REDUCING VULNERABILITIES OF POPULATIONS IN THE CENTRAL ASIA REGION FROM GLACIER LAKE OUTBURST FLOODS IN A CHANGING CLIMATE (GLOFCA)

Glacial Lake Mapping Analytical Toolbox User Manual

The GLOFCA analytical toolbox focuses on mapping and monitoring glacial lakes from Space at high temporal resolution and under all atmospheric conditions. Glacial lakes are mapped using the spectral indices (Normalised Difference Water Index, NDWI) and Deep Learning (DL). The toolbox was implemented in Python using open source libraries (Tkinter, GDAL, Tensorflow, rasterIO etc.) and freely available satellite data such as Sentinel-2 (S2, optical) Level 1C (L1C, “Top of Atmosphere”) product and Sentinel-1 (S1) Synthetic Aperture Radar (SAR) Ground Range Detected (GRD) product (IW swath). A snapshot of the toolbox is shown in Fig. 1.

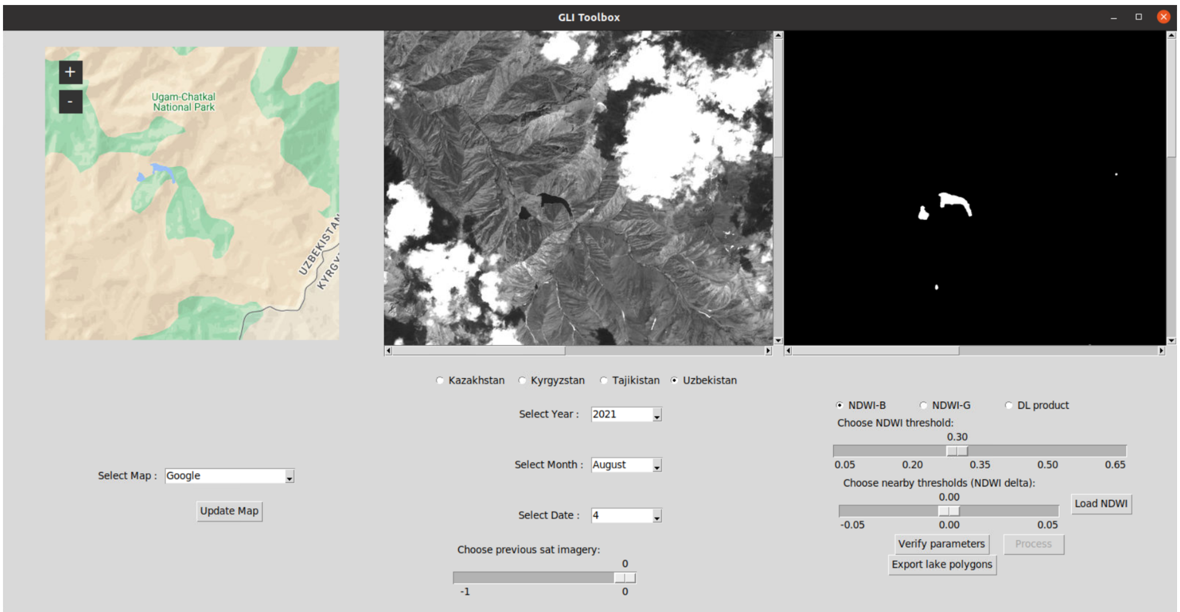


Figure 1. Snapshot of the GLOFCA Glacial Lake Mapping Analytical Toolbox

Section 1: How to install and open the toolbox?

Section 1.1 Toolbox installation

We recommend installing the toolbox on a computer with:

- *Operating system:* Windows 10 (64 bit)
- *RAM* 16GB or better
- *CPU*: Intel i5 (or similar) or better

We recommend installing the toolbox in the *C:\Users\<username>\Documents\Toolbox* folder (*Note*: the instructions provided below assume this folder path).

