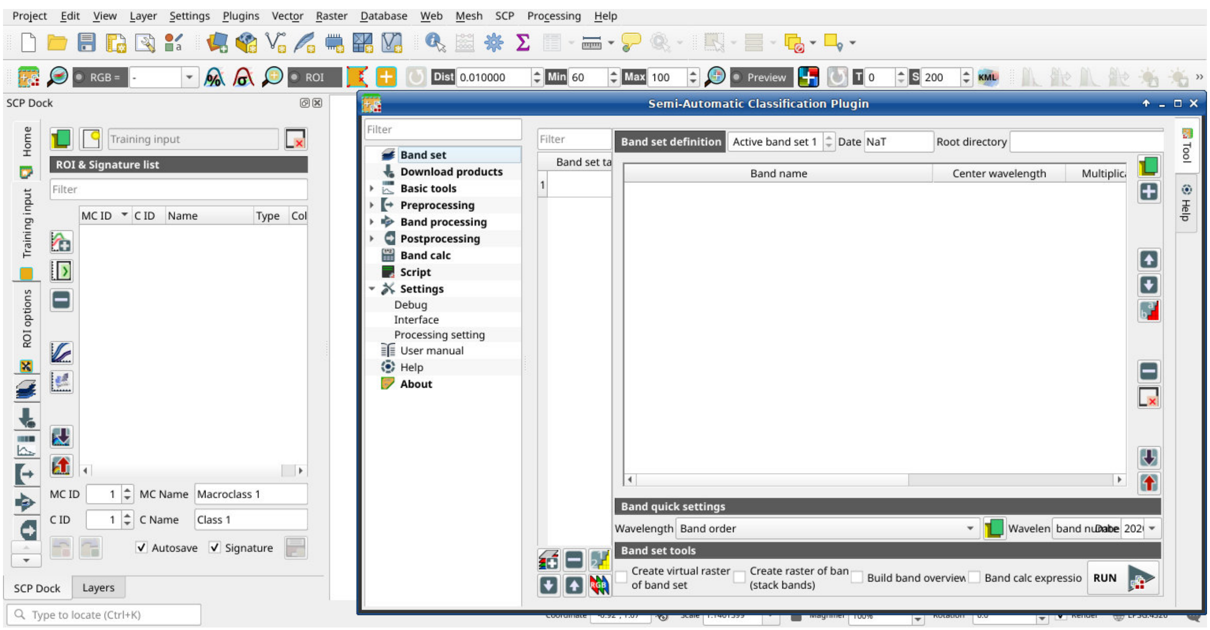


Fig. 55 – *Example Scatter Plot*



The functions described in the following paragraphs use these conventions :

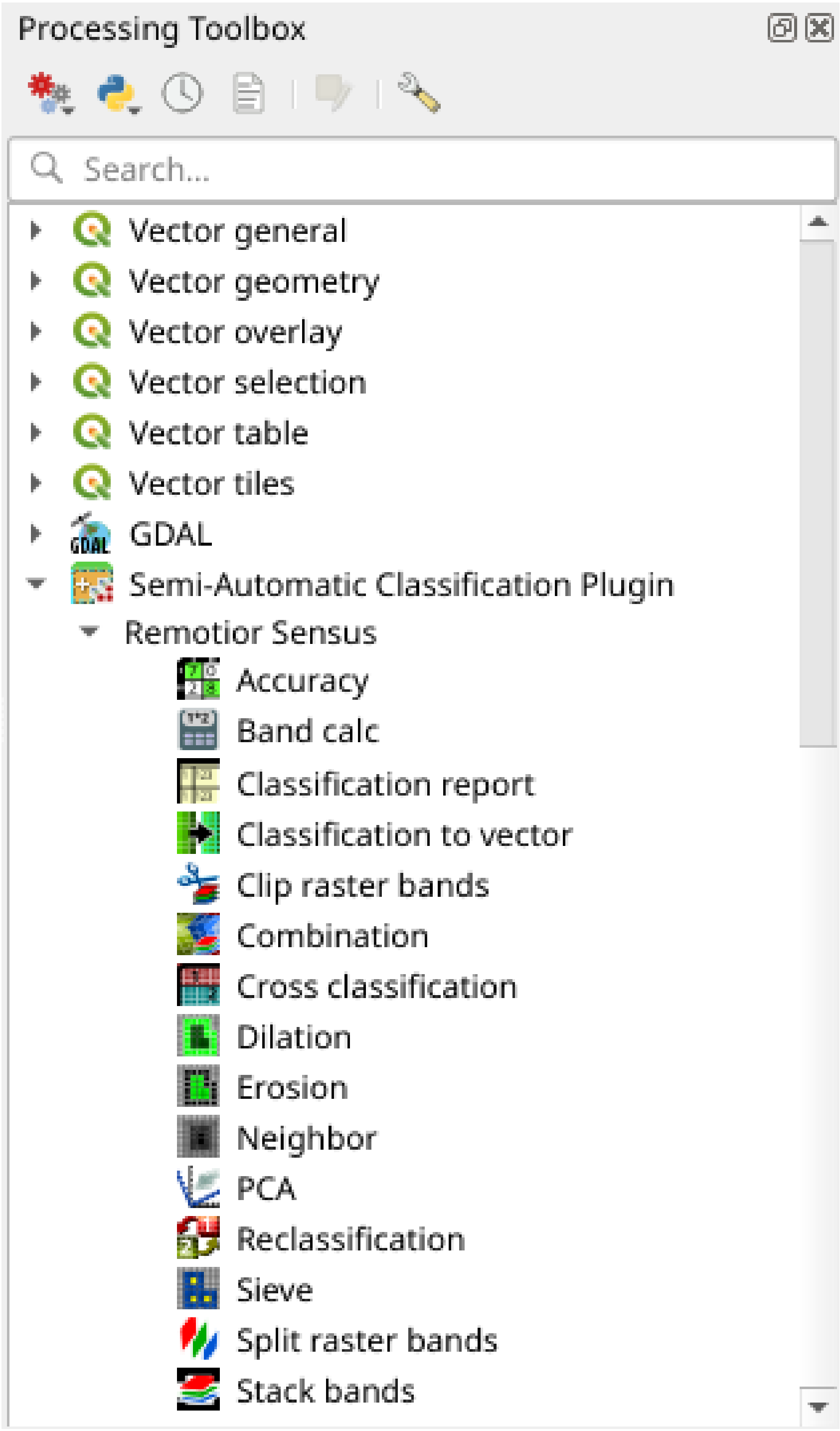


FIG. 56 – *Integration in QGIS Processing Toolbox*

	Input date
	Input text
	List
	Input number
	Optional
	Configuration stored in the active project of QGIS
	Configuration stored in QGIS registry
	Slider
	Table

CHAPITRE 4

Brief Introduction to Remote Sensing

4.1 Basic Definitions

This chapter provides basic definitions about GIS and remote sensing.

4.1.1 GIS definition

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

4.1.2 Remote Sensing definition

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

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

The **electromagnetic spectrum** is « the system that classifies, according to wavelength, all energy (from short cosmic to long radio) that moves, harmonically, at the constant velocity of light » (NASA, 2013). Passive sensors measure energy from the optical regions of the electromagnetic spectrum : visible, near infrared (i.e. IR), short-wave IR, and thermal IR (see Figure *Electromagnetic-Spectrum* (page 125)).

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.

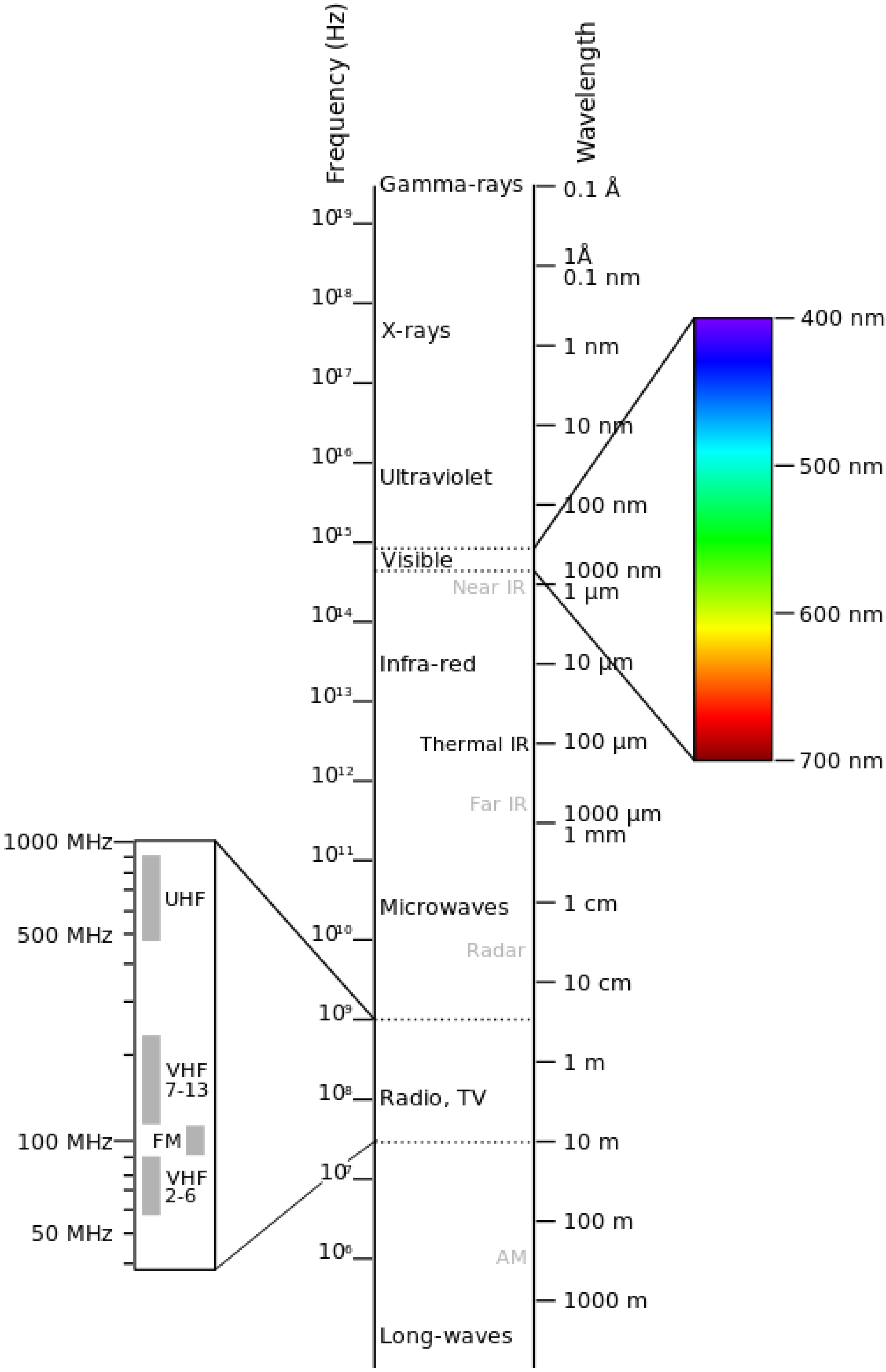


FIG. 1 – *Electromagnetic-Spectrum*
`by Victor Blacus (SVG version of File:Electromagnetic-Spectrum.png)`
`[CC-BY-SA-3.0 (http://creativecommons.org/licenses/by-sa/3.0)]`
`via Wikimedia Commons`
`http://commons.wikimedia.org/wiki/File%3AElectromagnetic-Spectrum.svg`

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 126)) ; each material has a unique signature, therefore it can be used for material classification (NASA, 2013).

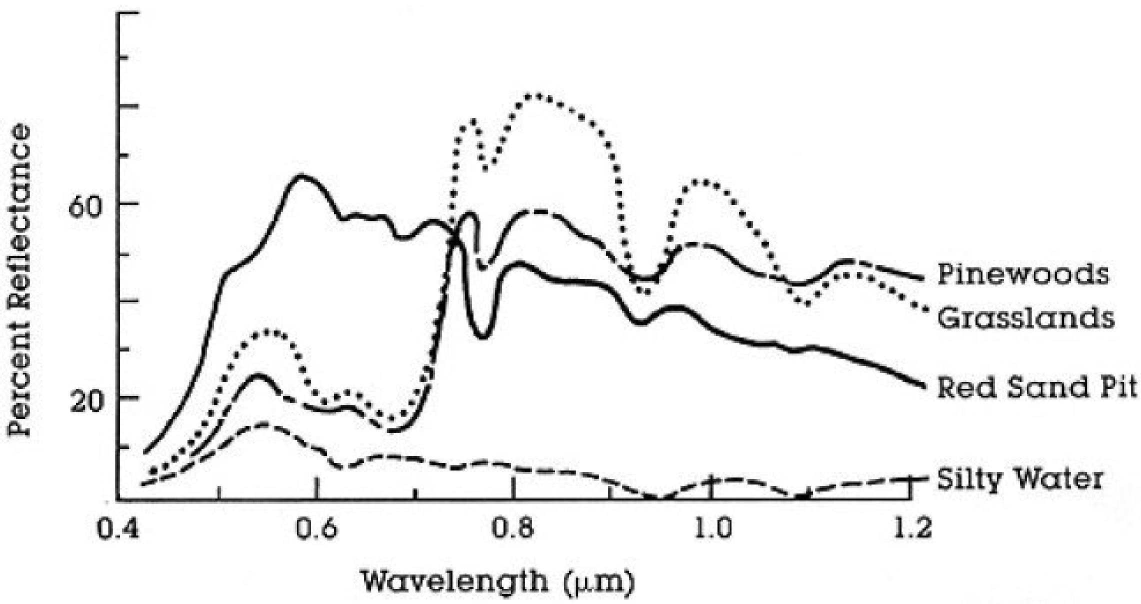


FIG. 2 – *Spectral Reflectance Curves of Four Different Targets*
(from NASA, 2013)

4.1.6 Land Cover

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

4.2 Multispectral satellites

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

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 m with a swath width of 1,270km and 300m spatial resolution (ESA, 2013). The revisit time is about 2 days.

Sentinel-3 Bands

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

4.2.4 ASTER Satellite

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

ASTER Bands

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

4.2.5 MODIS Products

The **MODIS** (Moderate Resolution Imaging Spectroradiometer) is an instrument operating on the Terra and Aqua satellites launched by NASA in 1999 and 2002 respectively. Its temporal resolutions allows for viewing the entire Earth surface every one to two days, with a swath width of 2,330km. Its sensors measure 36 spectral bands at three spatial resolutions : 250m, 500m, and 1,000m (see https://lpdaac.usgs.gov/dataset_discovery/modis).

