Global Lakes Sentinel Services

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GLaSS Training material, Lesson #7

Assessing colour of lakes influenced by glacier dynamics in the Mount Everest Region

Which Himalayan lake could cause glacial outburst floods?

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Lesson summary

Glacial lakes, whatever their origin and position with respect to glaciers, are strongly influenced by glacier dynamics that are extremely sensitive to climate change. Increasing melting rates induced by this phenomenon can have various effects among which the increase of both number and size of glacial lakes. Melting water from glaciers is in fact a main factor determining lake volume, but it also contributes to the loading of glacial sediments in the fronting lakes, whose waters are grey and very turbid. This lesson covers how we can use satellite data to classify the multiple lakes in the Sagarmatha National Park (SNP), an exceptional area with dramatic mountains, glaciers, lakes and deep valleys, dominated by Mount Everest, the highest peak in the world (8,848 m). The classification aims to recognize lakes colour and turbidity in terms of water reflectance brightness by focusing on finding potentially dangerous lakes with risk of outburst flood.

GLaSS training material outline

This lesson is part of the GLaSS training material. The complete training material outline is listed on http://data.waterinsight.nl/GLaSS/trainingmaterials/GLaSS_lesson_outline.pdf.

Note that the lessons logically follow up on each other, the later lessons might require skills that can be acquired during the earlier lessons.

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List of abbreviations

Abbreviation	Description
Chl	Chlorophyll
EO	Earth observation
NIR	Near Infrared
SNP	Sagarmatha National Park

1 Introduction

Global warming has resulted in a large-scale retreat of glaciers throughout the world. The evidence for this is particularly strong in high-altitude areas, such as the central Himalaya, where the widespread recession is evident from the rapid growth in the number and size of glacial lakes. The deglaciation processes are also revealed by the amount of suspended solids transported by melting glacier waters into the lake with consequences for light propagation in the water body. If glacier water influx into a lake increases, them the maximum suspended particle size and particle number density will increase, and this affects light scattering. For decreased meltwater input, absorption because of water increases and the preferential red absorption because of water are enhanced. In lakes that have no glacial input, lake water is clear, and there is almost no scattering or absorption because of suspended matter.

Light propagations in water bodies can be successfully investigated by optical sensors which can be operated both from field-based and space-borne platforms. Whatever the observation scale, they allow the spectral water reflectance to be captured and then analysed in terms of shape and magnitude. Typically, field data are then used for satellite data processing and validations.

In this lesson field measurements of water reflectance collected in October 2014 in five lakes in the Mount Everest region (Nepal) are analysed to provide reference data to classify the numerous lakes of SNP from two Landsat-8 images of October 2014 and September 2015. The classification aims to identify lakes depending on water reflectance spectra and consequently on water colour. A focus on lakes whose colour results grey is then performed as for these grey-turbid lakes (placed in proximity to glacier tongues having elongated shape) the risk of outburst flooding increases.

2 This lesson

2.1 Research question

Which Himalayan lake could cause glacial outburst floods?

2.2 Training objectives / skills to gain in this lesson

In this lesson, the main objective is the classification of lakes in Himalayan region through remote sensing products and techniques, on the basis of their own colour, to distinguish among lakes, those fed by glacier.

- Lakes identification and surface extension assessment through remote sensing techniques, classifying image surfaces trough new GLaSS Prediction Tool
- Assessment of lakes type through remote sensing colour
- Masks generation for change detection
- Classifying image surfaces trough new GLaSS *Prediction Tool* for the evaluation of new grey lakes on glacier tongues

2.3 Required software and data

Software and tools

To complete this lesson tasks, the following tools and software are required or suggested:

- BEAM (required, see Lesson #1).
  SNAP can't be used to complete this lesson tasks.

Downloadable files

- GLaSS_Training_Lesson7.pdf
  The main document of the lesson including exercises and questions.
- GLaSS_Training_Lesson7_Answers.pdf
  A document containing answers to all questions proposed in the exercises.
- GLaSS_Training_Lesson7_DataAndTools.zip
  Supplied data and tools, described below.

The zip-file with supplied data and tools contain:

A 'Sample_data' directory containing:

- an atmospheric corrected Landsat 8 image of Himalayan region of 30th September 2015 in BEAM-DIMAP format ('L8_20150930_AtmCorr.dim' and 'L8_20150930_AtmCorr.data')
- a subset of an atmospheric corrected Landsat 8 image of the same region of 29th October 2014 in BEAM-DIMAP format ('Subset_L8_20141029_AtmCorr.dim' and 'Subset_L8_20141029_AtmCorr.data')
- 'InSituMeasures.csv' and 'coordinates_inSituMeasurements.txt' containing respectively the values of some *in situ* measurements of reflectance and their coordinates
- a shapefile containing the database of the Sagarmatha National Park largest lakes

‘LAKES_SNP.shp’, with central lake pixel coordinates and lakes ID.

3 Exercise

Part 1 EO products use for large and small lakes identification

In this first part, a Landsat 8 product corrected for atmospheric and adjacency effects (i.e. an image containing reflectance values in each pixel) is used to identify large and small lakes extension. A mask of the lakes is generated exploiting the new *Prediction Tool,* to be used in the second part of the lesson, for lakes classification.

Activities

- Start VISAT, the BEAM interface (find it in ...\beam-5.0\bin).
- Open L8 product of September 30th 2015: *File>Open Product* and choose ‘L8_20150930_AtmCorr.dim’.
- Expand the main folder and then ‘Bands’ folder: five bands are shown from 443 to 864.6 nm. Right click on image name and choose *Open RGB Image View…:*

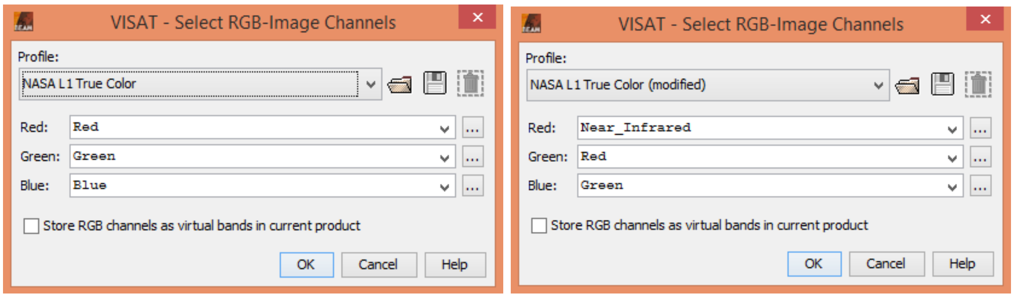


Figure 1. RGB bands combination selection window: True Color default profile (left) and False Colour composition (right).

- Confirm *Nasa L1 True Colour* profile: the RGB image is shown. Due to the clouds and snow brightness, the image could result dark. Use *Colour Manipulation* tab (on the left side) to stretch the image, to make lakes and land easier visible.