Follow the steps below (in the given order) to install the toolbox on a Windows PC:

- Clone the Toolbox GitHub repository (https://github.com/czarmanu/glofca/analytical_toolbox/Toolbox_windows)
- Copy the contents of "Toolbox_windows" folder to *C:\Users\<username>\Documents\Toolbox*
- Python 3 is a pre-requisite (https://www.python.org/downloads/). Some Python sub-libraries (*os, glob, subprocess, numpy, PIL, xlsxwriter, scipy, math, warnings, tkintermapview, pyproj*) need to be installed (using the *pip3* command) for the toolbox to function correctly. Some example installation commands (using *pip3*) are as follows:
  pip3 install tkintermapview
  pip3 install pyproj
  Note: *pip3* can be installed by following the instructions in:
  https://phoenixnap.com/kb/install-pip-windows
- Install *Anaconda Powershell Prompt* (if it not already installed). *Note*: while downloading and installing *Anaconda*, choose the configuration "just me"
- Once the *Anaconda Powershell Prompt* is installed, run it as *"Adminstrator" and*
  - Install *jupyter notebook* (https://jupyter.org/install)
  - Install *rasterio*. This can be done either using *pip3* with the command:
    pip3 install rasterio
    or using *conda* with the command:
    conda install -c conda-forge rasterio
  - Install *GDAL* using *conda* with the command:
    conda install -c conda-forge gdal
    After successful GDAL installation, the *gdal_polygonize.py* file will be created in the "Scripts" folder inside the *anaconda* installation folder. Do not forget to add this path to *GDAL_POLYGONIZE_FILE* variable in the
    C:\Users\<username>\Documents\Toolbox\notebooks\misc\paths.py
    For example,
    GDAL_POLYGONIZE_FILE ="C:\ProgramData\Anaconda3\Scripts\gdal_polygonize.py"
    Note: In some computers, add "r" just before the path, for example,
    GDAL_POLYGONIZE_FILE
    =r"C:\ProgramData\Anaconda3\Scripts\gdal_polygonize.py"
    Note: The anaconda installation folder might vary across computers.

Section 1.2 Opening the toolbox

Follow the steps below (in the given order) to open the toolbox:

- Start the *jupyter notebook*
  - Navigate to the Toolbox directory (*C:\Users\<username>\Documents\Toolbox*) by running the following commands (and press *Enter* key) in *Anaconda Powershell Prompt:*
    - cd C:\Users\<username>\Documents\Toolbox
  - Type "jupyter notebook" in the *Anaconda powershell prompt* and press *Enter* key. This will open the *jupyter notebook* in the web browser (Mozilla Firefox, Google Chrome etc.). If not automatically opened, copy and paste the link to the jupyter notebook (from the *Anaconda Powershell Prompt*) into a web browser
- In the web browser, open the notebook: "GLI_toolbox.ipynb"
- Start the kernel and run the whole notebook:
  - Run "Restart and Run All Cells"

Section 2: How to download and store the input satellite data?

The toolbox uses both Sentinel-2 and Sentinel-1 satellite data as input.

Section 2.1: How to download the Sentinel-2 data?

All Sentinel-2 tiles (from both S2A and S2B satellites, Level 1C, "Top of Atmosphere" product, "*.SAFE"* format) are downloaded using the Sencast toolbox. Instructions on installing the Sencast toolbox and downloading the Sentinel-2 data are at: https://renkulab.io/projects/odermatt/sentinel-hindcast

Note: The *T43TFH*, *T43TDH*, *T43SBB*, and *T42TXM* tiles are to be downloaded for Kazakhstan, Kyrgyzstan, Tajikistan and Uzbekistan respectively.

Section 2.2: How to download the Sentinel-1 data?

Synthetic Aperture Radar (SAR) data is downloaded in *.tif* format from Google Earth Engine (GEE) after performing the pre-processing steps (thermal noise removal, radiometric calibration, terrain correction). For more details on the Sentinel-1 data we use from GEE, refer to:
https://developers.google.com/earth-engine/datasets/catalog/COPERNICUS_S1_GRD

The javascript we developed to download the Sentinel-1 data from GEE is available in the GLOFCA git repository as: scripts_GEE\S1_dwnld_GRD_IW.js

Following are the steps to download the Sentinel-1 data:

1. Copy the contents of the javascript to the GEE code editor (Note: GEE account needed). Or, click the following direct link to GEE to access the download script:
   https://code.earthengine.google.com/cf9a8f0351ecd2a2b4c3c2c0b4b46d38
2. Set the main download parameters in the javascript as follows:
   a. Choose the region of interest (pilot site) using the "*roi*" parameter. The options available are: 'KZH', 'KYRG, 'TAJ', and 'UZB' for Kazakhstan, Kyrgyzstan, Tajikistan and Uzbekistan respectively
   b. Set the data download start and end dates using "*start_date*" and "*end_date*" parameters
   c. Choose the Sentinel-1 relative orbit number using the "*orbit*" parameter
      Note: For each pilot site, the available orbits are listed in the comments in the javascript. Additionally, do not forget to set the correct orbit type using the "*orbit_type*" parameter. For example, when choosing a descending orbit, set *orbit_type=dsc_only*. When an ascending orbit is chosen, set *orbit_type="asc_only"*
3. Run the script in GEE (click "Run") code editor
4. For saving the images to your Google drive (Google drive account needed), navigate to the "Tasks" panel in GEE code editor and click "Run" for each image (clicking "Control+Run" could speed up this process).
   Note: the images will be saved in the
   S1_<ROI>_lakes_mosaic_<POLARISATION>_<ORBIT_TYPE>_orb_<ORBIT_NUMBER><SUFFIX>
   folder in your Google drive. For example, the vv polarisation data from descending orbit 151 for the pilot site in Uzbekistan will be downloaded to the folder:
   "S1_UZB_lakes_mosaic_vv_dsc_orb_151"

5. Wait until the download finishes and download the images to your PC from google drive

Section 2.3 Where to store the input satellite imagery?

To use the Sentinel-1 and Sentinel-2 data as toolbox input, do the following:

- Store the Sentinel-2 data (.*SAFE* format) in the following directory:
  C:\Users\<username>\Documents\Toolbox_Data\<year>\<country>\Sentinel-2\all_tiles
  For example:
  C:\Users\tom\Documents\Toolbox_Data\2021\Kazakhstan\Sentinel-2\all_tiles

- Store the Sentinel-1 data (.*tif* format) in the following directory:
  C:\Users\<username>\Documents\Toolbox_Data\<year>\<country>\Sentinel-1
  For example:
  C:\Users\tom\Documents\Toolbox_Data\2021\Kazakhstan\Sentinel-1

Section 3: Toolbox features

The toolbox comprises of three windows, see Fig. 2:

- *Map window*: to select the Region Of Interest (ROI)
- *Satellite image window*: to visualise the Sentinel-2 satellite imagery for the chosen date. Note: A satellite image will be visualised in the middle window only when the correct date (on which an S2 image exists and is stored in the folder described in section 2.3) is chosen
- *Results window*: to visualise the results (lake pixel = white, background pixel = black) for the ROI selected using the left window