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.

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.

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.

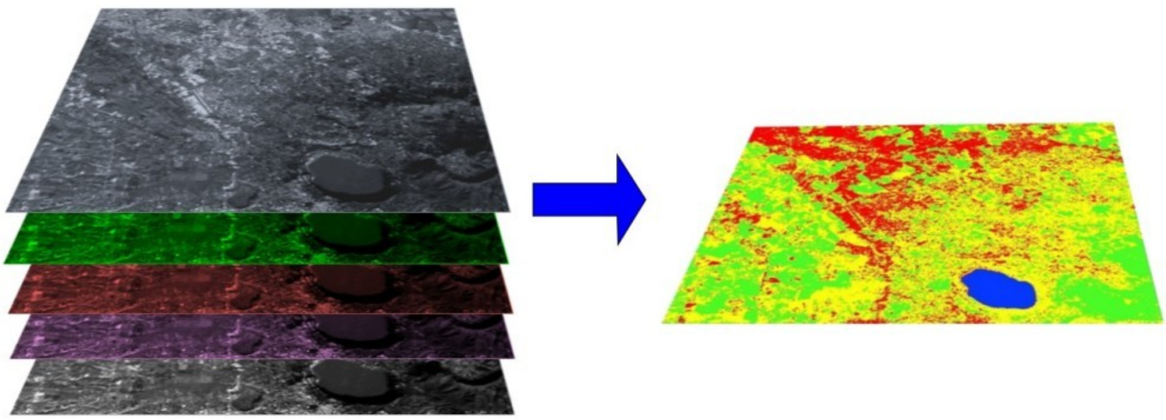


FIG. 3 – *A multispectral image processed to produce a land cover classification*
`(Landsat image provided by USGS)`

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 133) 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).

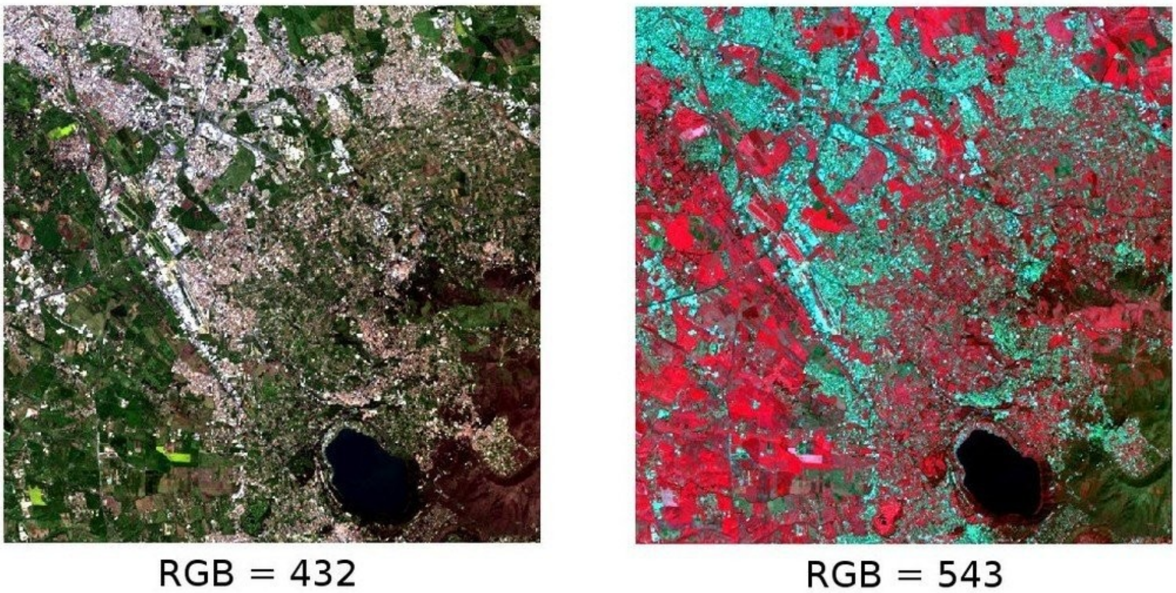


FIG. 4 – *Color composite of a Landsat 8 image*
`Data available from the U.S. Geological Survey`

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 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 134) 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).

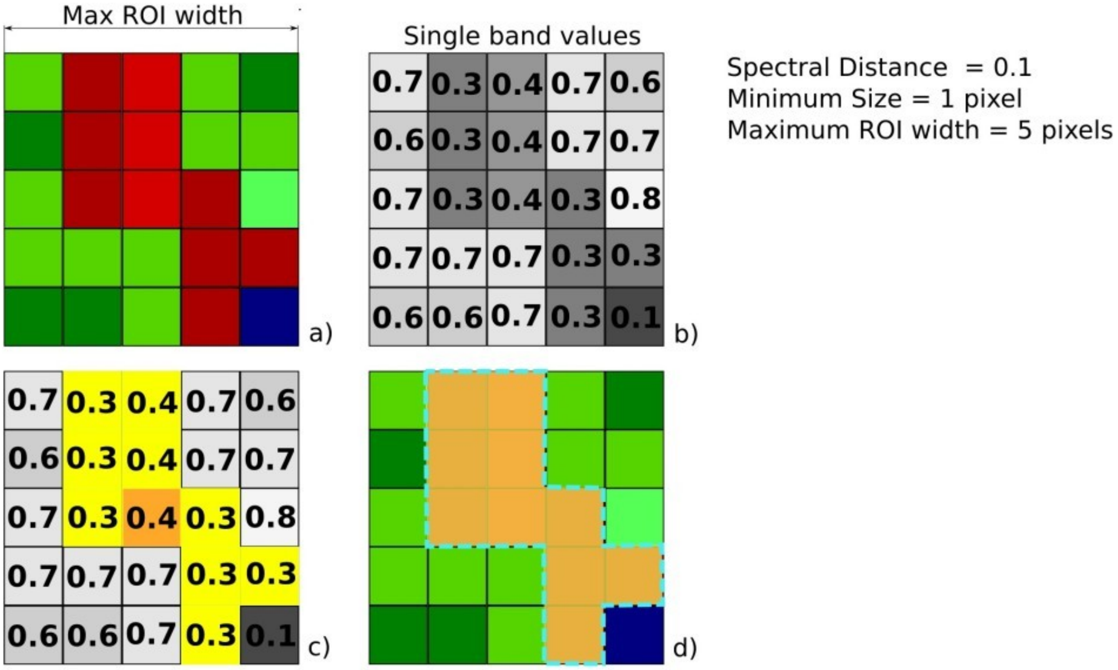


FIG. 5 – *Region growing example*

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

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 135).

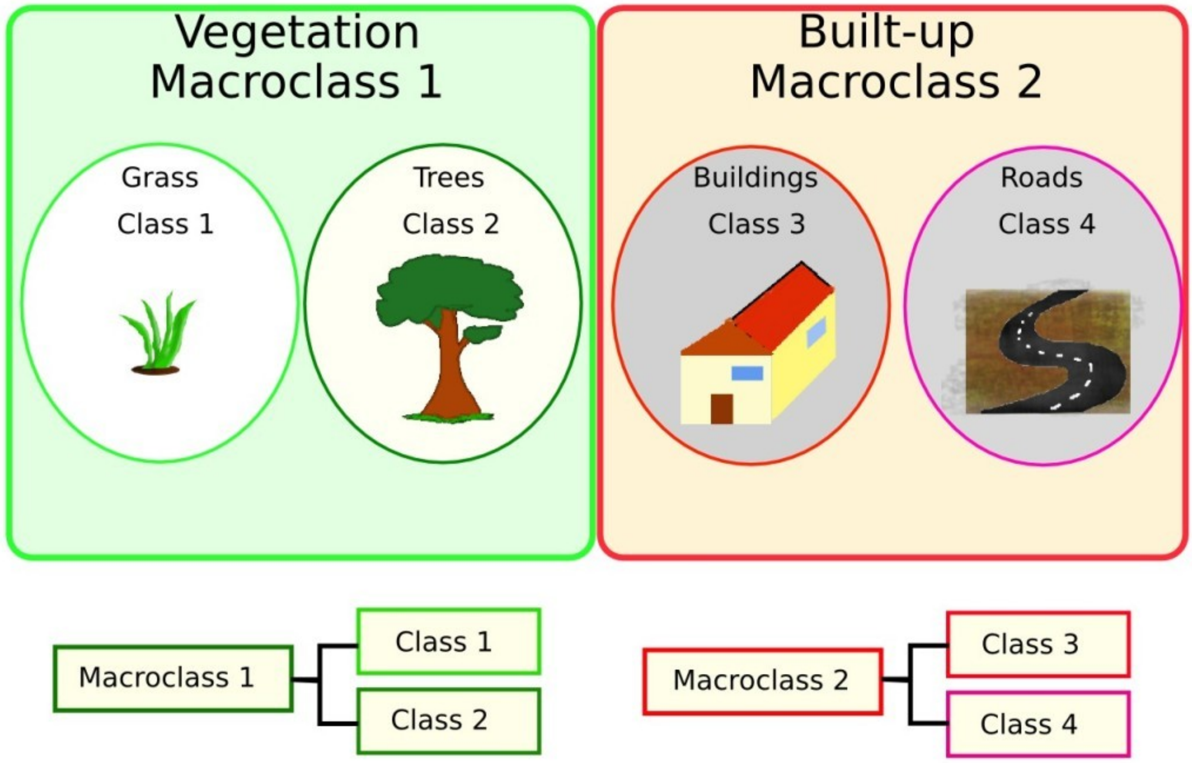


FIG. 6 – *Macroclass example*

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 ;
- 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 :

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

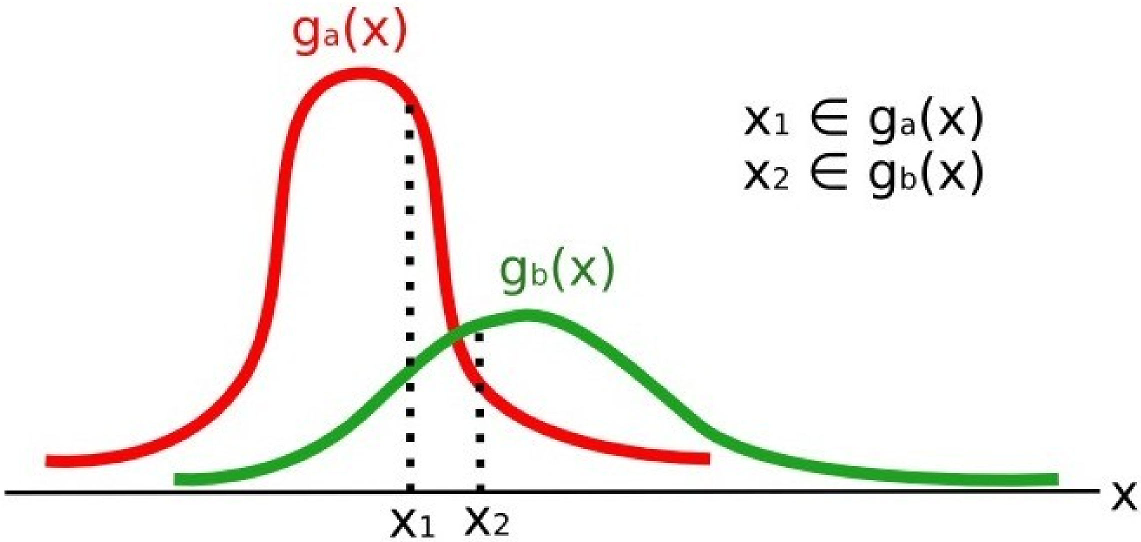


FIG. 7 – *Maximum Likelihood example*

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 135).

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) :

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

Where :

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

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

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

where :

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

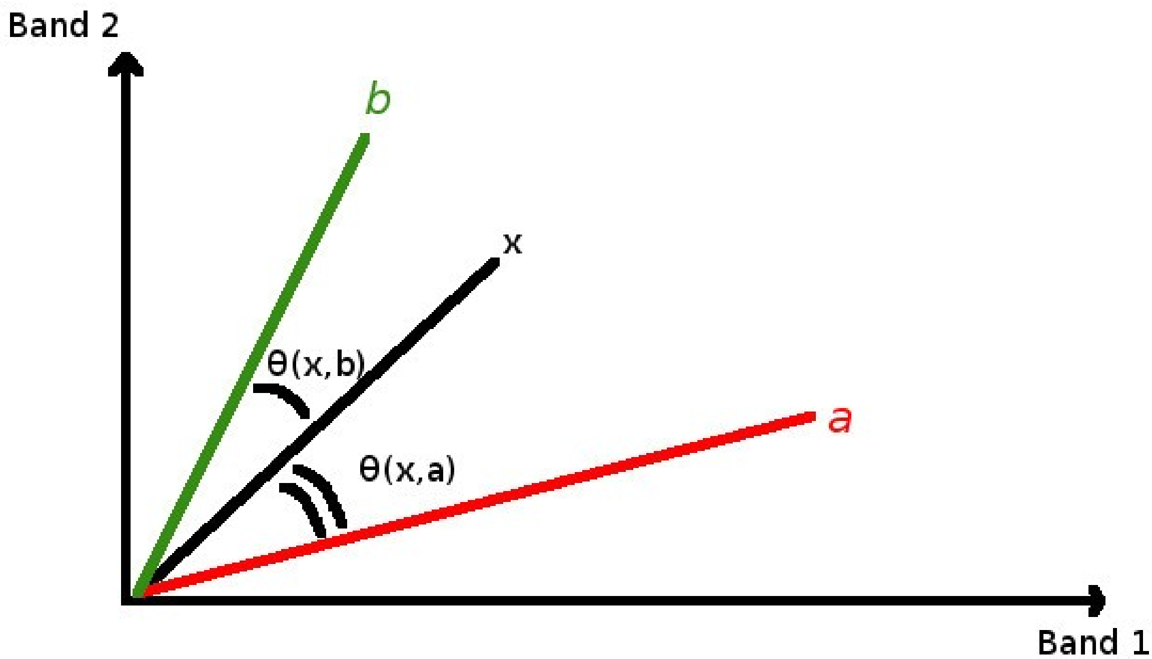


FIG. 8 – *Spectral Angle Mapping example*

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

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

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

Parallelepiped Classification

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

Land Cover Signature Classification

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 135), *Maximum Likelihood* (page 136), *Spectral Angle Mapping* (page 137)) 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 .