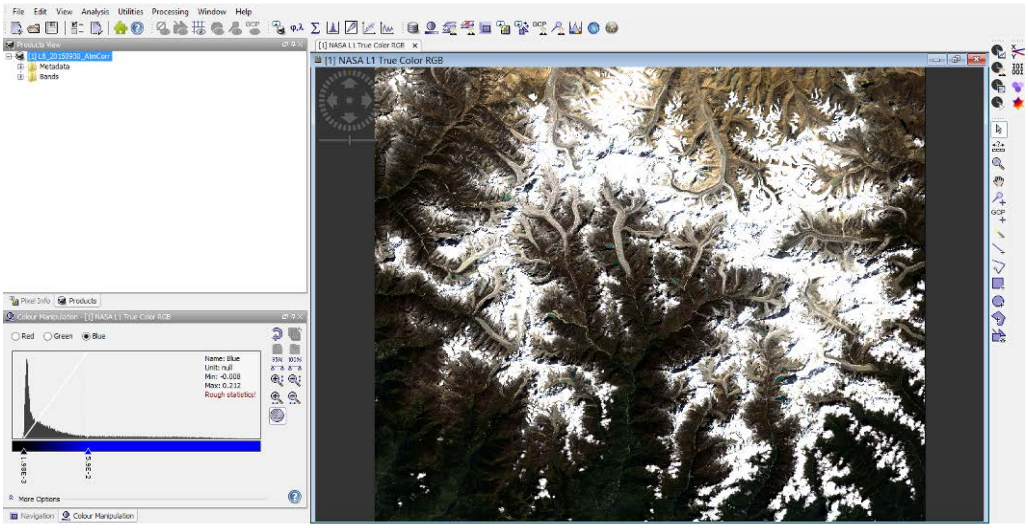


Figure 2. Landsat 8 True Colour image on Himalayan lakes on September 30th 2015

shown in BEAM-VISAT and Products and Colour manipulation tabs (left side).

- A second chance is to visualize the image in *False Colour* composition, choosing bands as in Figure 1(right).

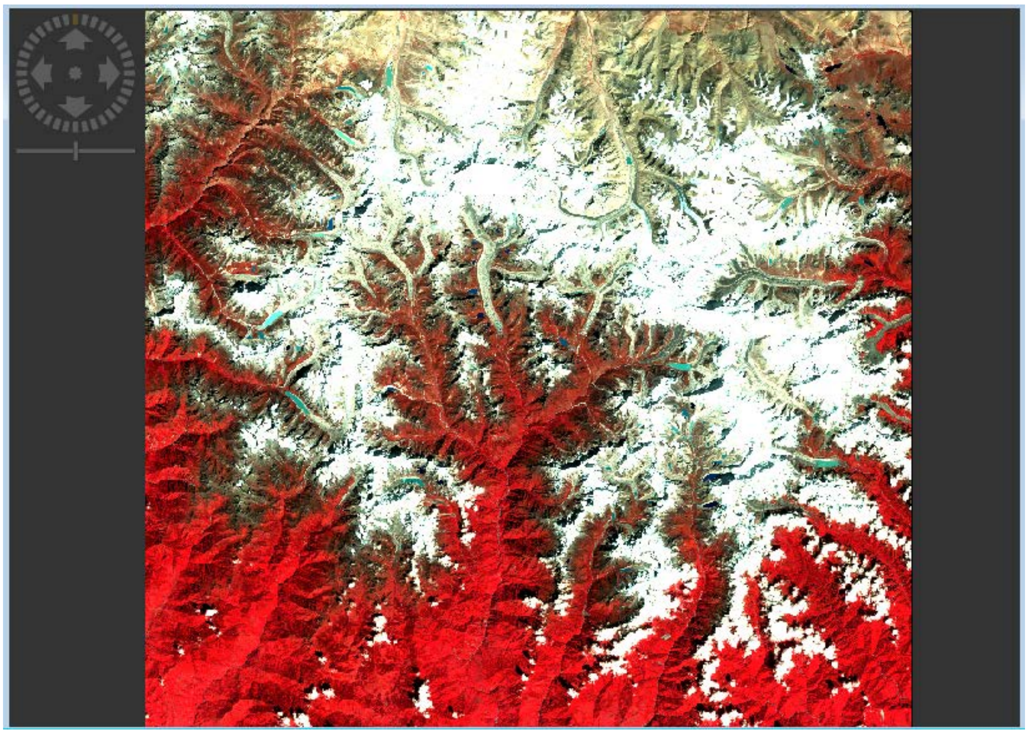
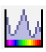


Figure 3. Landsat 8 False Colour image on Himalayan lakes on September 30th 2015 in BEAM-VISAT.

Look at the False Colour image. As you can probably see, in the image there are several lakes, with different shapes and colours, due to their different origin.

In *True Colour* map, they appear blue, turquoise or grey and in False Colour they appear, respectively, almost black, blue and turquoise. This is because blue lakes are clear lakes which reflect almost anything in Near-Infrared (NIR) and very few in green and red bands. On the other hand, grey lakes are much more reflective in the whole visible-NIR spectrum, due to the presence of suspended sediments. Turquoise lakes represent a middle situation.

To generate a mask containing lakes, several method are, in general, exploitable: importing existing shapefile, hand-drawing geometries on the image or exploiting colour, i.e. spectral characteristics, of lakes water. This last one is the most suitable in this case.

Open the *Spectrum View* clicking on . Moving cursor on the image you can visualize how the spectrum of reflectance changes in shape and magnitude values moving across different surfaces.

- *What are the ranges of reflectance values in the image?*
  What are the ranges of reflectance values for lakes?
  And for snow?

In this lesson, in order to generate a lakes mask, the new *Prediction Tool*, developed in GLaSS project framework (See lesson 2 for further information on *Prediction Tool* functioning), is used to classify the image in six classes: vegetation, rocks, snow, clouds, shadows, lakes.

As shown in lesson 2, the *Prediction Tool* use a training dataset defined on a set of pixels chosen in the image to calibrate and validate a classification model, which in turn can be used to classify the whole image as like as other images. To define the training set, in this lesson the *Magic Wand* tool is used (See Annex I of GLaSS deliverable 3.6 (2014)).

The next operations should be repeated for each class.

- Open *Magic Wand* tool clicking on .
- Approximately, define the range of pixel values for each class: this option do not influence the results but it is only useful to get a comparison between values range and tolerance.
- Do not apply any transformation on spectra (select *Identity* option) and use *Distance* for inclusion/exclusion test for pixels.
- Define the tolerance: of course, you should adjust this value considering the homogeneity/heterogeneity of the class. You could start with 0.02.

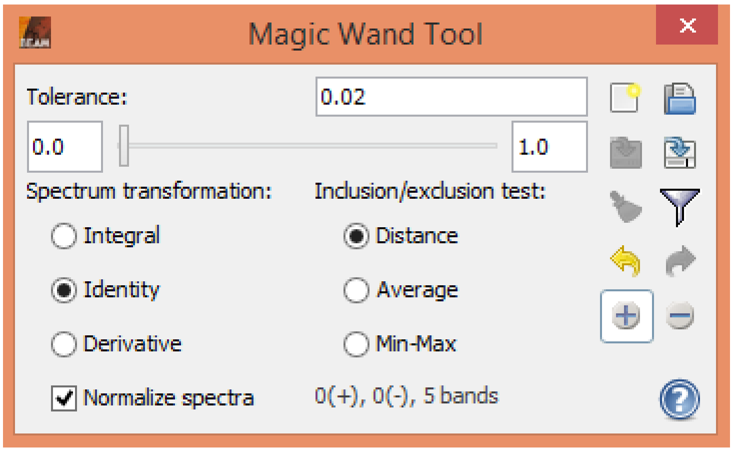


Figure 4. Magic Wand tool window.

- Start collecting spectra: select and click on some pixels of the surface you are considering, in different area of the image. In this way, you collect several spectra that *Magic Wand* tool uses to select pixels in the image through an inclusion/exclusion test. The more the pixels are heterogeneous, the less the test of inclusion will be strict. Pixels which pass the test are included in a new mask. If you notice (and it could probably happen in case of vegetation and rocks classes due to their heterogeneity) that tolerance is too strict, adjust it to higher values (for ex. 0.05).
- Once you are satisfied with your result, open the *Mask Manager* and change the name of the new mask created from 'magic_wand' to the name of the class. Finally clear *Magic Wand* results clicking on and start again with a new class.