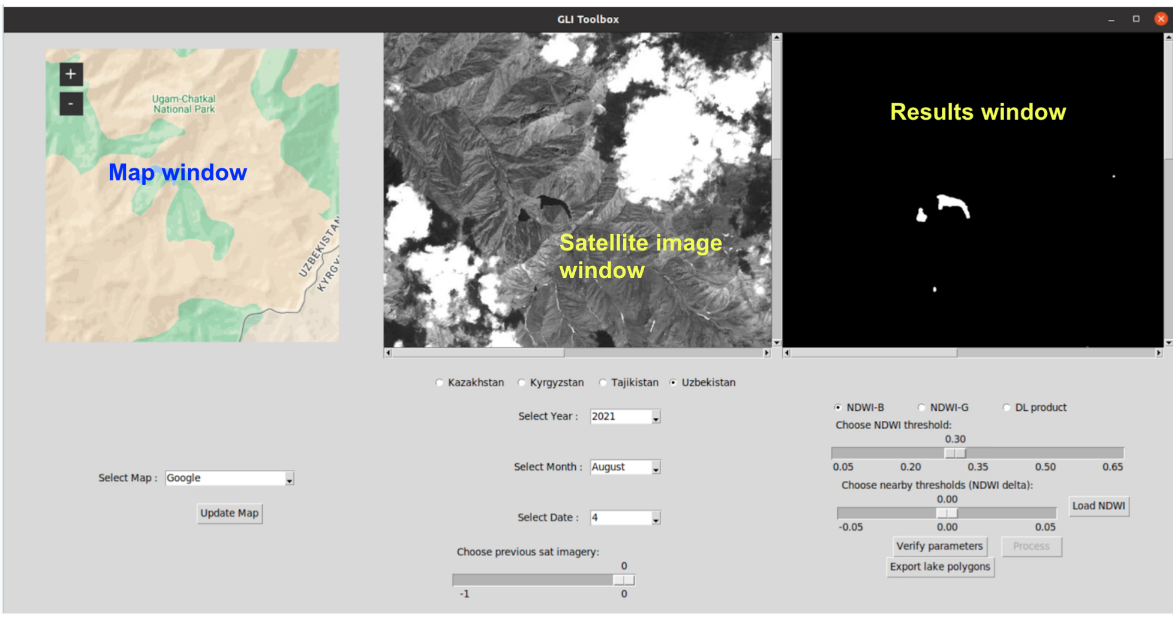
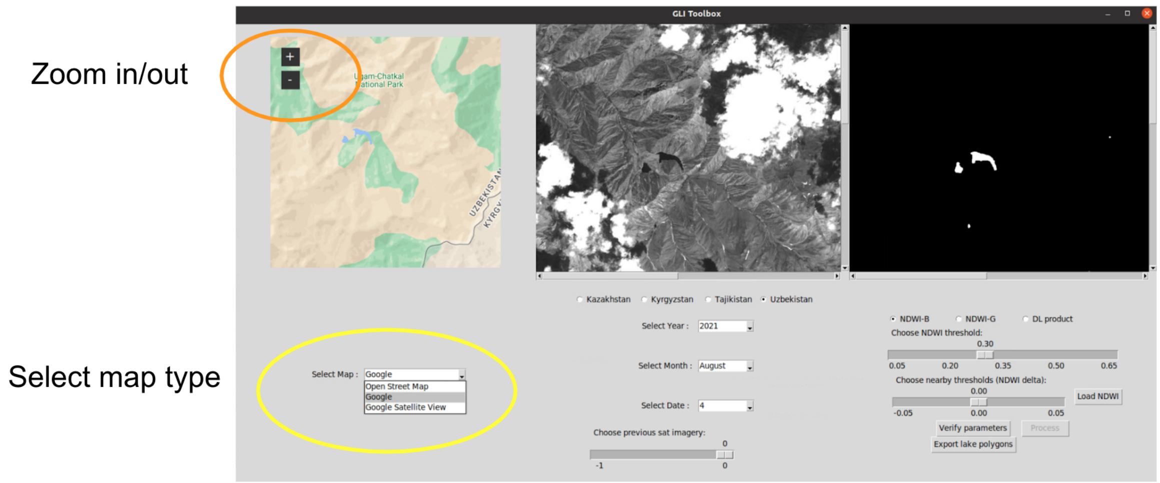
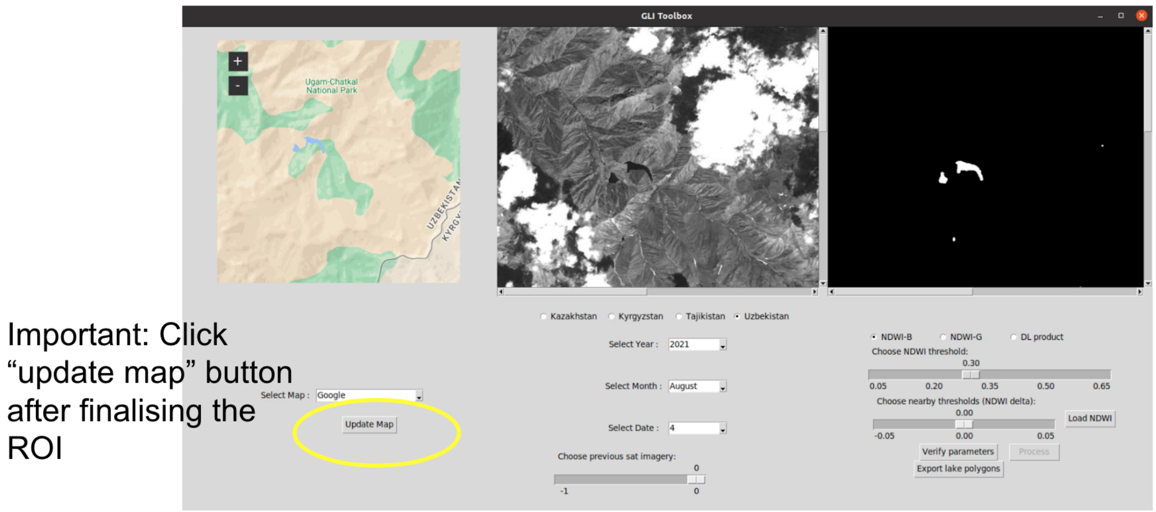