This is similar to *Parallelepiped Classification* (page 138), 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 139) the spectral ranges of three classes (g_a, g_b, and g_c) are displayed ; the colored lines inside the ranges (i.e. semi-transparent area) represent the spectral signatures of pixels that defined the upper and lower bounds of the respective ranges. Pixel p_1 (dotted line) belongs to class g_b because the spectral signature thereof is completely inside the range of class g_b (in the upper limit) ; pixel p_2 (dashed line) is unclassified because the spectral signature does not fall completely inside any range ; pixel p_3 (dotted line) belongs to class g_a.

It is worth noticing that these spectral thresholds can be applied to any spectral signature, regardless of spectral characteristics thereof ; this function can be very useful for separating similar spectral signatures that differ only in one band, defining thresholds that include or exclude specific signatures. In fact, classes are correctly separated if the spectral ranges thereof are not overlapping at least in one band. Of course, even if spectral regions are overlapping, chances are that no pixel will fall inside the overlapping region and be misclassified ; which is the upper (or lower) bound of a range do not imply the existence, in the image, of any spectral signature having the maximum (or minimum) range values for all the bands (for instance pixel p_1 of figure *Plot of spectral ranges* (page 139) 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.

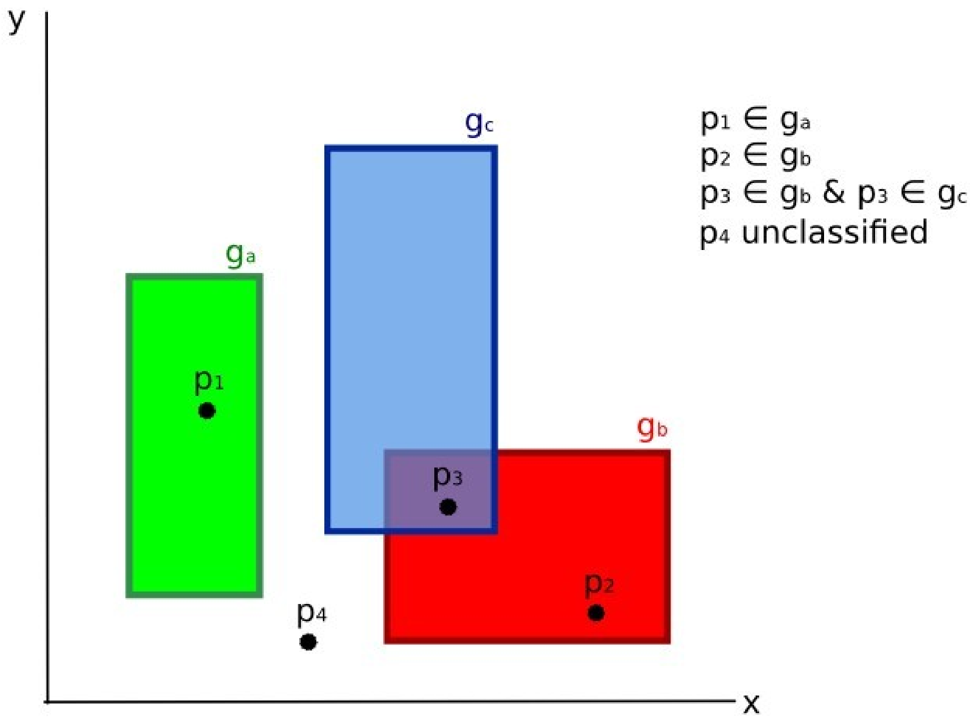


Fig. 9 – *Land cover signature classification*

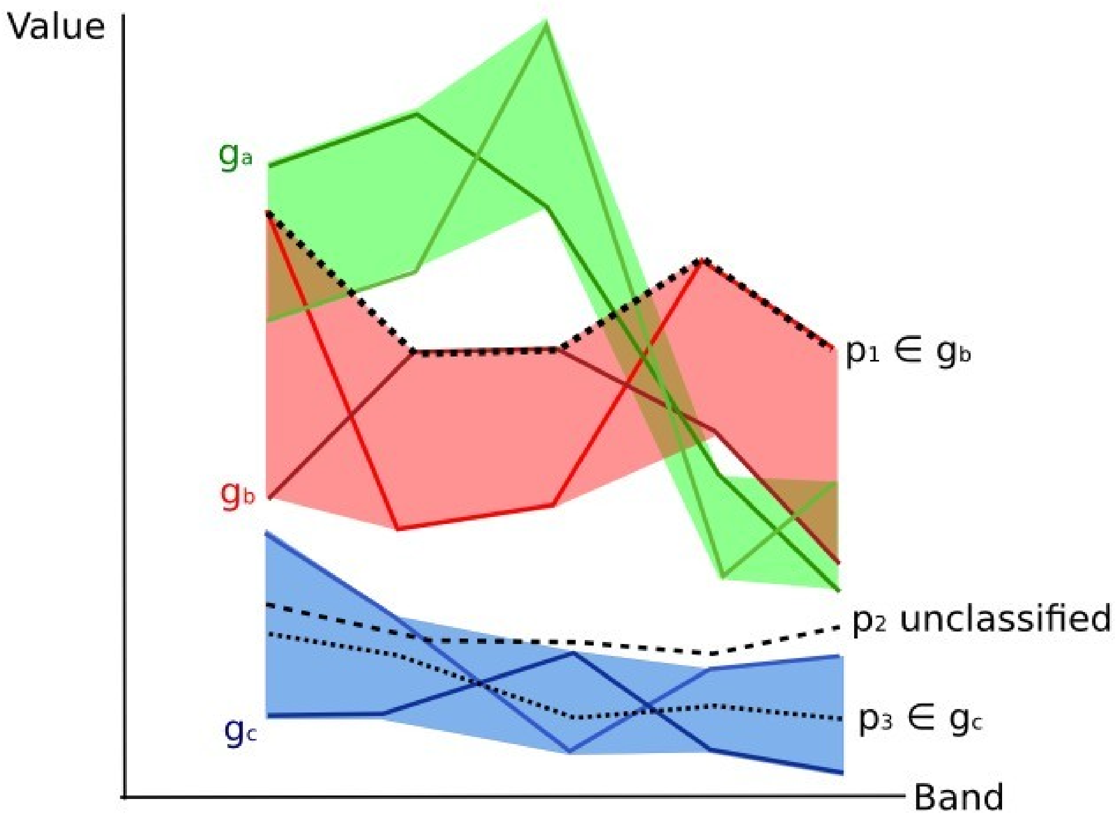


Fig. 10 – *Plot of spectral ranges*

Algorithm raster

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

In general, an algorithm raster is produced for every spectral signature used as training input. The value of every pixel is the result of the algorithm calculation for a specific spectral signature. Therefore, a pixel belongs to `class X` if the value of the algorithm raster corresponding to `class X` is the lowest in case of *Minimum Distance* (page 135) or *Spectral Angle Mapping* (page 137) (or highest in case of *Maximum Likelihood* (page 136)).

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 44)).

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 133) 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.

Multi-Layer Perceptron

Multi-Layer Perceptron is a supervised classification algorithm that is based on the definition of an artificial neural network. A Multi-Layer Perceptron is made of an input layer, one or more hidden layers (made of a defined number of neurons that are fully connected by non-linear activation functions), and the output layer (also read this documentation

Several parameters can be defined as described here

Support Vector Machine

Support Vector Machine is a supervised classification algorithm that is based on the calculation of hyperplanes in order to separate input data values.

Several parameters can be defined as described at this link

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 136) classifications.

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

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

where :

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

where :

- x = first spectral signature vector ;
- y = second spectral signature vector ;
- 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 137) 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 135) 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 142)), where pixel values correspond to class IDs and each color represent a land cover class.

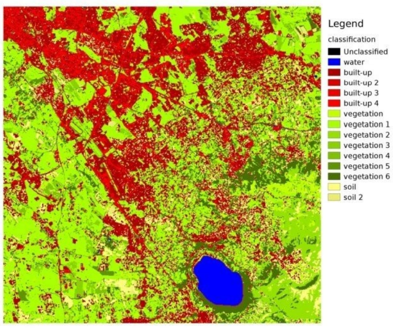


FIG. 11 – *Landsat classification*
Data available from the U.S. Geological Survey

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 133) for highlighting *Land Cover* (page 127) classes, or used as input for *Supervised Classification* (page 132).

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 142) or *Spectral Angle* (page 141)) 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 132) 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 142) or *Spectral Angle* (page 141) 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 142) 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 σmax_i > σ_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 + σmax_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 spectral signatures calculate D_{xy} = *Euclidean Distance* (page 142) 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 147), 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 150).

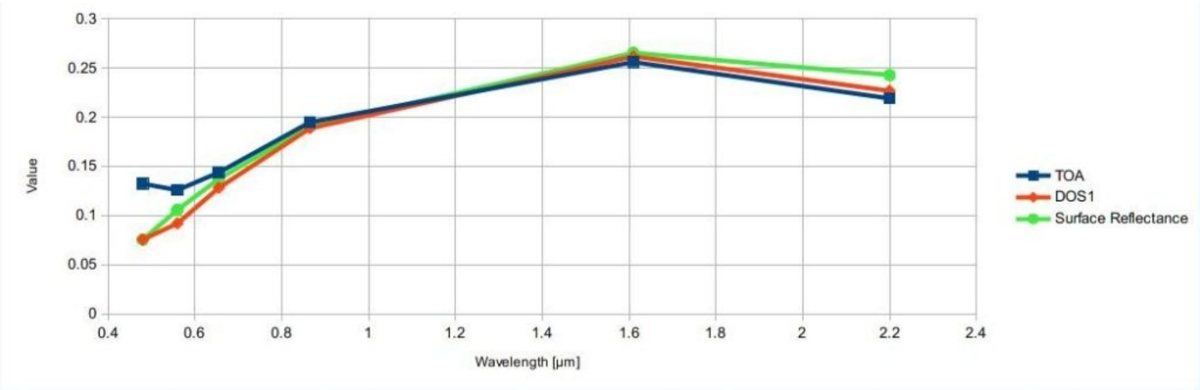


FIG. 13 – *Spectral signatures of a built-up pixel*

`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 127) and *ASTER Satellite* (page 129).

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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CHAPITRE 5

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 : Basic Land Cover Classification

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. Following the video of the tutorial.

https://www.youtube.com/watch?v=7SZDCFXjIbA

5.1.1 Tutorial 1 : Basic 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 123) before following 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 basic steps are :

1. the definition of input data (image bands) in a *Band set* (page 45) ;
2. the creation of a *Training input* (page 33) to collect training areas to train the classification algorith ;
3. the *Classification* (page 74) of input data.

Download the Data

Other tutorials will show how to search and download satellite images within *SCP*. In this tutorial we are going to use a *Sentinel-2 Satellite* (page 128) image, already converted to reflectance and clipped to the study area, downloading a `.zip` file (which contains modified Copernicus Sentinel data 2023).

The study area of this tutorial covers part of the Lake Garda in the Northern Italy. Download the `.zip` file from this link and extract the directory containing the image bands.

Define the Band set and create the Training Input File

We are going to use a subset of *Sentinel-2 Satellite* (page 128) 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

First, we need to define the *Band set* which is the input image for *SCP* classification. Open the tab *Band set* (page 45) clicking the button  in the *SCP menu* (page 29) or the *SCP dock* (page 31).

Click the button  to select the `.tif` files from the extracted directory to the *Band set* tab.

Astuce : It is possible to define multiple *Band sets*. It is also possible to add to a *Band set* bands that are already loaded in QGIS. Each *Band set* definition is saved with the QGIS project.

In the table *Band set definition*, we need to order the band names in ascending order and assign the center wavelength to each bands (required for spectral signature calculation). We can do this in one step by selecting *Sentinel-2* in the *Wavelength* list of the *Band quick settings* (page 47).

We can display a *Color Composite* (page 133) of bands : Near-Infrared, Red, and Green.

Astuce : If a *Band set* (page 45) is defined, a temporary virtual raster (named `Virtual Band Set 1`) is created automatically, which allows for the display of a *Color Composite* (page 133).

In the *Working toolbar* (page 41), click the list *RGB=* and select the item `7-3-2` (corresponding to the band numbers in *Band set* (page 45)). You can see that `Virtual Band Set 1` is added to QGIS Layers as multiband image, and the displayed bands correspond to the selected color composite.

Because we selected Near-Infrared, Red, and Green bands, in the map, vegetation is highlighted in red. Selecting the color composite `3-2-1`, natural colors would be displayed.

After *Band set* (page 45) creation, we need to create a *Training input* (page 33) file in order to collect *Training Areas* (page 133) (ROIs) and calculate the *Spectral Signature* (page 126) thereof (which are required to train the classification algorithm).