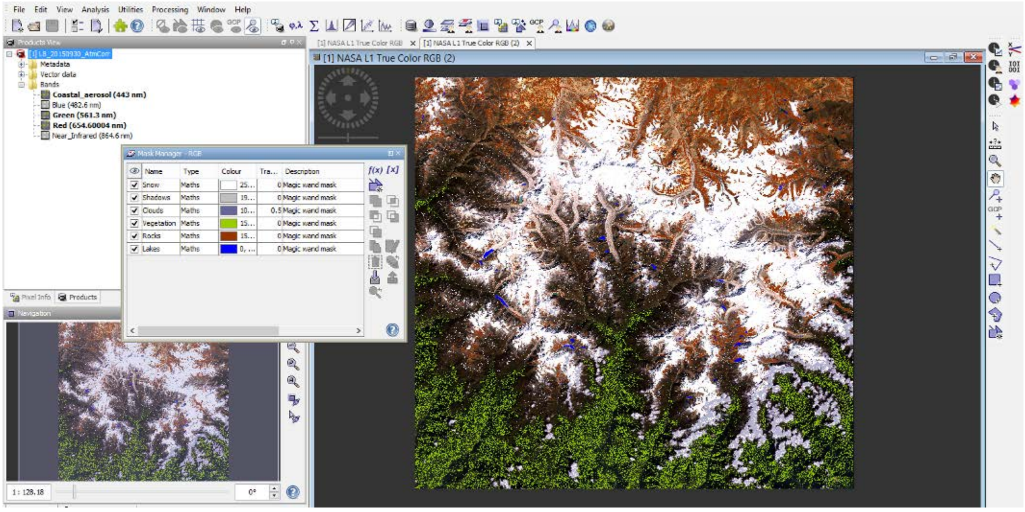


Figure 5. Masks used as training set for the Prediction Tool loaded on September 30th 2015 image, created through Magic Wand Tool, and Mask Manager window showing colours legend.

The new six masks generated can be now used as training set to feed the *Prediction Tool*.

- Open the *Prediction Tool* . In the first tab (*Training Set*) select all the bands to be included in the model for classification. In the *Available product masks* table, all masks you have previously created are reported. Select the six classes masks and click on the left arrow to include them in the *Selected training area* table. In this way you have defined the training set of the model. A valid pixel expression can eventually added, but in this lesson we want all the image pixels to be included in the classification process.
- Click on *Train Model.*

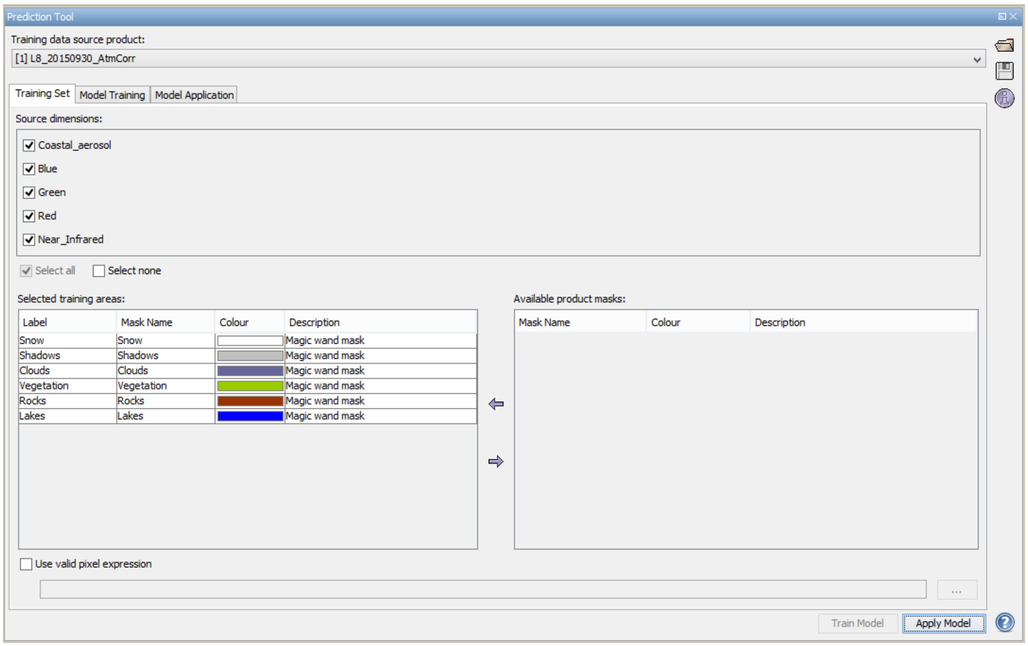


Figure 6. Prediction Tool window – Training Set tab for image classification.

➢ Once the model is trained, choose the *Model Training* tab and click on *Evaluate Model Performance.* You can validate the results both through the confusion matrix (Figure 7) or with overall *Accuracy Measurements.* In the case shown in Figure 7, only 81 lakes pixels has been classified as ‘snow’, 29 as ‘shadows’ and 57 as ‘clouds’ on a total of more than 16,000. The number of misclassified pixels is higher in the other classes, which are not important for this task objective. If the accuracy for lakes class is not high enough, create a new training set and repeat the training operation.

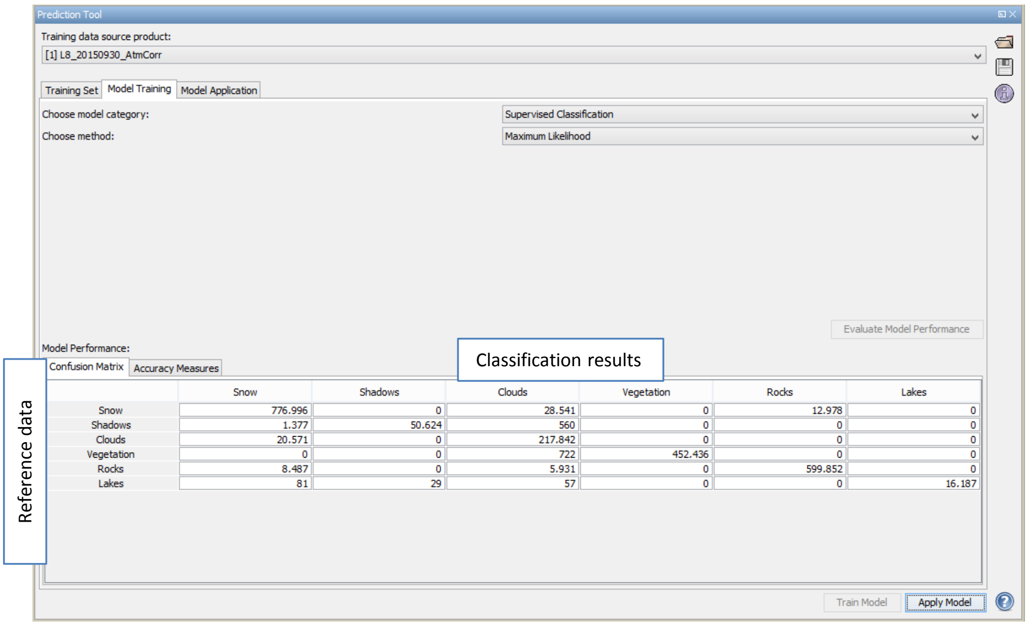


Figure 7. Prediction Tool window – Model Training tab for accuracy evaluation.

o *What’s the overall accuracy of the model you have just created?*

The model can now be applied or saved to be used in a second moment. Remember that if you want to modify your model in a different session you should save the masks you have created. Otherwise, you can only apply the model you have just created.