Figure 2. Toolbox windows

Map window. The map window (refer to Fig. 3) can be used to select the ROI. Usage of a mouse is recommended especially for the zoom-in and zoom-out functions. Three different types of maps (Open Street Map, Google, Google Satellite View) can be selected as highlighted in Fig. 3a. After selection, to load the new map type, click the “update map” button (see Fig. 3b).



a) Map type selection and zoom functionality



b) Update map button

Figure 3. Map feature in the toolbox

Note: Do not forget to click the *update map* button after choosing the ROI using the map window. Additionally, each time the map is updated and a new ROI is chosen, click the *update map* button.

Log window. The log window shows the toolbox execution log, errors and warnings (if any). The log window is not part of the toolbox Graphical User Interface (GUI). It can be spotted in the *GLI_Toolbox* tab (in the web browser, after the jupyter notebook is run). An example log window is shown in Fig. 4.

```
Your selection:
Country:  Uzbekistan
Year:  2021
Month:  August
Date:  4
Product type: NDWI b
NDWI threshold:  0.3

Chosen satellite image:  S2B_MSIL1C_20210804T060639_N0301_R134_T42TXM_20210804T071023.SAFE

Just previous (and current) satellite images:  ['S2B_MSIL1C_20210715T060639_N0301_R134_T42TXM_20210715T071659.SAF
E', 'S2A_MSIL1C_20210720T060641_N0301_R134_T42TXM_20210720T071400.SAFE', 'S2B_MSIL1C_20210725T060639_N0301_R134_T4
2TXM_20210725T071357.SAFE', 'S2A_MSIL1C_20210730T060641_N0301_R134_T42TXM_20210730T071723.SAFE', 'S2B_MSIL1C_20210
804T060639_N0301_R134_T42TXM_20210804T071023.SAFE']
ROI too big, choose a smaller window and try again
```

Figure 4. Example log window

Choosing the country. The radio button as shown in Fig. 5 can be used to choose the country.
Note: The toolbox shows an error in the log window if an ROI from one country is selected using the map window and a different country is selected using the radio button.

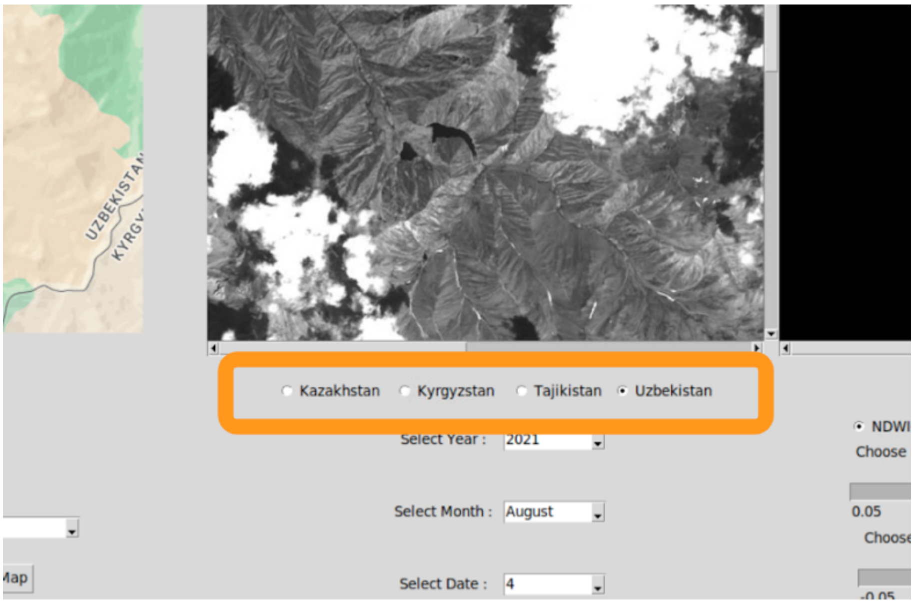


Figure 5. Choosing the country

Product selection. Three lake mapping products (NDWI-B, NDWI-G, DL product) are incorporated in the toolbox and can be selected using a radio button, see Fig. 6.