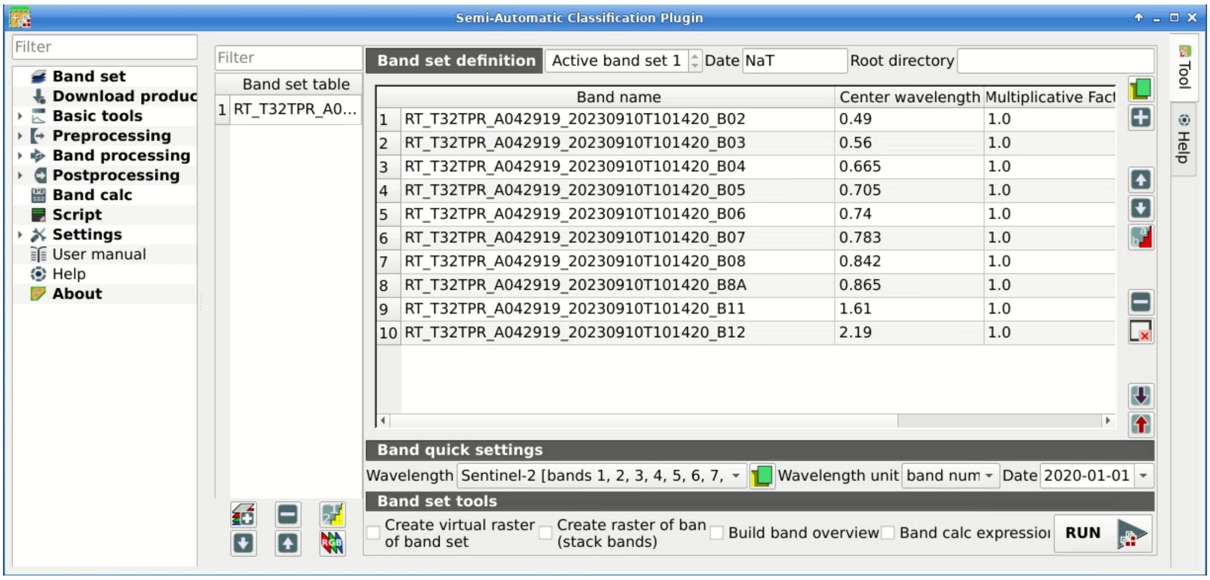


FIG. 1 – *Definition of a band set*

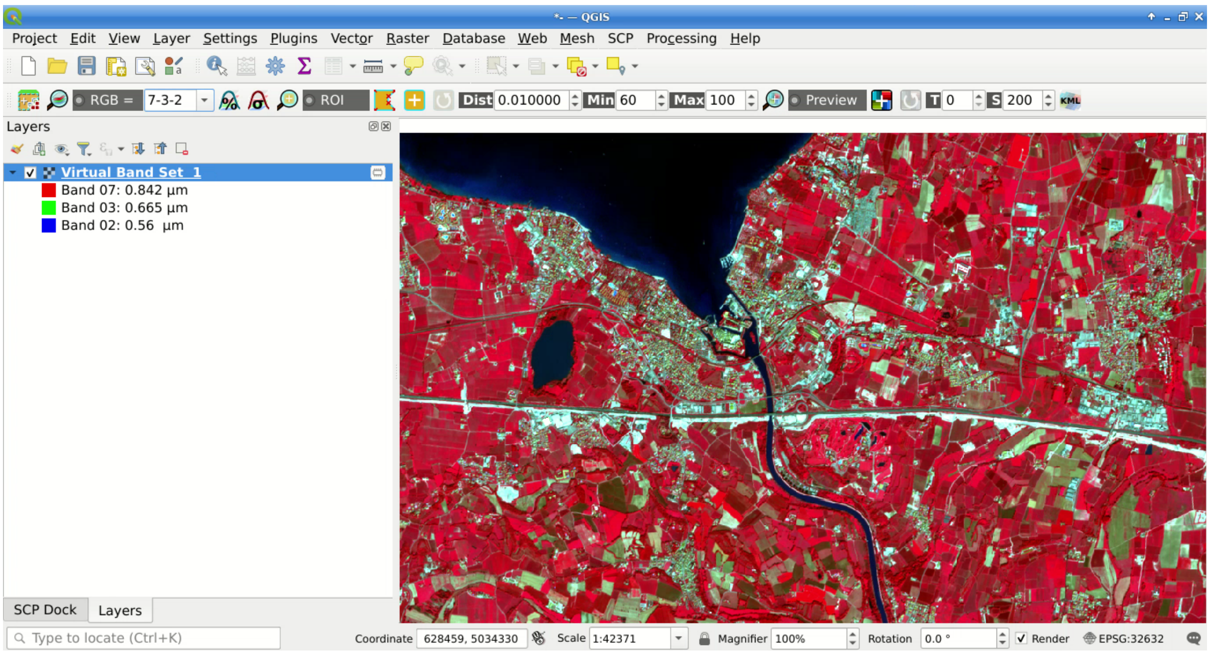


FIG. 2 – *Color composite RGB=7-3-2*

In the *SCP dock* (page 31) select the tab *Training input* (page 33) and click the button to create the *Training input* (define a name such as `training.scpx`).

Astuce : A *Training input* is a `.scpx` file which stores the geometries and the spectral signatures. Once it is created, it is configured with the wavelength properties of the corresponding *Band set*. To use a *Training input* create with a different *Band set*, one should create a new *Training input*, and then import the existing *Training input* with *Import library file* (page 54) .

The path of the file is displayed and a vector is added to QGIS layers with the same name as the *Training input*.

Avertissement : In order to prevent data loss, one should not edit the *Training input* using QGIS vector tools.

Create the ROIs

We are going to create ROIs defining the *Classes and Macroclasses* (page 134). Each ROI is identified by a Class ID (i.e. C ID), and each ROI is assigned to a land cover class through a Macroclass ID (i.e. MC ID).

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

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

Macroclass name	Macroclass ID
Water	1
Built-up	2
Vegetation	3
Soil	4

Astuce : 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 upper left corner of the image which is a water body. To manually create a ROI inside the dark area, click the button in the *Working toolbar* (page 41). 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* (page 33)).

Astuce : 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 sufficiently covers the water area, we can save it to the *Training input* (page 33).

Open the *Training input* (page 33) to define the *Classes and Macroclasses* (page 134) . In the *ROI & Signature list* (page 36) set *MC ID* = 1 and *MC Name* = `Water`; also set *C ID* = 1 and *C Name* = `Lake`. Now click to save the ROI in the *Training input*.

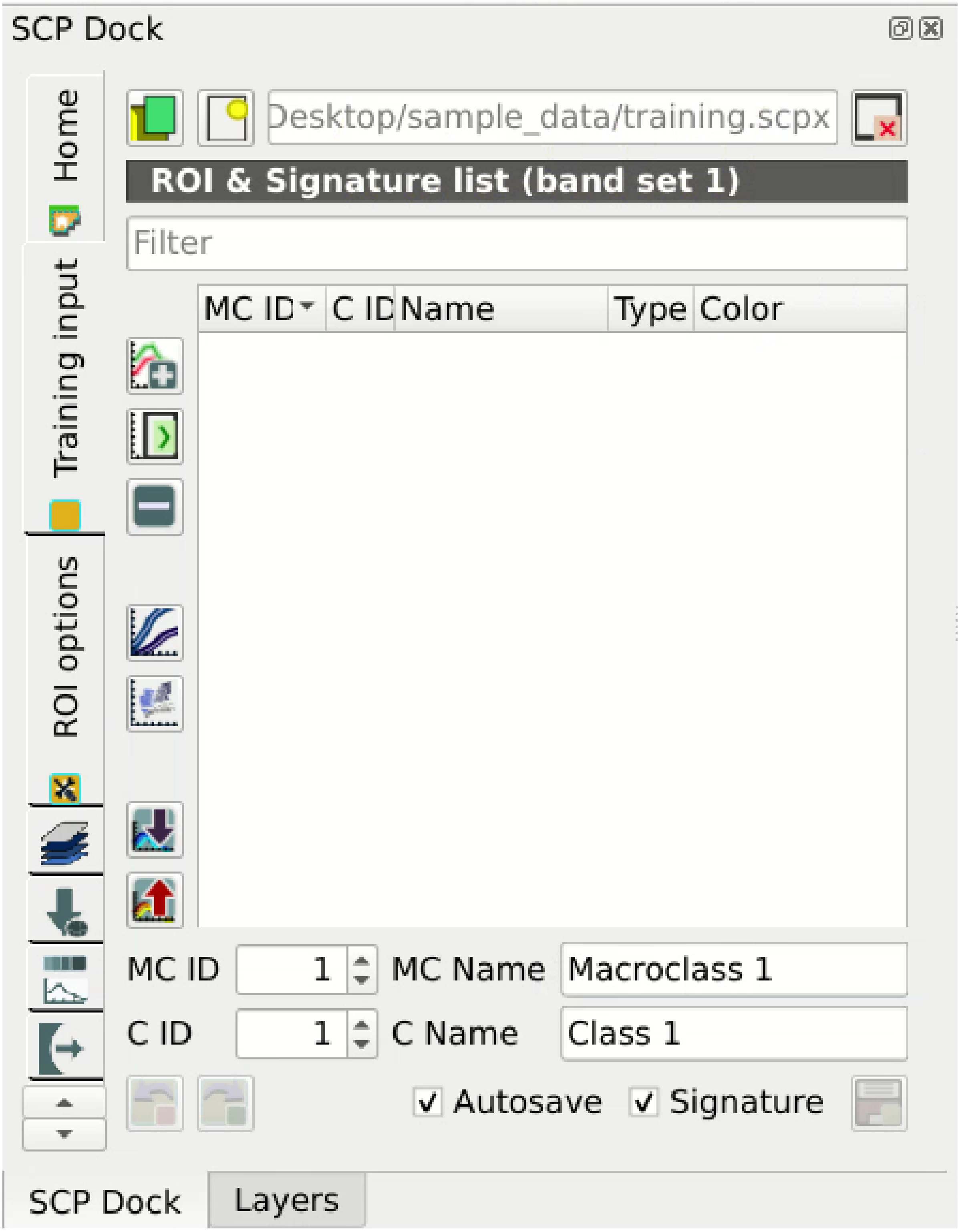


FIG. 3 – *Definition of Training input in SCP*

FIG. 4 – *A temporary ROI created manually*

After a few seconds, the ROI is listed in the *ROI & Signature list* (page 36) and the spectral signature is calculated (because *Signature* is checked).

As you can see, the *C ID* in *ROI & Signature list* (page 36) 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 36) you can notice that the *Type* is *RS* (i.e., ROI and spectral signature), 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 near the center of the image. In *Working toolbar* (page 41) set the *Dist* value to 0.03 . Click the button in the *Working toolbar* (page 41) and click over the light blue area of the map. After a while the orange semi-transparent polygon is displayed over the image.

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

In the *ROI & Signature list* (page 36) 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 36) is automatically increased by 1.

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.

Astuce : It is possible to display the *Spectral signatures* of created ROIs in the *Spectral Signature Plot* (page 113).

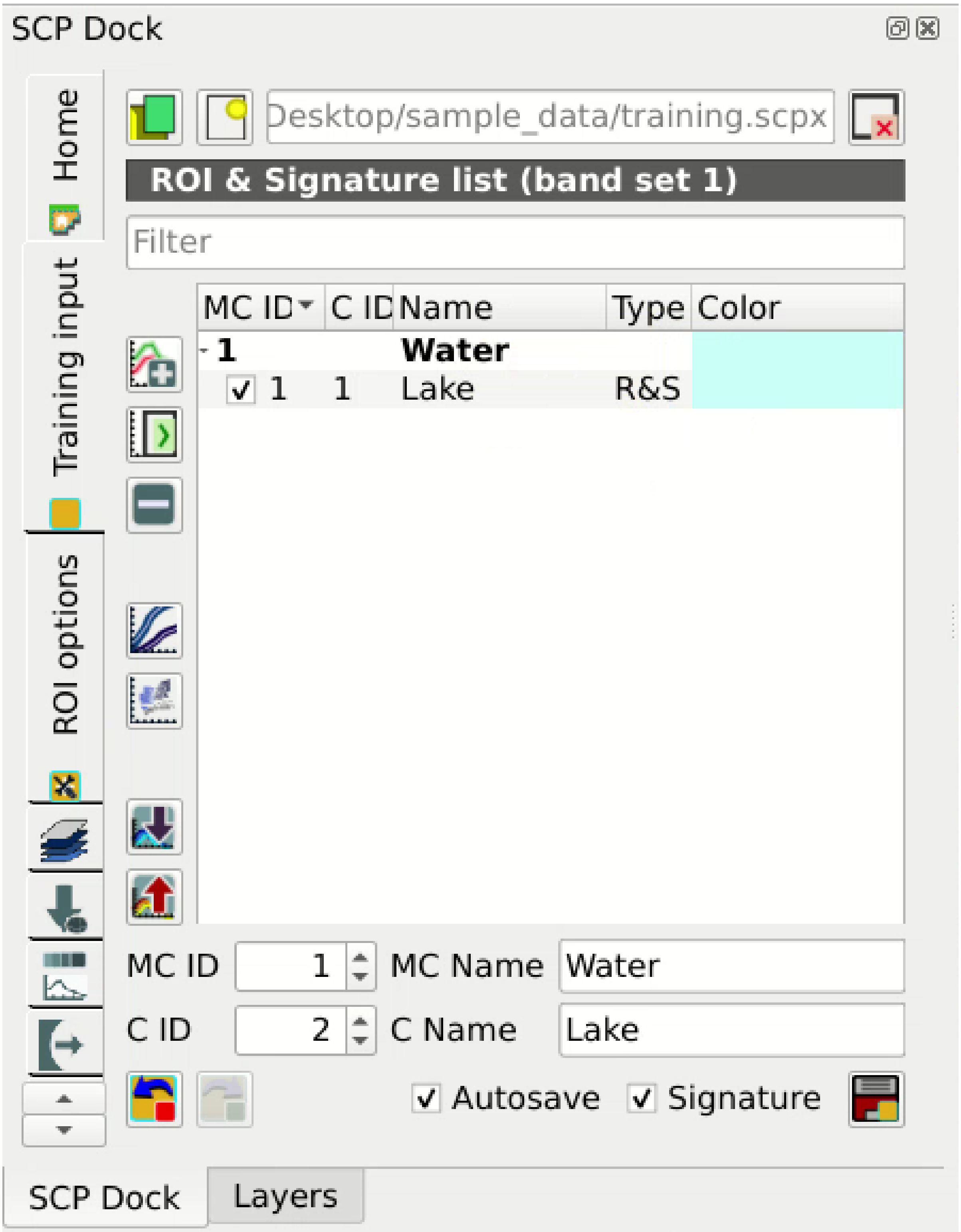


FIG. 5 – *The ROI saved in the Training input*

FIG. 6 – *A temporary ROI created with the automatic region growing algorithm*

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 44) in order to assess the results (influenced by spectral signatures) before the final classification. In case the results are not good, we can collect additional 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 36), 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 36).

Now we need to select the classification algorithm. In this tutorial we are going to use the *Maximum Likelihood* (page 136).

Open the tool *Classification* (page 74) to set the use of classes or macroclasses. Check *Use* *Class ID* and in *Algorithm* (page 75) select the *Maximum Likelihood*. The *input band set* is 1 because it is the number of the band set containing the image (bands) that we want to classify.

In *Classification preview* (page 44) 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 the clicked coordinates.

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 74) check *Use* *MC ID* and click the button in *Classification preview* (page 44). The preview now represents the colors defined for macroclass.