➢ Leave the option in *Model Application* tab unchanged but enable *Output to a new target product* option and specify file name and path to save the classification results.

➢ Apply the model on the image clicking on *Apply Model.*

The classification product is thus opened in BEAM-VISAT.

➢ Expand ‘Bands’ folder of the new product: it contains, in addition to the source product bands, a first band called ‘classification’ (where the number of the predominant class is indicated with a value from 0 to 5, indicating the six classes in the same order you defined them), and a band for each class containing the probability of the pixel to belong to the class itself.

➢ Double click on ‘classification’ band to visualize the classification results (Figure 8).

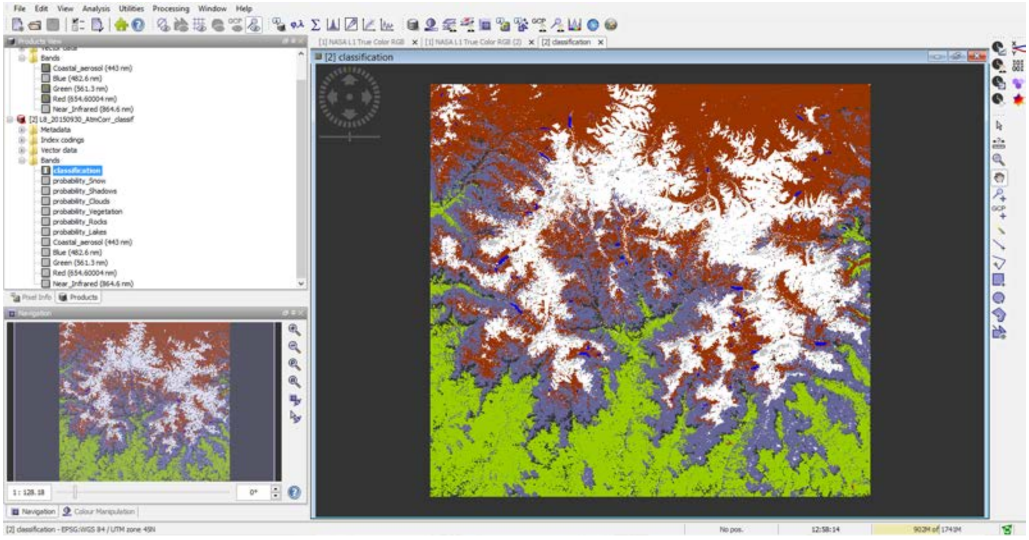


Figure 8. Classification results of Landsat 8 image of 30th September 2015. See Figure 6 for colours legend.

Let’s now create a mask containing only lakes pixels.

➢ Open *Colour Manipulation* tab and verify the values used in the image to indicate ‘Lakes’ class. In this case lakes pixels are indicated by the value 5.

Label	Colour	Value
Snow	255, 255, 255	0
Shadows	192, 192, 192	1
Clouds	102, 102, 153	2
Vegetation	153, 204, 0	3
Rocks	153, 51, 0	4
Lakes	0, 0, 255	5

Figure 9. Colour Manipulation tab showing colour legend and pixel values coding for classification.

➢ Open *Mask Manager* and click on *f(x)* to define a mask through a *New Logical Band Math Expression* and type ‘classification==x’ where x is the value for ‘Lakes’ class.

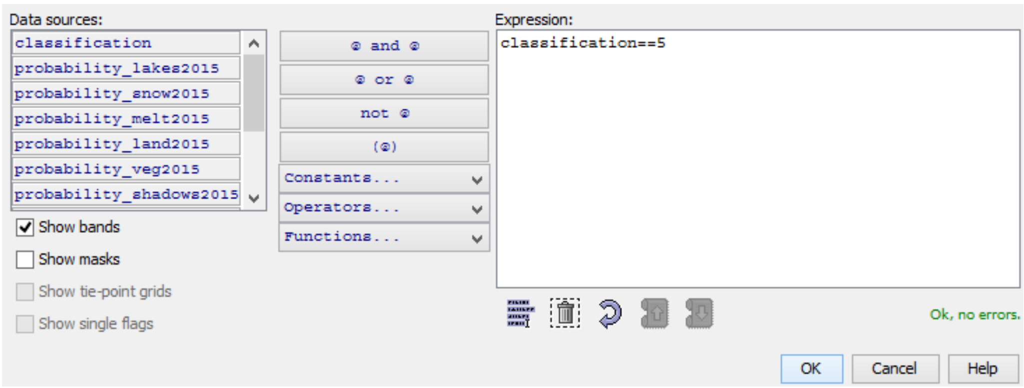


Figure 10. New Logical Band Math Expression Editor for the definition of Lakes mask on the basis of Prediction Tool classification.

- Click *OK* and a new mask of lakes is generated. Save the products to store the new mask in the file.

  - *How many pixels have been classified as 'Lakes'?*

Part 2 Lakes type definition and classification

In this lesson spectral characteristics will be exploited to classify lakes in three different classes: blue lakes, turquoise lakes and grey lakes in order to add this information to the provided Sagarmatha National Park lakes database.

In Figure 11 there's a zoom of some lakes belonging to the three different classes.

  - *How would lakes A, B and D appear in False Colour composition?*

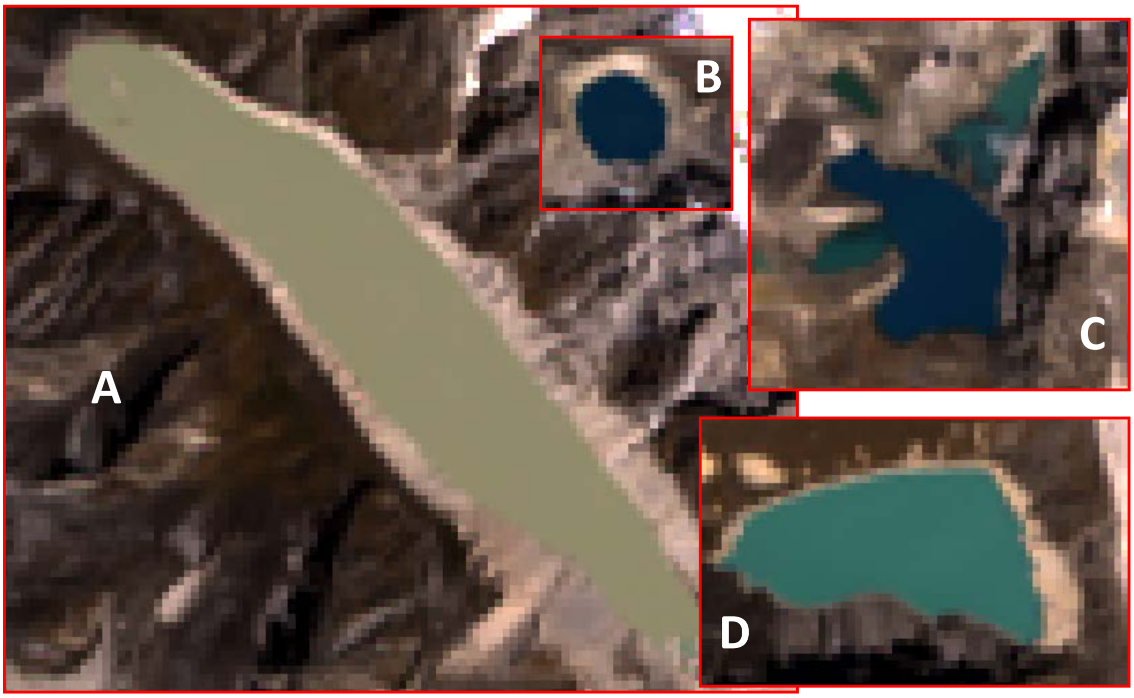


Figure 11. Zoom on some Himalayan lakes belonging to different classes: A) Grey lake, B) Blue lake, D) Turquoise lake. Lake pixels in C) belong to different classes.