Astuce : It is useful to perform a classification preview every time a ROI (or a spectral signature) is added to the *ROI & Signature list* (page 36), in order to assess the contribution thereof to the classification ; if the ROI causes

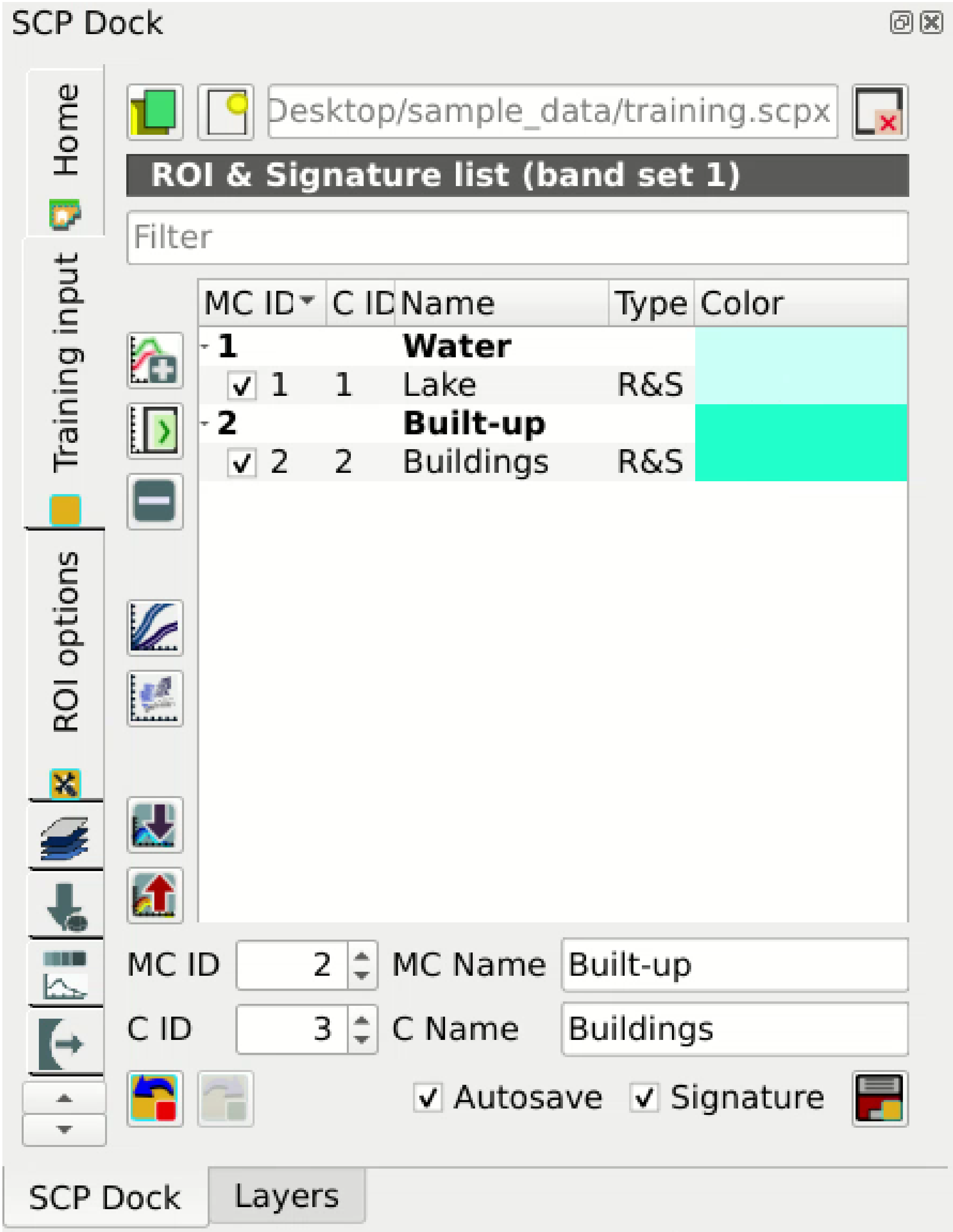


FIG. 7 – *The ROI saved in the Training input*

FIG. 8 – *Vegetation. Color composite RGB = 7-3-2*

Fig. 9 – *Soil. Color composite RGB = 7-3-2*

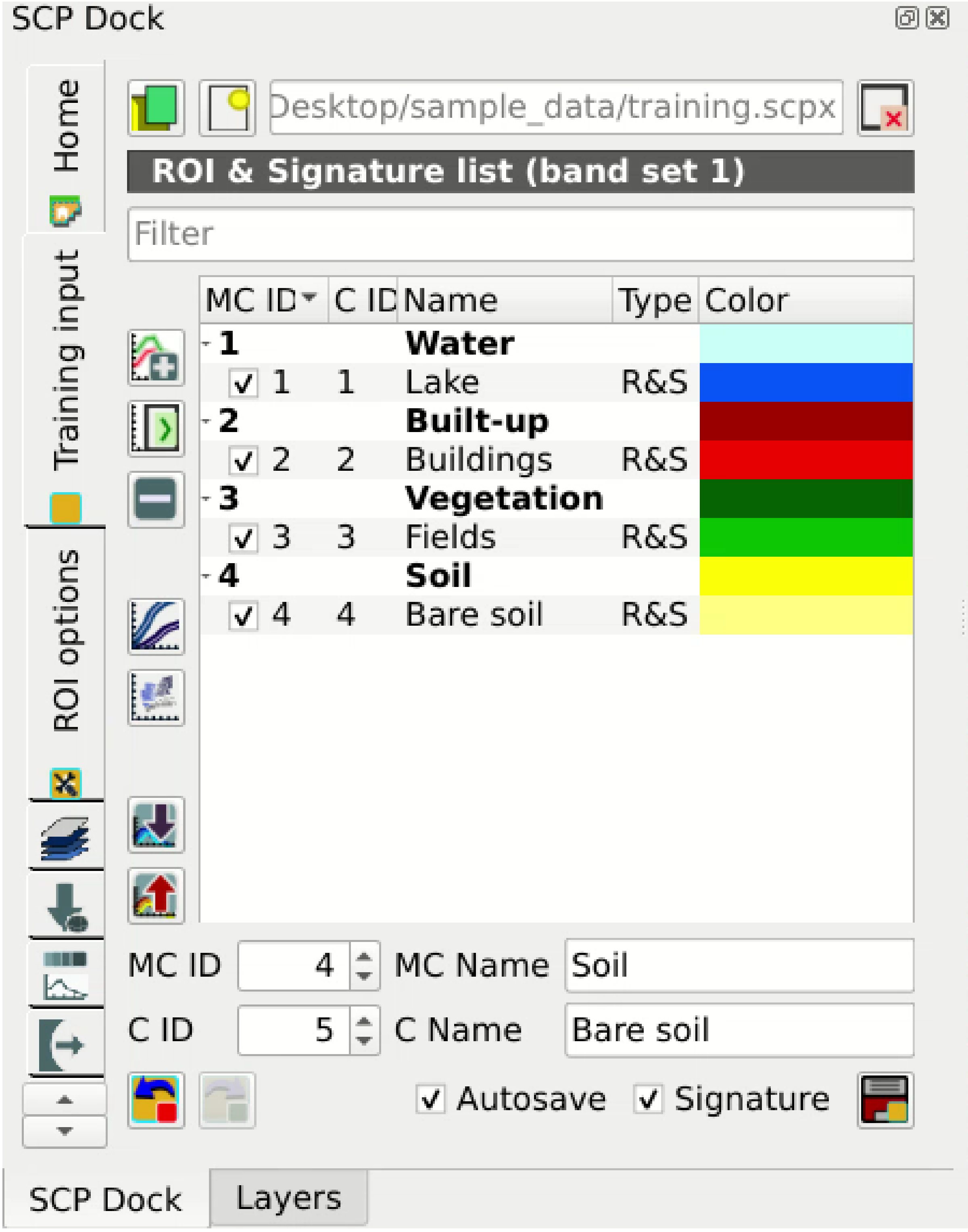


FIG. 10 – *Definition of class colors*

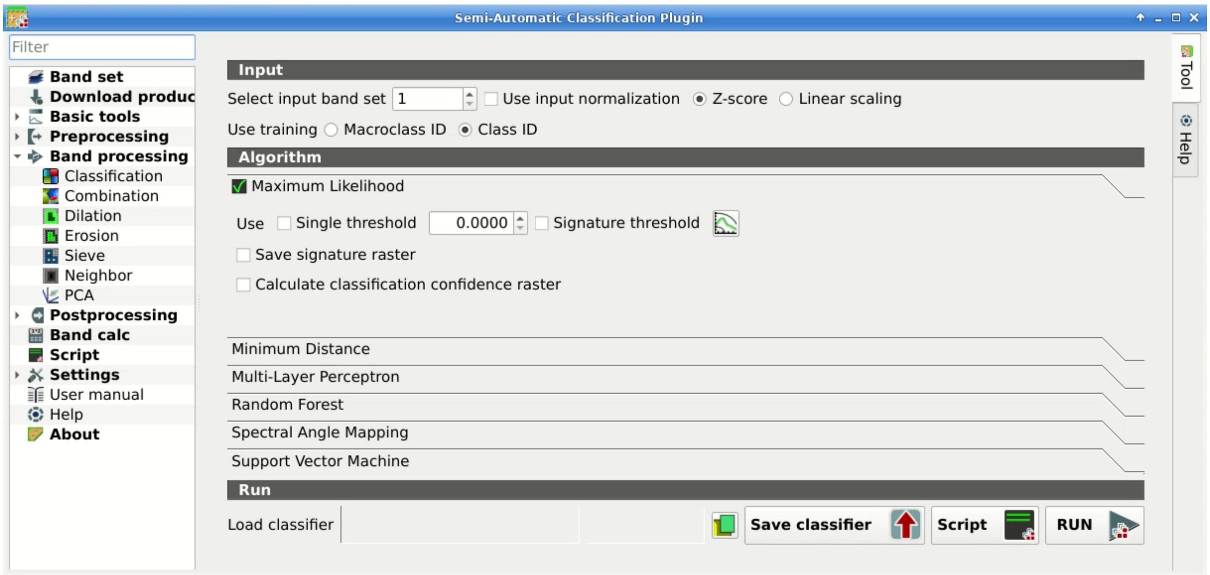


FIG. 11 – *Setting the algorithm and using C ID*

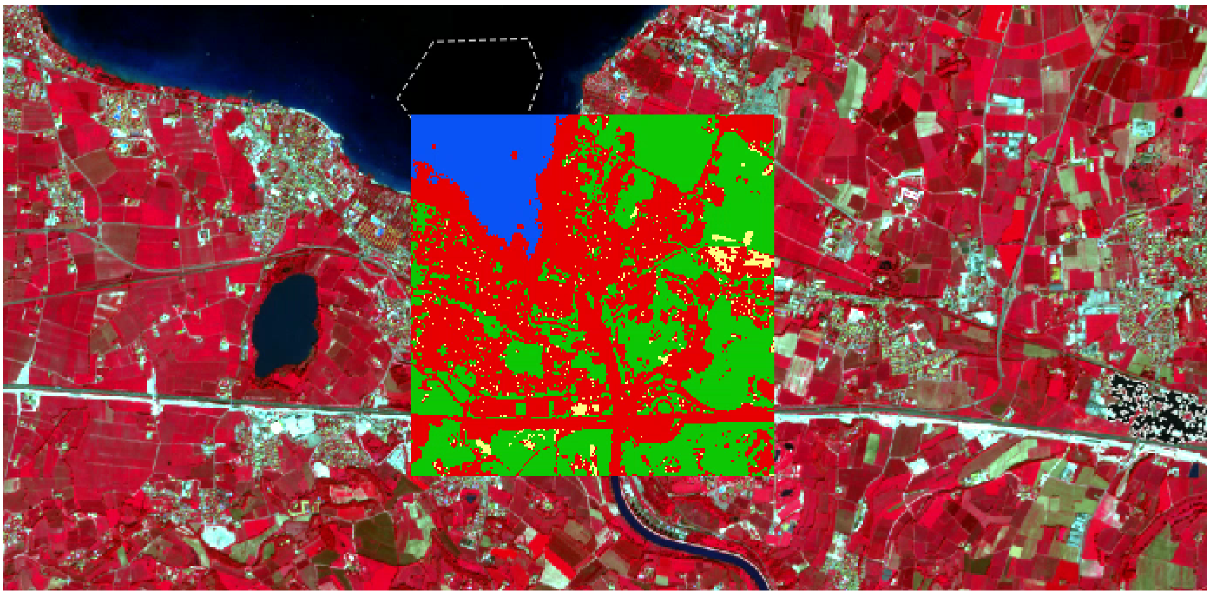


FIG. 12 – *Classification preview displayed over the image using C ID*

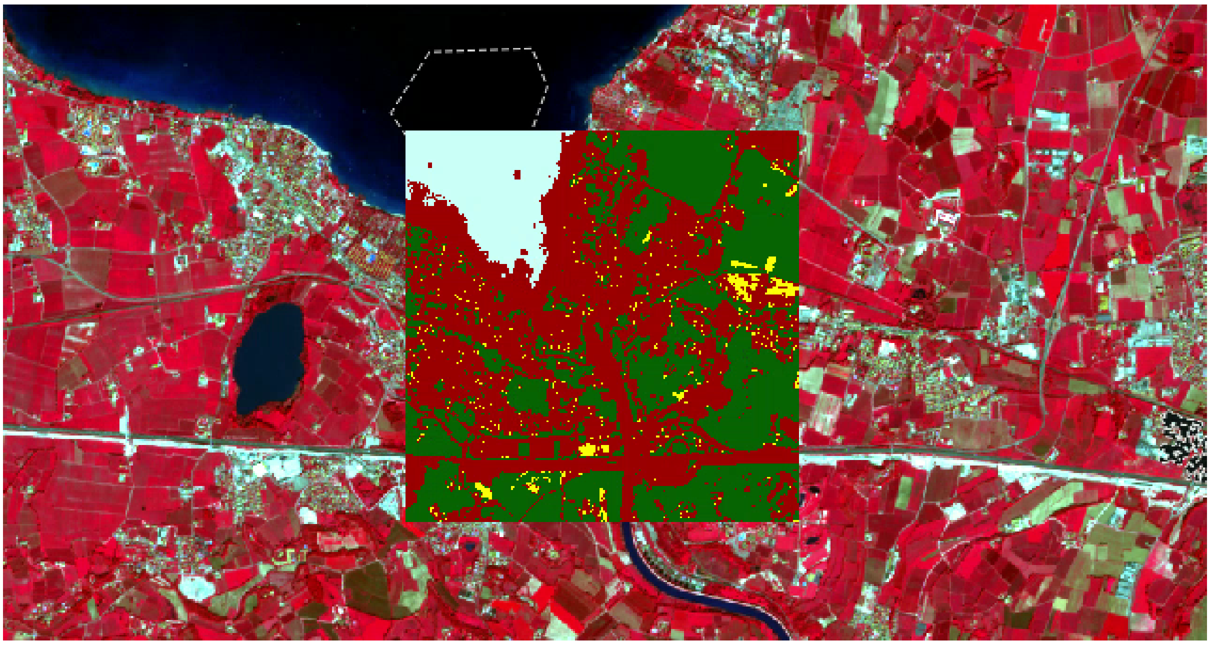


FIG. 13 – *Classification preview displayed over the image using MC ID*

errors, it can be removed from the *Training input* with the button .