The *Prediction Tool* is exploited once again to classify the lakes: pixels for the training set are chosen on the basis of their spectrum shape, comparing it to some sample *in situ* measures of reflectance.

Activities

- Open file 'InSituMeasures.csv' in a spreadsheet software (e.g. Excel): the spectra obtained from four measures in four different lakes are there reported, with the ID number of the lake and the class it belongs to.

- Create a plot of *in situ* measures: as shown in Figure 12, blue lakes are the less reflective, especially in red-infrared region. Each lake type can thus be distinguished through the shape of its spectrum.

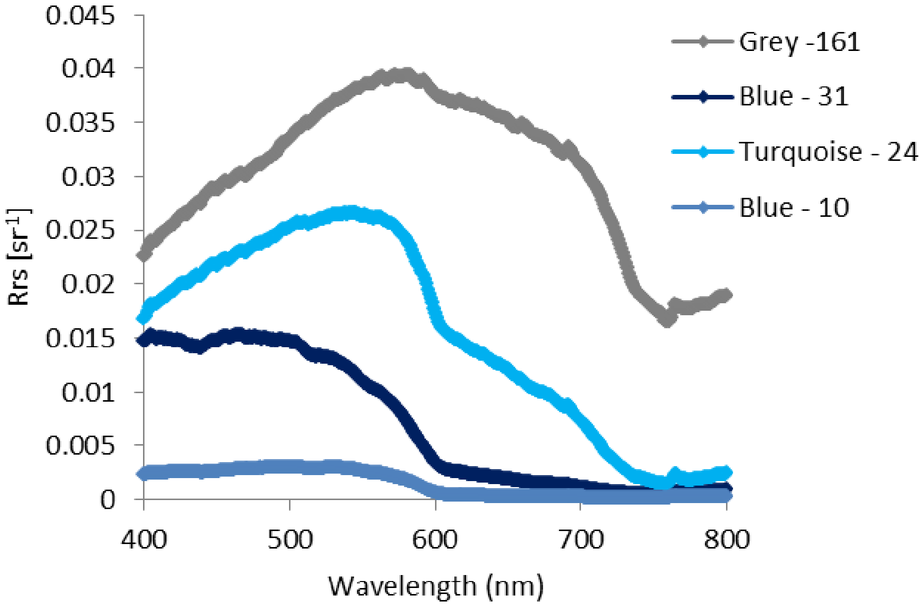


Figure 12. In situ reflectance measurements in four different lakes (ID number is the cadastre number of SNP lakes), belonging to classes Blue, Grey and Turquoise.

- Return to the BEAM software and import measures coordinates: *File>Import>Vector Data>CSV* and choose 'coordinates_inSituMeasurements.txt'. Specify in the dialog window the Coordinate System of coordinates file: *Geographic Lat/Lon (WGS 84)* and select *Leave imported data unchanged* when BEAM asks for point data interpretation.

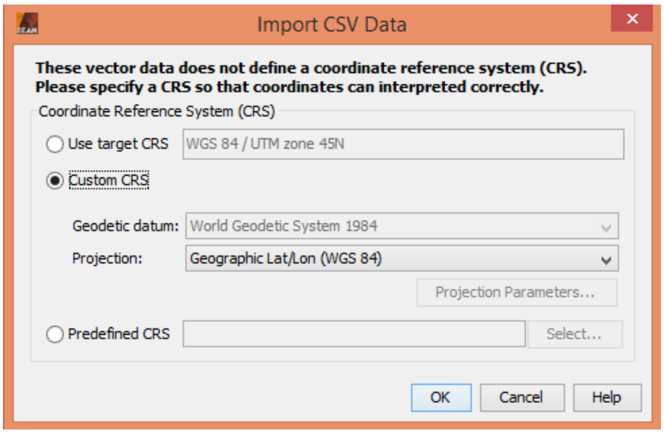


Figure 13. Import CSV Data options window, for CRS definition.

- The coordinates are imported both as vector and as masks and you can manage the colour, shape and visibility through *Vector Manager* and *Mask Manager* , respectively.

- Open the *Spectrum View* : in the window the spectrum of the pixel you are pointing with the cursor is shown selecting . Move across the image and look at how it changes on different lakes. If you press the 'Shift' key while moving, BEAM will adjusts the min/max range of the y axis.

➢ Collect the spectra of the measurements stations: select *pin placing* tool and click on the pixels corresponding to each station. Through *Pin Manager* choose a colour for each pin and rename each pin with the number ID of each lake. Finally, let *Spectrum View* show spectra for pins clicking on . The result is shown in Figure 14.

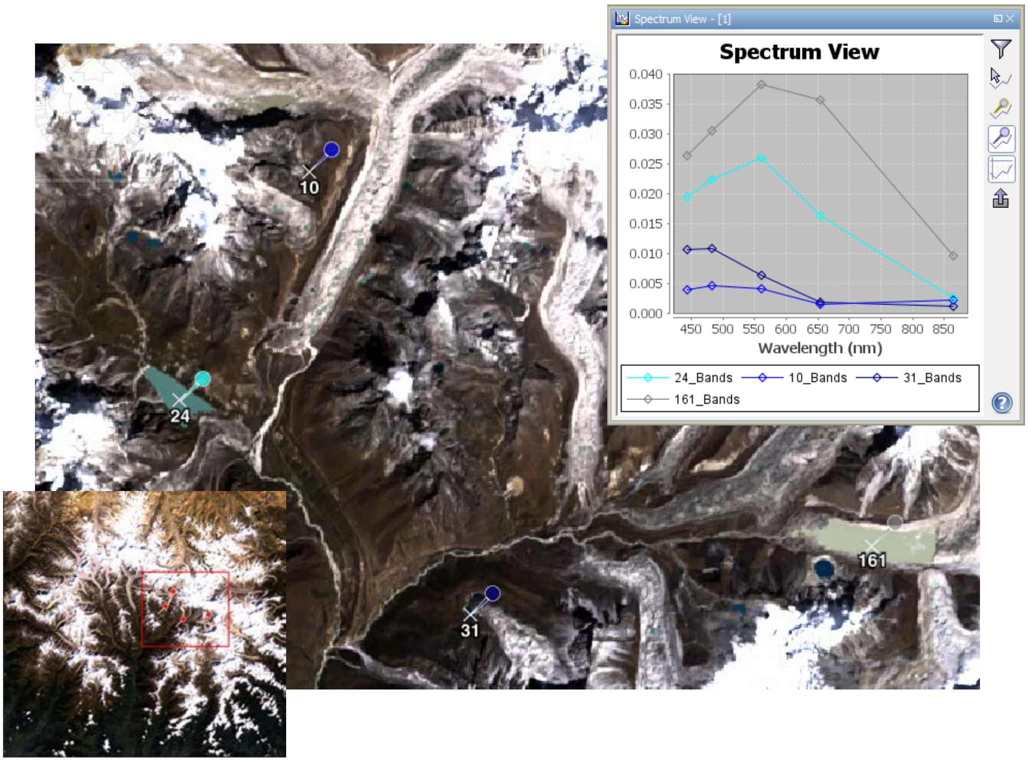


Figure 14. Measurements Stations and Spectrum View. Numbers refer to lake ID number reported in csv 'InSituMeasures.csv' file.

o *Compare spectra to in situ measurements: are they similar?*

Observe the position of the four sampled lakes: lake 10, 31 and 24 are not directly fed by glacial waters, while lake 161 is placed at the confluence of three glaciers, and its shape follows the one of a terminal glacier tongue. This lake is well known and studied (e.g. Bolch et al., 2008; Bayers et al., 2013) because of its risk of outburst since its surface is gradually increasing and its basin is not adequate to contain all its waters. Lake 161 is a typical example of a lake at risk of GLOF (Glacial Lake Outburst Flow), born as multiple surface ponds on the terminal part of a glacier tongue and evolved as a proglacial lake, as a consequence of global climate changes. It also has a grey colour, sign of high concentration of suspended sediments. The combination of morphological characteristics (e.g. near the glacier and with elongated shape) and biophysical parameters (e.g. water colour), which can be observed by EO instruments, give some indication about the risk of such remote lakes of causing serious damages to the local population.

Let's define training set for the classification of lakes.

➢ Keeping enabled the visualization of pins spectra, enable the visualization of the spectrum of the pixel pointed by the cursor clicking on .

➢ For each class, use the *Magic Wand* tool: choose some sample lakes pixels across the image comparing their spectrum shape to those in Figure 14 for each class. For ex. for class ‘Turquoise’, select pixels with spectrum shape similar to lakes 24, as in Figure 15.

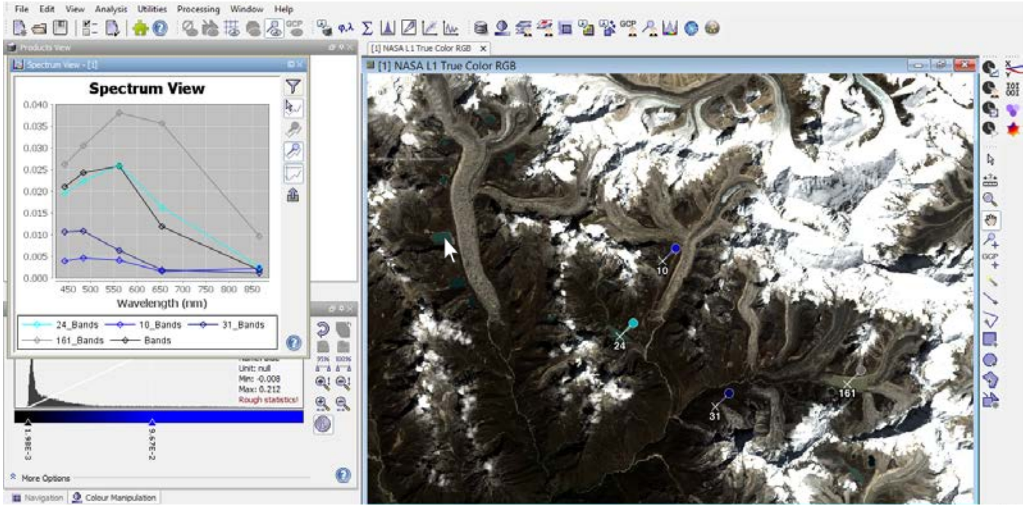


Figure 15. Spectrum visualization for pixel pointed by the cursor (black line in Spectrum View) similar to turquoise lake 24 spectrum shape.

Once you have generated three masks containing the training set for each class:

➢ Open the *Prediction Tool* and select again all the available bands of the September 30th 2015 and select the three masks as training areas as in Figure 16.

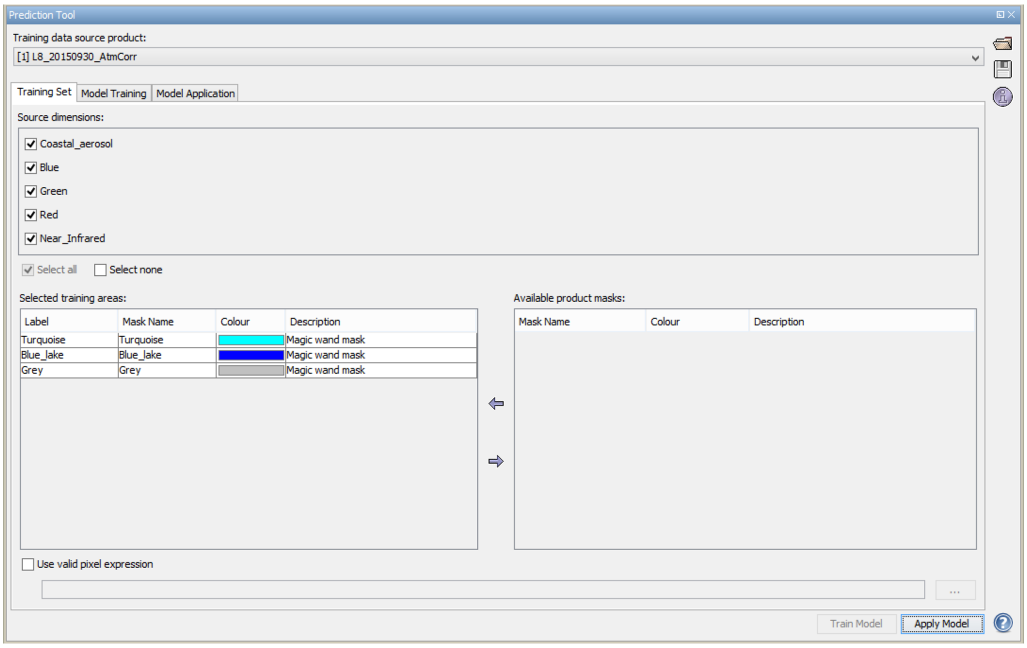


Figure 16. Prediction Tool window – Training Set tab for lakes classification in three different classes.

➢ Evaluate the accuracy of the model clicking Evaluate Model Performance in the *Model Training* tab.

- Set the model to be applied only on lakes pixels: enable the option 'Use valid pixel expression' and type 'Lakes' in the row below, which means to consider pixels that are comprised in the mask 'Lakes'.
- Select saving the output to a new target product and choose the name of the file.
- Save the model in order to use it in the third part of this lesson ().
- Apply the model.

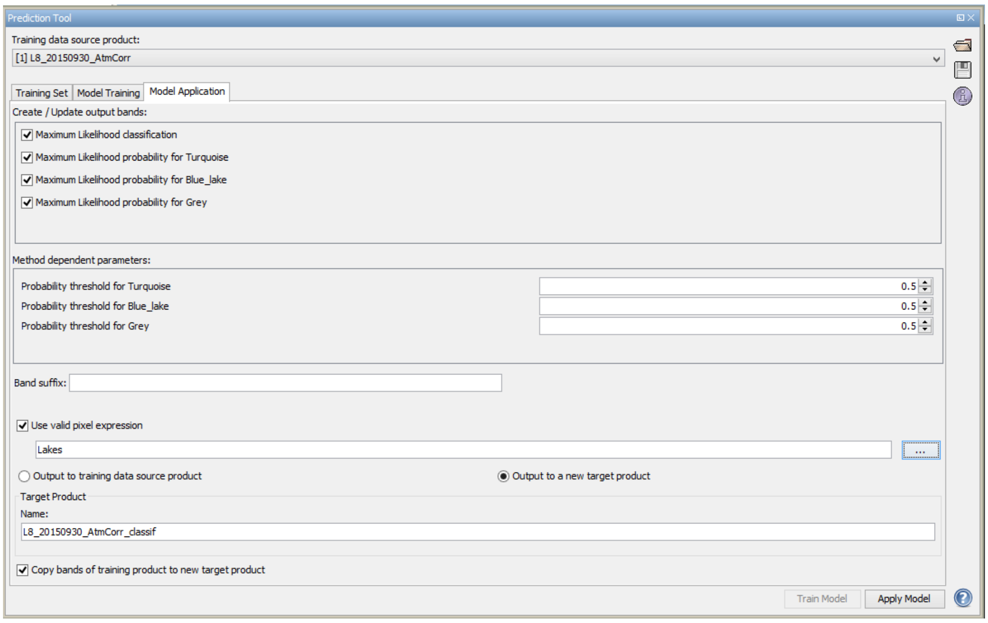


Figure 17. Prediction Tool window – Model Application tab.