Create the Classification Output

Assuming that the results of classification previews show a good agreement with the image (i.e. pixels are assigned to the correct class defined in the *ROI & Signature list* (page 36)), we can perform the actual land cover classification of the whole image.

In *Classification* (page 74) check *Use* *Macroclass ID*. Click the button *Run* (page 82) and define the path of the classification output, which is a raster file (.tif).

Astuce : If *Play sound when finished* is checked in *Calculation process* (page 111) 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.

In other tutorials we are going to learn about the download and preprocessing of bands, the classification algorithms, and the postprocessing of classifications.

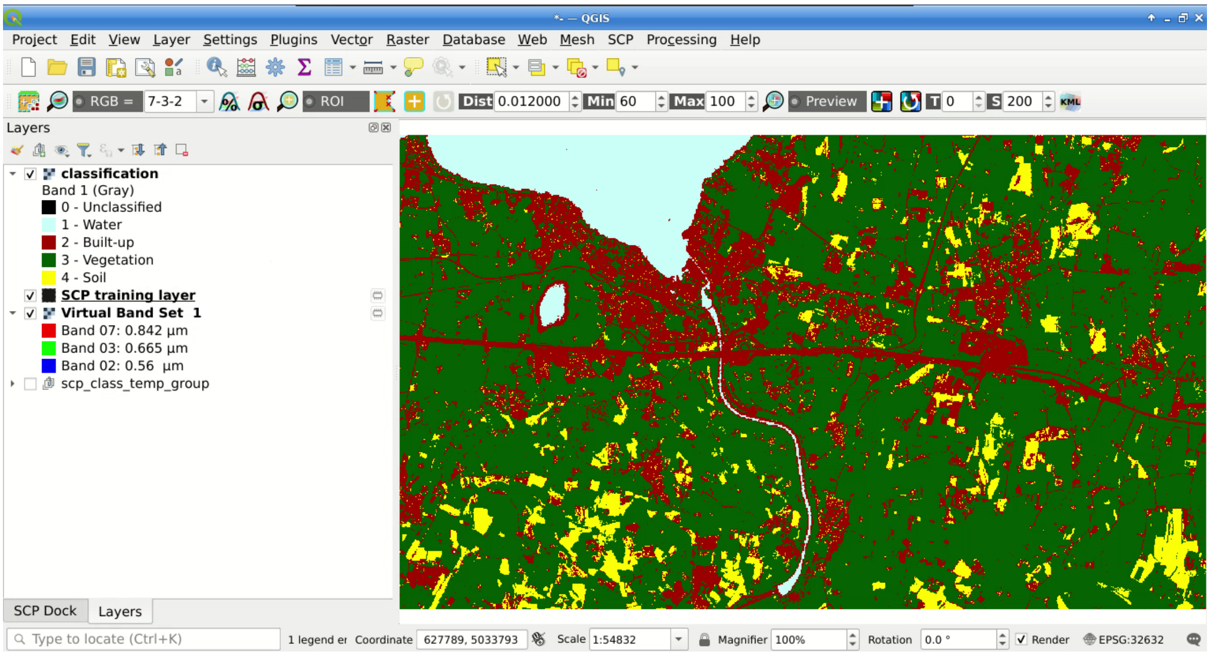


FIG. 14 – *Result of the land cover classification*

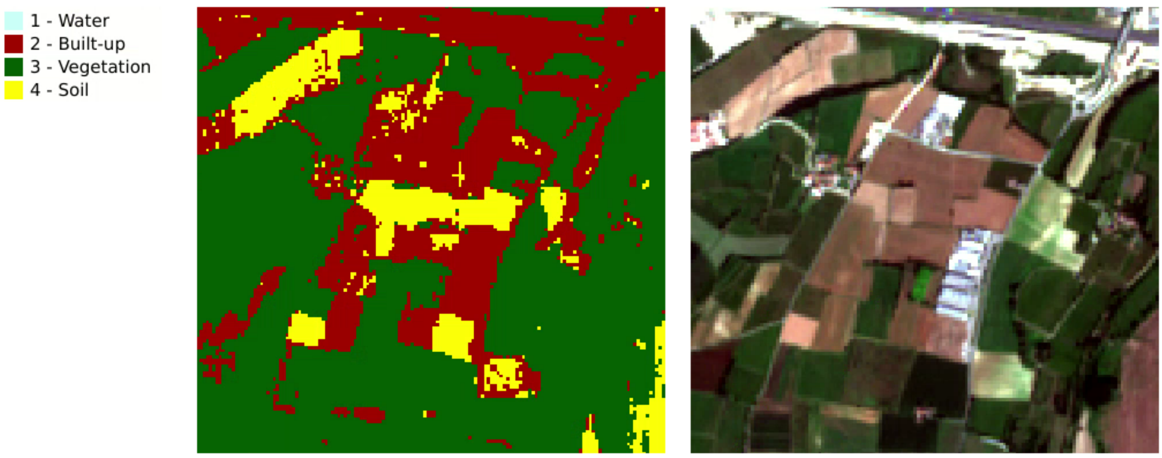


FIG. 15 – *Example of error : Soil classified as Built-up*

5.2 Tutorial 2 : Managing input bands, the Band set tab

The following is a basic tutorial about the *Band set* (page 45) tab, which allows for managing input bands.

Following the video of the tutorial.

https://www.youtube.com/watch?v=DQXfBPke2J4

5.3 Tutorial 3 : Downloading free satellite images, the Download product tab

The following is a basic tutorial about the *Download products* (page 48) tab, which allows for downloading free satellite images such as Landsat and Sentinel-2.

Following the video of the tutorial.

https://www.youtube.com/watch?v=NwL2f5Nrn3U

CHAPITRE 6

Thematic Tutorials

The following are thematic tutorials. Before these tutorials, it is recommended to read the *Basic Tutorials* (page 155).

CHAPITRE 7

Questions fréquemment posées

Si vous avez des commentaires ou des questions, veuillez rejoindre le groupe Facebook .

Avant de demander, veuillez consulter le site officiel From GIS to Remote Sensing et suivre les questions fréquemment posées.

7.1 Installation de l'extension

7.1.1 Comment installer manuellement l'extension ?

Le SCP peut-être installé manuellement (ce peut-être utile quand une connexion internet n'est pas disponible ou l'installation est demandée sur plusieurs ordinateurs), en suivant quelques mesures :

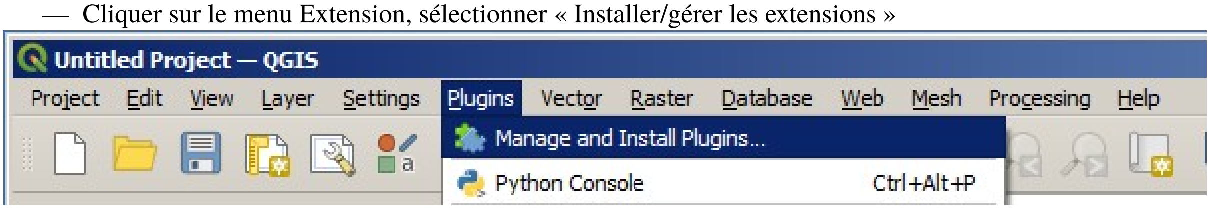
1. Télécharger les archives ZIP pour SCP depuis : https://github.com/semiautomaticgit/SemiAutomaticClassificationPlugin/archive/master.zip ;
2. extraire le contenu de l'archive (plusieurs fichiers tels que `COPYING.txt` et des dossiers tels que `ui`) dans un nouveau dossier nommé `SemiAutomaticClassificationPlugin` (sans``-master``) ;
3. ouvrir le répertoire `` plugins "" de QGIS (sous Windows habituellement `C:\Users\username\AppData\Roaming\QGIS\QGIS3\profiles\default\python\plugins`, sous Linux et Mac habituellement `/home/username/.local/share/QGIS/QGIS3/profiles/default/python/plugins`) et effacer le dossier `SemiAutomaticClassificationPlugin` s'il est présent ;
4. copier le dossier `SemiAutomaticClassificationPlugin` dans le dossier `plugins` de QGIS ;
5. l'extension devrait être installée ; Démarrer QGIS, ouvrir le gestionnaire d'extensions et s'assurer que l'extension `Semi-Automatic Classification Plugin` est cochée.

7.1.2 Comment installer l'extension depuis le dépôt officiel de SCP ?

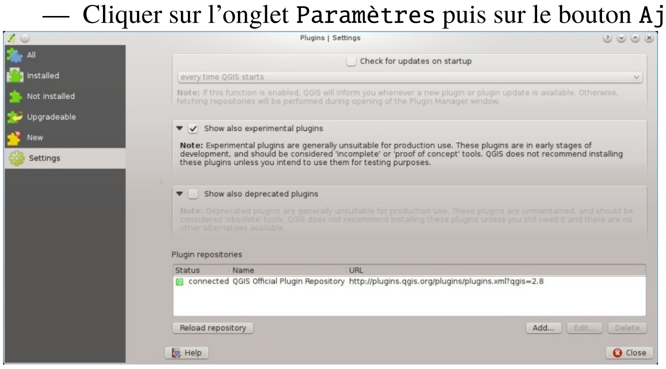
Il est possible d'installer le SCP en utilisant le dépôt officiel. Ce dépôt permet l'installation de la dernière version de SCP (`master`), dans certains cas également avant leur disponibilité dans le dépôt QGIS. Par conséquent, cela peut être utile si vous avez besoin d'un correctif ou d'une nouvelle fonction qui n'est toujours pas disponible dans le dépôt QGIS. De plus, la version `master` dans le dépôt SCP peut être installée avec la version disponible du dépôt QGIS.

Pour installer le dépôt SCP, suivez ces étapes :

— Lancez QGIS ;
— Cliquer sur le menu Extension, sélectionner « Installer/gérer les extensions »



— Cliquer sur l'onglet `Paramètres` puis sur le bouton `Ajouter` ;



— Dans le `Détails du dépôt` entrer :

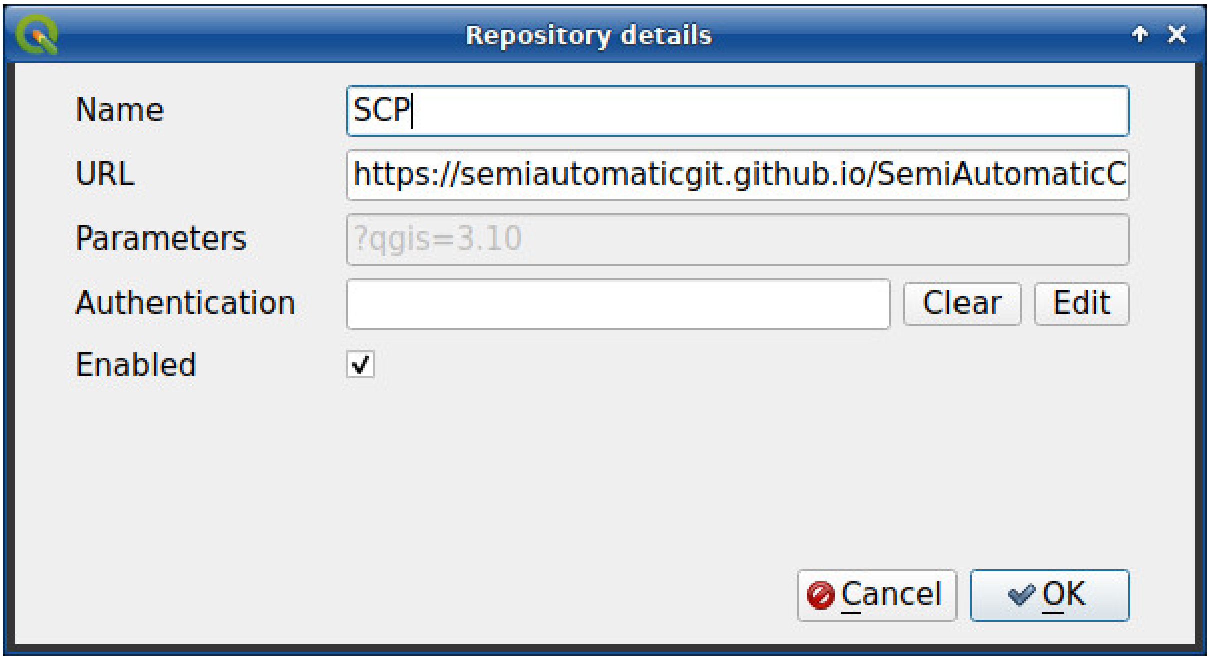
Nom :

```
SCP
```

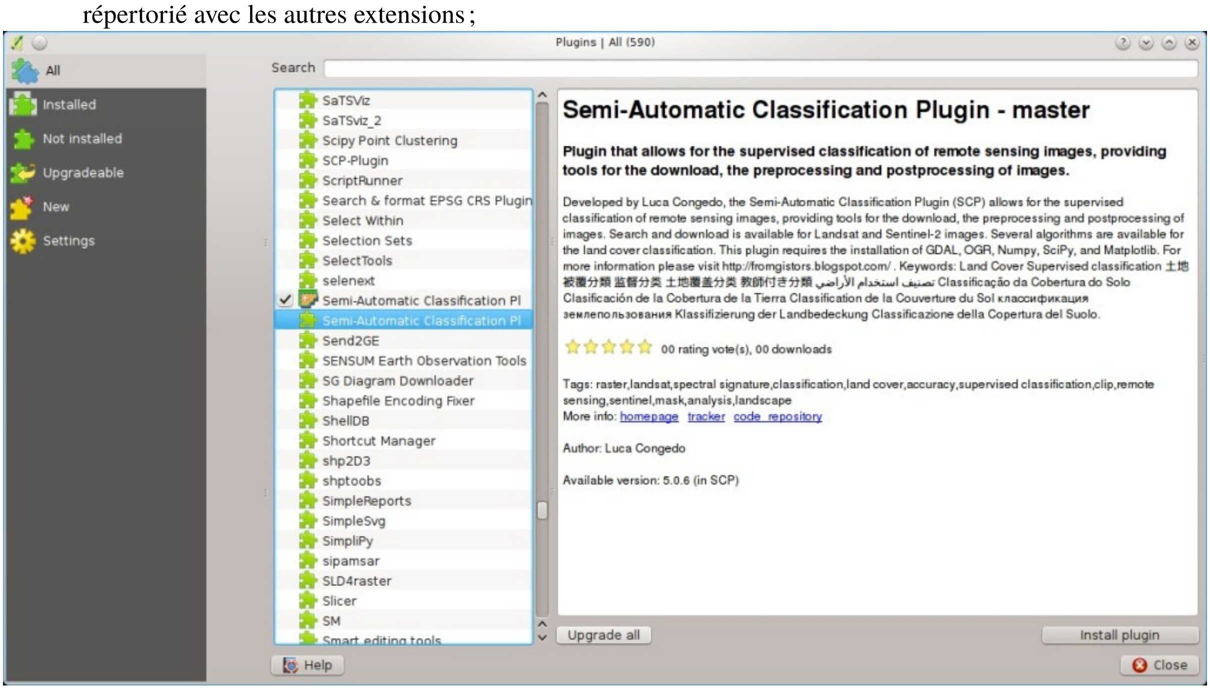
URL :

```
https://semiautomaticgit.github.io/SemiAutomaticClassificationPlugin/repository.xml
```