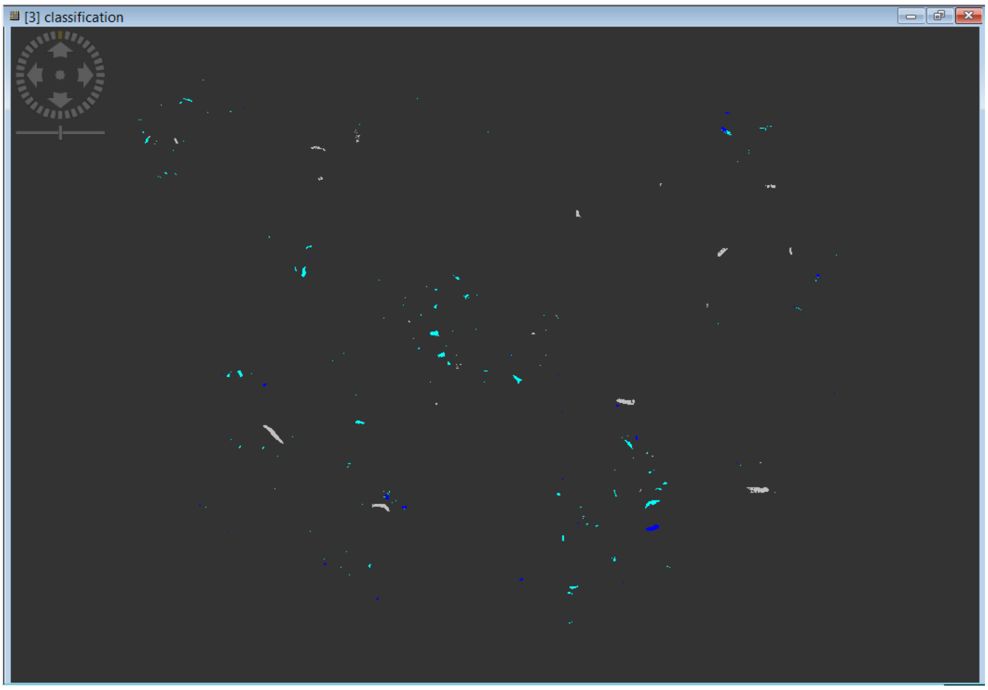


Figure 18. Results of the classification of Himalayan lakes on September 30th 2015 Landsat 8 atmospherically corrected image.

The classification results can be now exploited to update the database provided with the information on lakes class.

- Import the database shapefile to visualize lakes position in the image (*File>Import>Vector Data>Esri Shapefile* and choose 'LAKES_SNP.shp' file. In the vector folder a new vector of points (LAKES_SNP) is created and shown on the image with white crosses.
- For each cross, left click on it (the cross becomes yellow) and click on : the point information is shown, including the ID of the lake.
- For each lake you can add the class it belongs to in the shapefile.

Part 3 Change detection

Activities

In this third part, the model previously trained is applied to a second image acquired on October 29th 2014, in order to evaluate meaningful differences in smallest lakes extension and class, considering a smaller sample area.

- Open the classification product of September 30th 2015.
- Open *Mask Manager* and click on *f(x)*. Create a mask for each class typing 'classification==x', where x is the value used in 'classification' band to identify each class. Rename them as 'Blue_mask', 'Turquoise_mask' and 'Grey_mask'.
- Open Landsat atmospherically corrected image of October 29th 2014 (*File>Open Product*: choose 'Subset_L8_20141029_AtmCorr.dim'.
- Repeat the same operation did on 2015 image to generate a lakes mask and called it 'Lakes_2014'.
- Return to 2015 image and open *Mask Manager* ; select 'Lakes' (the corresponding table row becomes blue left clicking on the name) and click on to transfer the mask to the 2014 image. Select the option *Pixels* for the masks transfer (see Figure 19 for this choice explanation). Masks are now available on 2014 image.

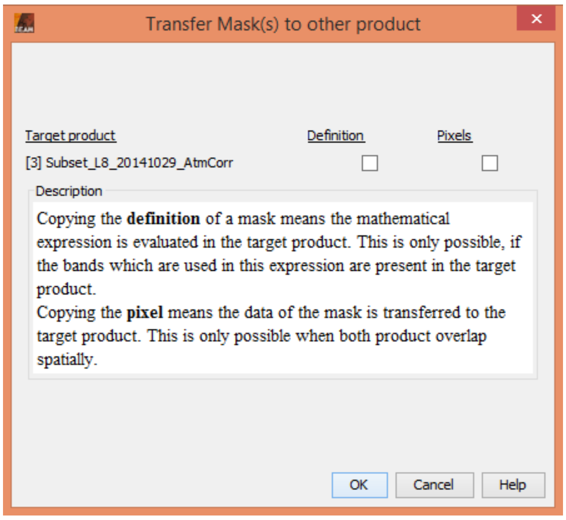


Figure 19. Masks transfer options window.

- Open a *False Colour* view of 2014 image and enable the visibility of 'Lakes' and 'Lakes_2014 masks in *Mask Manager* to compare lakes extension of the two different years. At first glance, the largest lakes did not undergo any change in their extension.

To evaluate possible changes in lakes colour, apply the model for lakes classification previously calibrated:

- Open the *Data Model Application* Operator: *Processing>Image Analysis>Data Model Application.*
- Select as input the subset of 2014 image and set the name and path for the output product.
- In *Processing Parameters* tab, load the model previously saved in Part 2 of this lesson.
- Enable the processor to *Use Valid Pixel Expression* and define it as 'Lakes_2014'.
- Apply the model.

The result may appear as in Figure 20 where few pixels are classified.

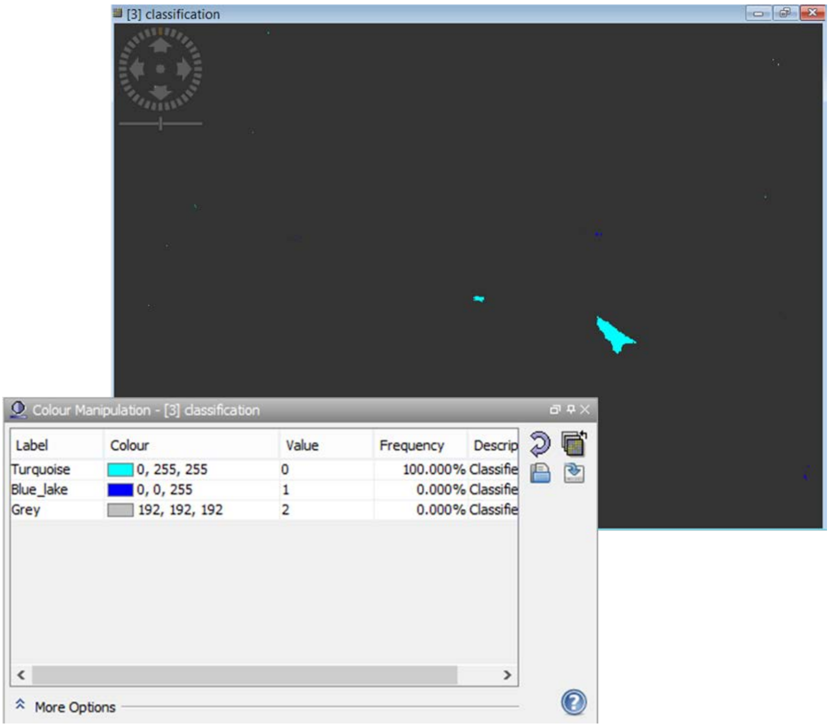


Figure 20. Result obtained applying a sample classification model calibrated on 2015 image to 2014 image.