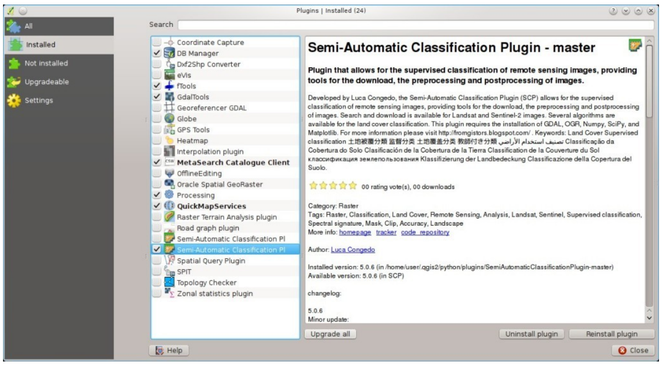
Et cliquer OK ;



— Après la mise à jour du dépôt, l'élément `` Semi-Automatic Classification Plugin - master `` devrait être répertorié avec les autres extensions ;



— Dans le menu `` Toutes "", sélectionnez le `Semi-Automatic Classification Plugin - master` et cliquez sur le bouton `` Installer le plugin "" ; la dernière version de SCP devrait être activée automatiquement (ignorer les erreurs, le redémarrage de QGIS pourrait être nécessaire pour terminer l'installation de SCP) ; il est possible de désactiver les autres SCP installés dans le dépôt QGIS ;



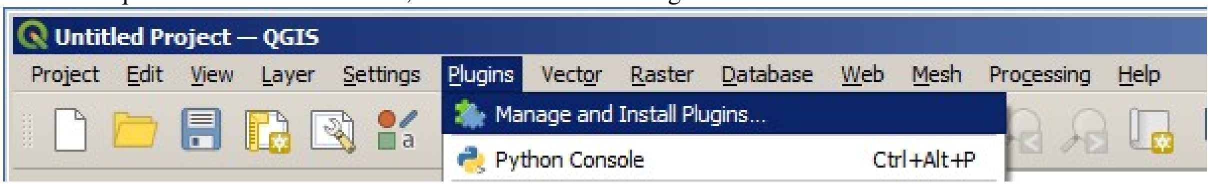
7.1.3 Can I use the previous version 7 of SCP ?

It is possible to install the previous version 7 of SCP using the official repository. Also, this version can be installed along with the SCP version 8.

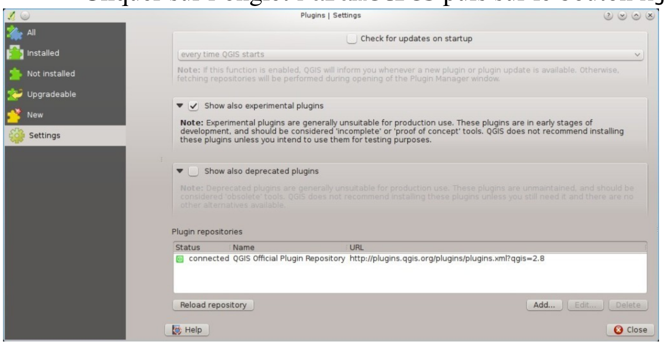
Pour installer le dépôt SCP, suivez ces étapes :

— Lancez QGIS ;

— Cliquer sur le menu Extension, sélectionner « Installer/gérer les extensions »



— Cliquer sur l'onglet `Paramètres` puis sur le bouton `Ajouter` ;



— Dans le `Détails du dépôt` entrer :

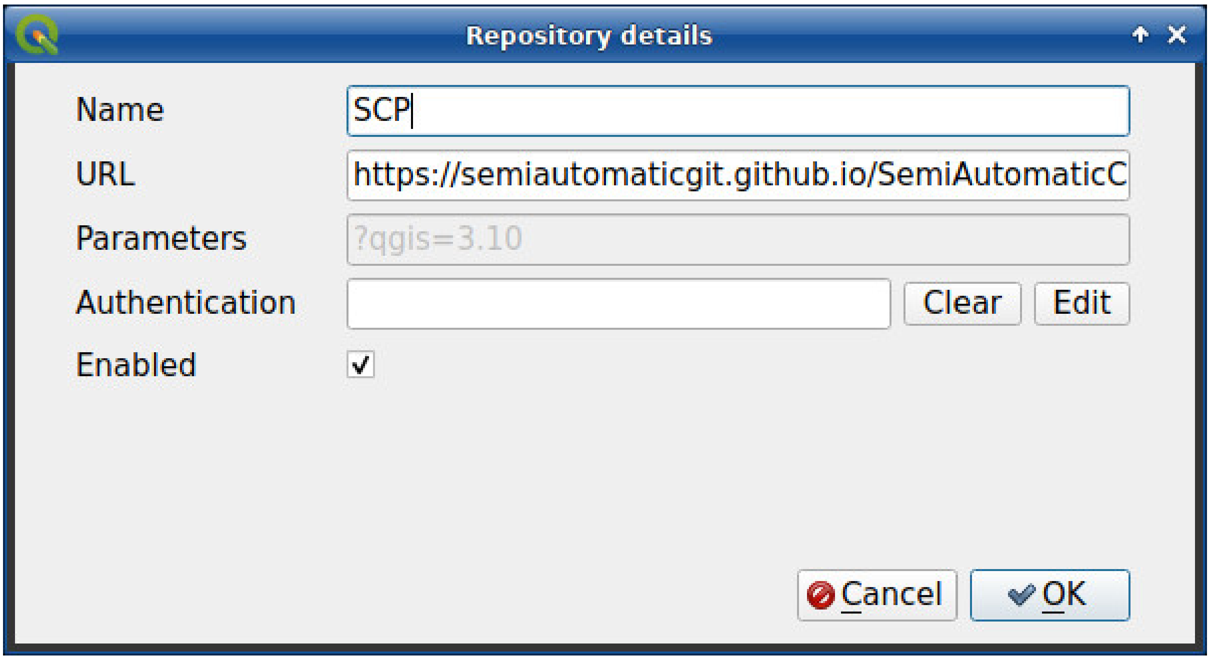
Nom :

```
SCP
```

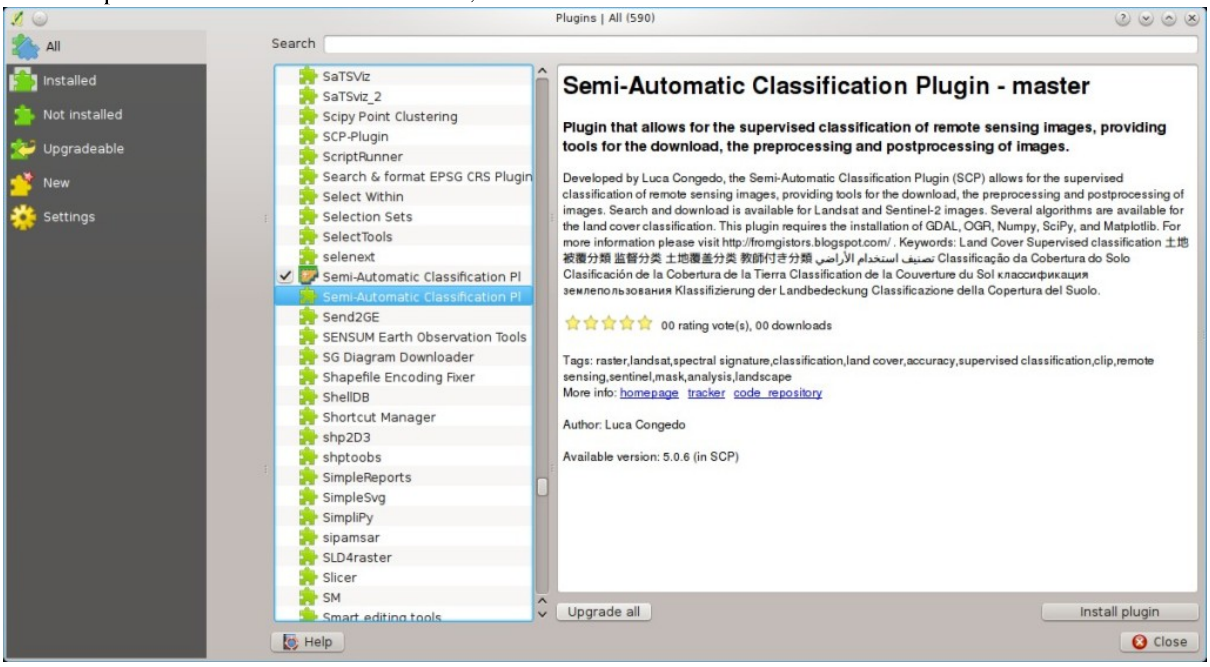
URL :

```
https://semiautomaticgit.github.io/SemiAutomaticClassificationPlugin_v7/repository.xml
```

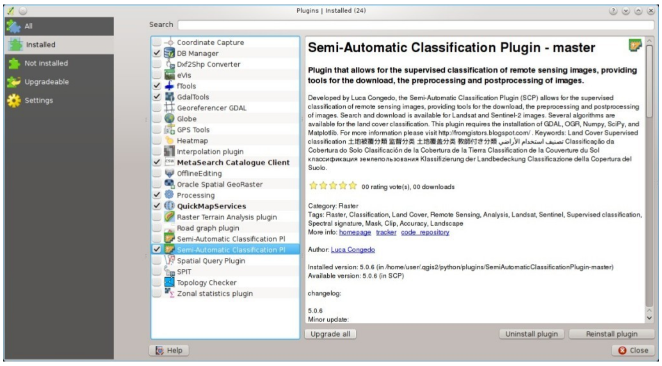
Et cliquer `OK` ;



— Après la mise à jour du dépôt, l'élément `` Semi-Automatic Classification Plugin - master `` devrait être répertorié avec les autres extensions ;



— Dans le menu `` Toutes "", sélectionnez le `Semi-Automatic Classification Plugin - master` et cliquez sur le bouton `` Installer le plugin ""; la dernière version de SCP devrait être activée automatiquement (ignorer les erreurs, le redémarrage de QGIS pourrait être nécessaire pour terminer l'installation de SCP) ; il est possible de désactiver les autres SCP installés dans le dépôt QGIS ;



7.2 Pré-traitement

7.2.1 Quelles bandes d'images dois-je utiliser pour une classification semi-automatique ?

En général, il est préférable d'éviter les bandes infrarouges thermiques. Si vous utilisez Landsat 4, 5 ou 7, vous devez sélectionner les bandes : 1, 2, 3, 4, 5, 7 en évitant la bande 6 qui est infrarouge thermique ; pour Landsat 8, vous devez sélectionner les bandes : 2, 3, 4, 5, 6, 7. La bande 1 de Landsat 8 est généralement évitée car elle est très similaire à la bande bleue et elle est principalement utilisée pour l'étude des aérosols côtiers. La bande infrarouge thermique Landsat est exclue des classifications car les valeurs sont principalement liées à la température de l'objet.

Pour les images Sentinel-2, vous pouvez utiliser des bandes : 2, 3, 4, 5, 6, 7, 8, 8A, 11, 12.

7.2.2 Quelles bandes Landsat peuvent être converties en réflectance par le SCP ?

Toutes les images Landsat 1,2 et 3 MSS et Landsat 4, 5, 7 et 8 téléchargées depuis http://earthexplorer.usgs.gov/ et traitées avec le système de génération de produits de niveau 1 (LPGS) peuvent être converties automatiquement en réflectance par le SCP ; les produits générés par le LPGS ont un fichier MTL inclus qui est requis pour la conversion.

7.2.3 Can I apply the conversion to Sentinel-2 images downloaded 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 *Image conversion* (page 64). Images are converted to reflectance.

7.2.4 Can I apply the conversion to Sentinel-2 L2A downloaded 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 *Image conversion* (page 64). Images are converted to reflectance.

7.2.5 Puis-je appliquer la conversion Landsat et la correction DOS aux bandes coupées ?

Oui, vous pouvez découper les images avant la conversion en réflectance, puis copier le fichier MTL (contenu dans le jeu de données Landsat) dans le répertoire avec les bandes coupées. Si vous souhaitez appliquer la correction DOS (qui est une technique basée sur l'image), vous devez convertir les bandes Landsat d'origine (l'image entière), puis couper la sortie de conversion (c'est-à-dire les bandes converties en réflectance).

7.2.6 Puis-je appliquer la correction DOS aux bandes avec une bordure noire (c'est-à-dire avec une valeur NoData) ?

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.

7.2.7 Comment supprimer la couverture nuageuse des 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.

7.3 Traitement

7.3.1 J'ai des erreurs de classification. Comment puis-je améliorer la précision ?

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 113) to assess their similarity. You can also use a *Signature threshold* (page 60) for these signatures in order to reduce the variability thereof (only pixels very similar to the input signatures will be classified).

7.3.2 Est-il possible d'utiliser la même entrée d'apprentissage pour plusieurs images ?

Oui, c'est possible si toutes les images ont le même nombre de bandes. Cependant, si les images sont acquises au cours de mois différents, les changements de couverture terrestre (en particulier de l'état de la végétation) affecteront la signature spectrale (c'est-à-dire que le même pixel a une signature spectrale différente à différentes périodes). Les effets atmosphériques pourraient également affecter les images différemment. Cela pourrait réduire la précision de la classification. Par conséquent, il est suggéré de collecter toujours les ROI et les signatures spectrales pour chaque image.

7.3.3 Quelle est la différence entre les classes et les macroclasses ?

Veuillez voir : ref : *classes_definition*.