- In this case, open the band of the output product showing probability for each class: probability values are below the default threshold of 0.5 where pixels haven't been classified. This is probably due to small differences in reflectance values but not in shape as it can be assessed looking at *Spectrum View* for this second image. In this case, the model can be applied again increasing the value x (where: probability threshold=1-x) in the *Model Application* tab. In this way pixels are assigned to the class with the highest probability, without any condition on minimum probability value.

Compare 2015 and 2014 results:

- ➢ Create a mask for each class on 2014 classification product as previously did for 2015 classification product, calling them ‘Blue_mask_2014’, ‘Turquoise_mask_2014’ and ‘Grey_mask_2014’.

- o *What’s the percentage of pixels classified as blue/grey/turquoise lakes in 2014?*
- o *What’s the percentage of pixels classified as blue/grey/turquoise lakes in 2015 considering the same area included in 2014 subset?*
- o *Is there any change between these two consecutive years?*

Part 4 Evaluation of new grey lakes on glacier tongues

The most evident changes are in the smallest lakes located in the tongues, for ex. in the red box in Figure 21 the two central tongues in the 2014 subset are shown: in 2015 the sediments rich grey lakes (which appears light blue in the False Colour composition) are larger than in 2014.

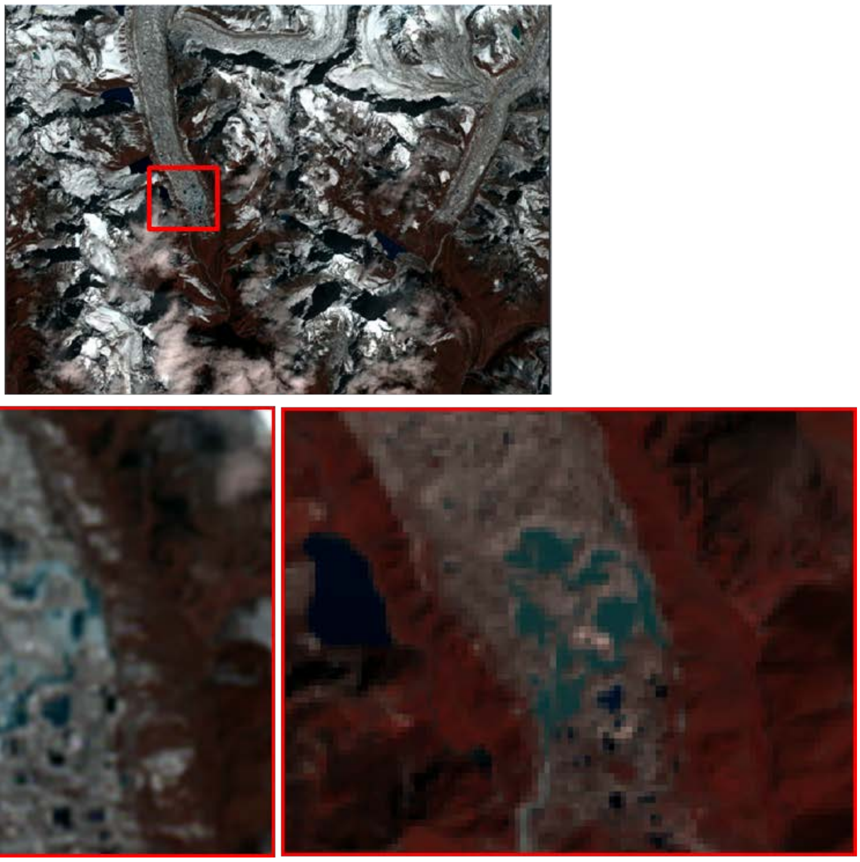


Figure 21. False Colour composition of Landsat 8 image of October 29th 2014 (top and a zoom on the area in the red box on the same date (left bottom) and on September 30th 2015.

This phenomenon could be the precursor of the creation of lake similar to lake 161 (See Part 1). To define the extension of these lakes. In this third part we try to identify the extension and colour of new lakes in two glacier tongues.

Activities

As you previously did, collect spectra with *Magic Wand* in order to define two classes on 2014 image: ponds and glacier tongues:

- Open *Magic Wand* tool and collect spectra for both classes, calling them 'Ponds_2014' and 'Glacier_tongues_2014'
- With , crate a new geometry and call it 'Tongues'. With the *Polygon drawing tool* , draw two polygons including only the two tongues in the image on 2014 and then transfer the new mask 'Tongues' to 2015 image.
- Generate a mask for each class intersecting the mask created with *Magic Wand* with 'Tongues' mask: in *Mask Manager* select 'Tongues' mask and 'Glacier_tongues_2014' and click on . Repeat the same for 'Ponds_2014' mask.
- Open *Prediction tool* and train the model using these last two generated masks as training set. If the accuracy is satisfying, apply the model, using as valid pixel value expression the string 'Tongues', to include the area of tongues only.
- Save the model and apply it on 2015 image, again only on the area of tongues.

o *How many pixels are classified as ponds in 2014? And in 2015? Are there any differences?*

4 More information and further reading

This lesson is based on the following report:

- GLaSS Deliverable 5.4, 2015. Global Lakes Sentinel Services, D5.4: Shallow lakes with low transparency due to sediment resuspension. WI, CNR, VU/VUmc in cooperation with Witteveen+Bos. Available via: http://www.glass-project.eu/downloads/

The report is suggested for further reading. It contains processed data for SNP area, but also for the following shallow lakes:

- Lake Markermeer
- Lake Böyük Şor

For more information on GLaSS, and to download all public reports: www.glass-project.eu.

References

- Bolch T., Buchroithner M. F., Peters J., Baessler M., Bajracharya S (2008) - Identification of glacier motion and potentially dangerous glacial lakes in the Mt. Everest region/Nepal using spaceborne imagery. Natural Hazards and Earth System Sciences, 8: 1329-1340. DOI: 10.5194/nhess-8-1329-2008.
- Byers A. C., McKinney D.C., Somos-Valenzuela M., Watanabe T., Lamsal D. (2013) - Glacial lakes of the Hinku and Hongu valleys, Makalu Barun National Park and Buffer Zone, Nepal. Natural Hazards, 69 (1): 115-139. DOI: 10.1007/s11069-013-0689-8.
- GLaSS Deliverable 3.6, 2014. Global Lakes Sentinel Services, D3.6: Data mining BEAM module, BC. Available via: www.glass-project.eu/downloads

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GLaSS Training material, Lesson #7

Assessing colour of lakes influenced by glacier dynamics in the Mount Everest Region

Which Himalayan lake could cause glacial outburst floods?

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2016

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