7.3.4 Puis-je utiliser SCP avec des images de drones ou des photographies aériennes ?

Oui, vous pouvez les utiliser s'ils ont au moins 4 bandes. Avec moins de 4 bandes, les algorithmes de classification semi-automatiques sont incapables de classer correctement la couverture terrestre. Il existe d'autres méthodes de classification, telles que la classification orientée objet, qui n'est pas implémentée dans SCP.

7.3.5 Pourquoi utiliser uniquement Landsat 8 bande 10 dans l'estimation de la température de surface ?

Plusieurs méthodes ont été développées pour estimer la température de surface. La méthode décrite dans le tutoriel pour l'estimation de la température ne nécessite qu'une seule bande. De plus, l'USGS recommande aux utilisateurs de ne pas s'appuyer sur les données Landsat 8 Band 11 dans l'analyse quantitative des données du capteur infrarouge thermique (voir `Modifications apportées aux données du capteur infrarouge thermique (TIRS) <http://landsat.usgs.gov/calibration_notices.php > `_ par USGS).

7.3.6 How can I speed up the processing ?

In order to speed up the processing you should set the available RAM and the number of threads available in *System* (page 110). *Available RAM (MB)* should be half of the system RAM (e.g. 1024MB if system has 2GB of RAM) or more if the system has a large amount of RAM (e.g. 10240MB if system has 16GB of RAM). *CPU threads* should be a value lower than the maximum number of system threads (e.g. if the system has 4 available threads set value 3).

Also, several tools allow for selecting the output format `.vrt` avoiding the time required to create a unique `.tif` raster (after multiprocess), especially useful for large rasters.

7.3.7 How do I perform accuracy assessment and how to design the number of samples ?

Accuracy assessment is described in this tutorial .

Sample design is required to provide an adequate number of samples for each class, as described in « Olofsson, et al., 2014. Good practices for estimating area and assessing accuracy of land change. Remote Sensing of Environment, 148, 42 – 57 ».

The number of samples (N) should be calculated as (Olofsson, et al., 2014) :

$$N = (\sum_{i=1}^{c}(W_i - S_i)/S_o)^2$$

where :

- W_i = mapped area proportion of class i ;
- S_i = standard deviation of stratum i ;
- S_o = expected standard deviation of overall accuracy ;
- c = total number of classes ;

To stratify the sample we should conjecture user's accuracy and standard deviations of strata (Olofsson, et al., 2014). One can hypothesize that user's accuracy is lower and standard deviations S_i is higher for classes having low area proportion, but of course these values should be carefully evaluated.

This requires some conjectures about overall accuracy and user's accuracy of each class. We should base these conjectures on previous studies.

As starting values, we could assume $S_o = 0.01$ and perform a rough accuracy assessment with random samples, and eventually calculate the S_i to perform the sampling design. Alternatively, one could start with Si = 0.5 for all the classes. Basically the higher is Si, the larger is the number of samples for that class.

7.4 Avertissements

7.4.1 Avertissement [12] : La signature suivante sera exclue si vous utilisez le maximum de vraisemblance. Pourquoi ?

Le ROI est trop petit (ou trop homogène) pour l'algorithme : ref : *max_likelihood_algorithm* car ce ROI a une matrice de covariance singulière. Vous devez créer des ROI plus importants ou ne pas utiliser l'algorithme de probabilité maximale dans le processus de classification.

7.5 Erreurs

7.5.1 Comment puis-je signaler une erreur ?

Si vous avez trouvé une erreur du plug-in de classification semi-automatique, veuillez suivre ces étapes afin de collecter les informations requises (fichier log) :

1. fermez QGIS s'il est déjà ouvert ;
2. open QGIS, open the Plugin tab *Debug* (page 107) and check the checkbox *Records detailed events in a log file* ;

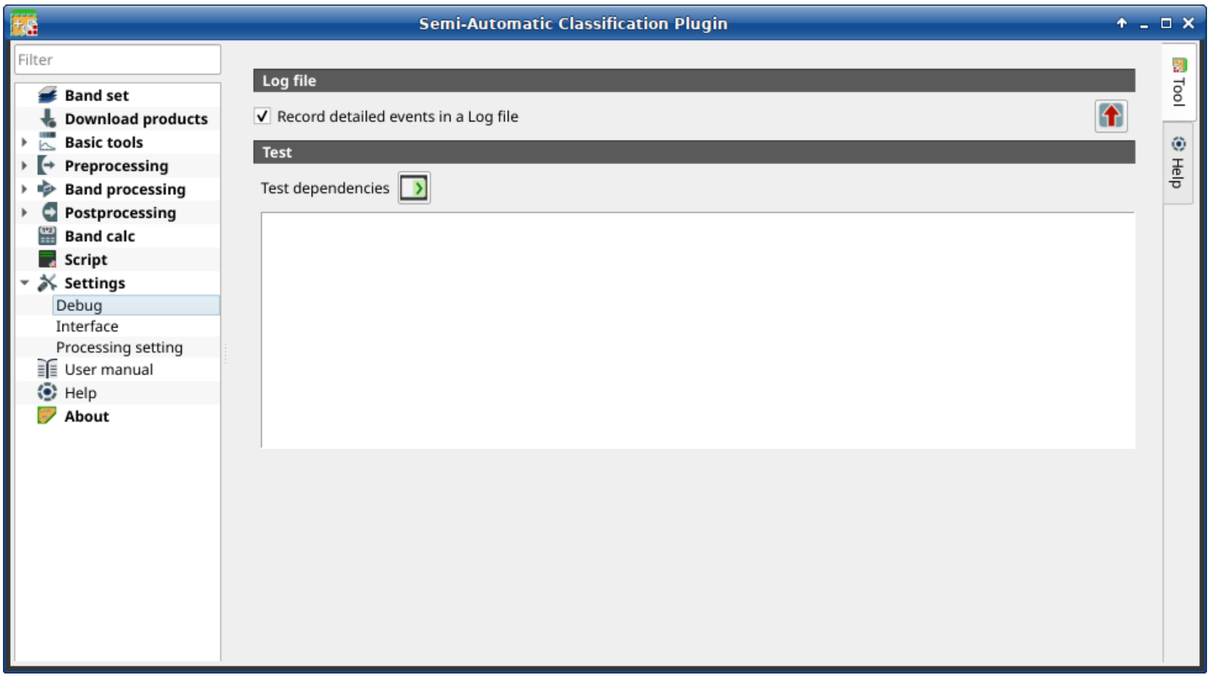


Fig. 1 – *Debug*

3. cliquez sur le bouton : guilabel : *Test dependencies* | enter | dans l'onglet : ref : *settings_debug_tab* ;
4. **charger les données dans QGIS (ou ouvrir un projet QGIS précédemment enregistré) et répéter toutes les étapes qui provoquent l'erreur dans l'extension ;**
   — si le problème est lié aux données d'image, veuillez utiliser *cet exemple de jeu de données <https ://docs.google.com/uc ?id=0BysUrKXWIDwBc1llME4yRmpjMGc&export=download>*
5. si un message d'erreur apparaît (comme celui de l'image suivante), copiez tout le contenu du message dans un fichier texte ;
6. ouvrez l'onglet : ref : *settings_debug_tab* et décochez la case | case à cocher | : guilabel : *Enregistre les événements dans un fichier journal*, puis cliquez sur le bouton | exporter | et enregistrez le ** fichier journal ** (qui est un fichier texte contenant des informations sur les processus du plugin) ;

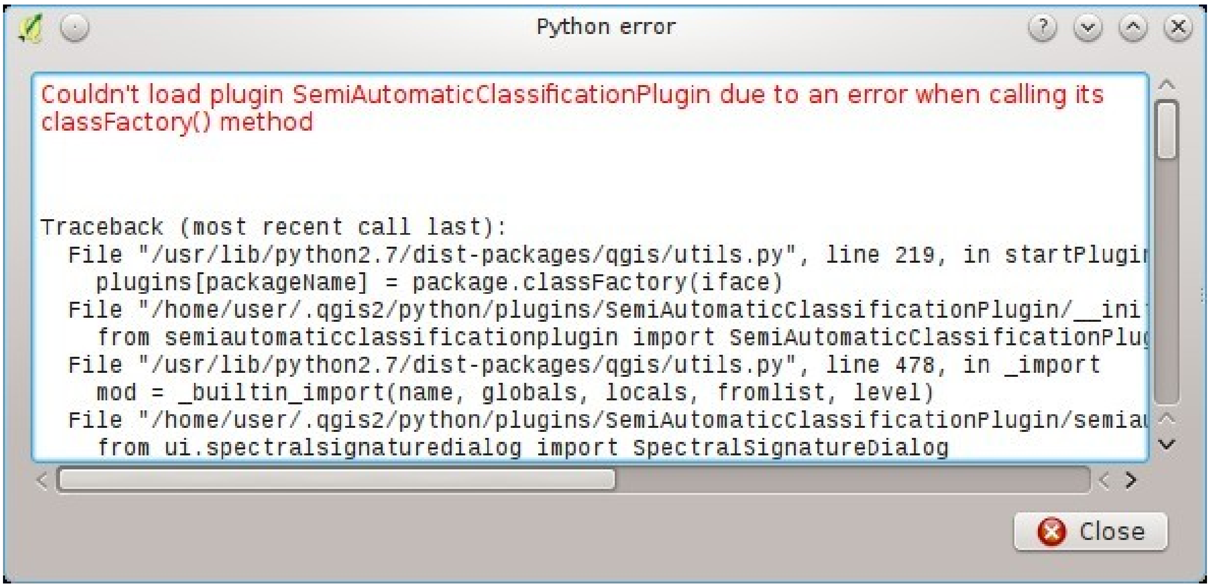


FIG. 2 – *Message d'erreur*

7. ouvrez le ** fichier journal ** et copiez tout le contenu du fichier ;
8. join the Facebook group , create a new post and copy the error message and the **log file** (or attach them).

7.6 Divers

7.6.1 Que puis-je faire avec le SCP ?

SCP allows for the **land cover classification** of remote sensing images through *Supervised Classification* (page 132). You can produce a land cover raster using one of the *Classification Algorithms* (page 135) available in SCP. These algorithms require spectral signatures or ROIs as input (for definitions please read *Brief Introduction to Remote Sensing* (page 123)) that define the land cover classes to be identified in the image.

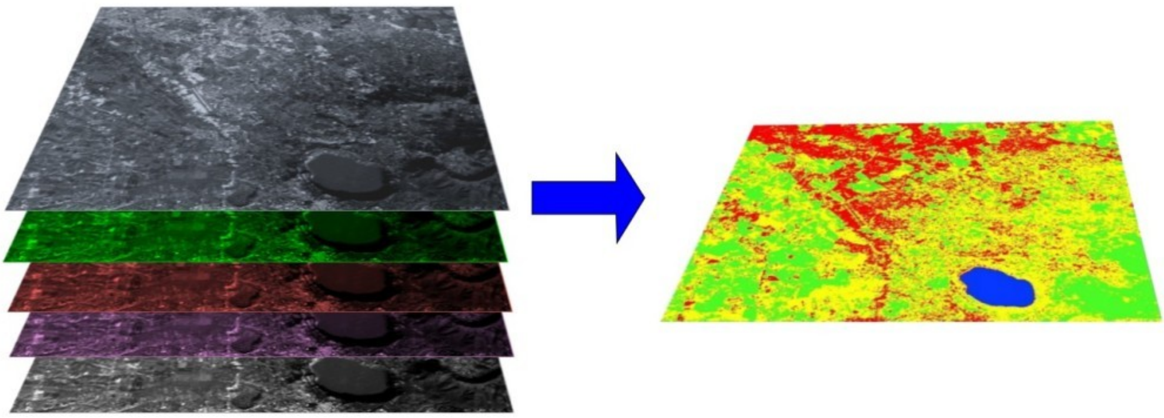


FIG. 3 – *A multispectral image processed to produce a land cover classification*
`(Landsat image fournie par l'USGS)`

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 48)). You cannot use orthophotos with less than 4 bands and LIDAR data with SCP.

** Image en entrée ** dans : guilabel : *SCP* s'appelle : ref :` band_set_tab`, qui est utilisé comme entrée pour la classification. :guilabel : *SCP* fournit plusieurs outils pour : ref :` pre_processing_tab` des images téléchargées, comme la conversion en réflectance et la manipulation des bandes.

Les :ref : *spectral_signature_plot* et :ref :` scatter_plot` permettent l"**analyse des signatures spectrales et des ROI **. De plus, plusieurs : ref : *tools_tab* sont disponibles pour faciliter la création de ROI et l'édition des signatures spectrales.

Raster calculation is available through the seamless integration of the tool *Band calc* (page 98) with bands in the *Band set* (page 45), calculating mathematical expressions and spectral indices.

Voir : ref :*tutorials* pour plus d'informations et d'exemples.

7.6.2 Comment contribuer à SCP

Vous pouvez contribuer à : guilabel :*SCP* en corrigeant et en ajoutant des fonctionnalités (voir : ref :*other_5*), ou en traduisant le manuel d'utilisation (voir : ref :*other_4*).

7.6.3 Comment puis-je traduire ce manuel dans une autre langue ?

Il est possible de traduire facilement le manuel d'utilisation dans n'importe quelle langue, car il est écrit en reStructuredText en tant que langage de balisage (à l'aide de Sphinx). Par conséquent, votre contribution est fondamentale pour la traduction du manuel dans votre langue. Le guide suivant illustre les principales étapes de la traduction, qui peuvent être effectuées :

- en utilisant le service en ligne gratuit Transifex ;
- en utilisant les fichiers gettext .po.

Avant de traduire, veuillez `lire ce document <http://docs.qgis.org/testing/en/docs/documentation_guidelines/do_translations.html#translate-a-manual>"_ du guide de traduction QGIS, qui vous aide à comprendre le reStructuredText.

Méthode 1. Traduction à l'aide du service en ligne gratuit Transifex

C'est probablement le moyen le plus simple de traduire le manuel à l'aide d'un service en ligne.

1. Rejoignez le projet Manuel de classification semi-automatique

   Accédez à la page https://www.transifex.com/semi-automatic-classification/semi-automatic-classification-plugin-manual et cliquez sur le bouton `Aide à la traduction`. Vous pouvez vous connecter en utilisant votre compte Google ou Facebook, ou avec une inscription gratuite.

2. Choisissez votre langue

   Sélectionnez votre langue et cliquez sur le bouton `Rejoindre l'équipe`. Si votre langue ne figure pas dans la liste, cliquez sur le bouton `Demander la langue`.

3. Traduction

   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.

7.6.4 Where is the source code of SCP ?

The source code of SPC is available at the following link https://github.com/semiautomaticgit/SemiAutomaticClassificationPlugin