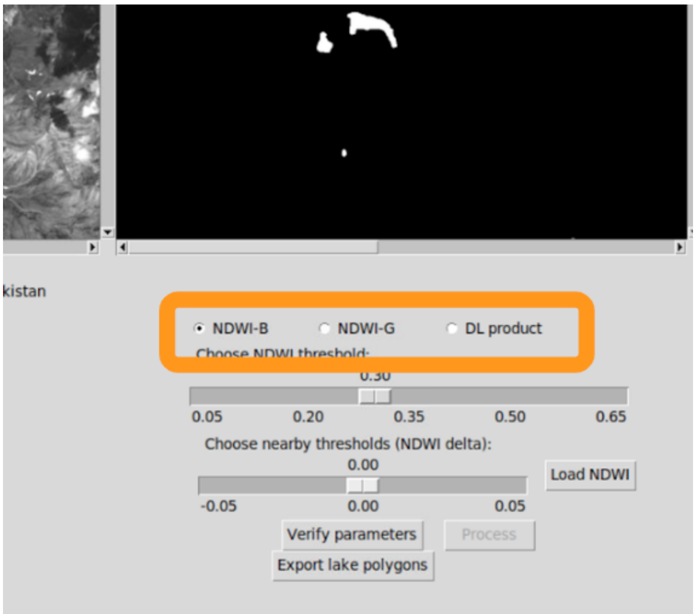


Figure 6. Three available lake mapping products

Lake mapping results can be generated using the two NDWI products whenever a Sentinel-2 image is available and stored in the folder as described in Section 2.3. The DL product is a weighted combination of NDWI-G results, Sentinel-2 DL results and Sentinel-1 DL results, and one DL result per month can be visualised in the toolbox. Note that the DL product cannot be generated on computers without a powerful dedicated Graphic Processing Unit (GPU, memory >10GB). Hence, it was processed on the UZH PC (24GB GPU memory) and the pre-computed DL results (for May-October 2021) can be loaded and viewed on normal computers (without GPU). Unzip and store the pre-computed DL results (already shared with the May 2023 webinar participants as "Toolbox_Results.zip") as per the following folder structure:
C:\Users\<username>\Documents\Toolbox_Results\<country>

For more details in NDWI-G and NDWI-B, refer Section 10.

Selecting year, month and date: To generate the lake mapping results, the year, month and date of the input satellite imagery can be selected using the combo boxes as highlighted in Fig. 7.

Note: the toolbox will throw an error in the log window if no input satellite imagery is available for the date chosen. In such a case, select the date for which the imagery is available (also shown in the log window) and try again.

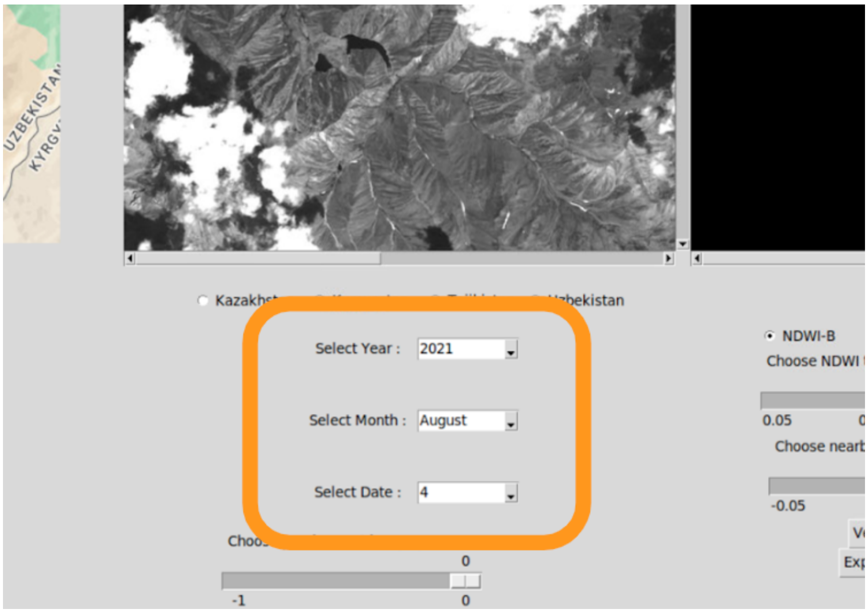
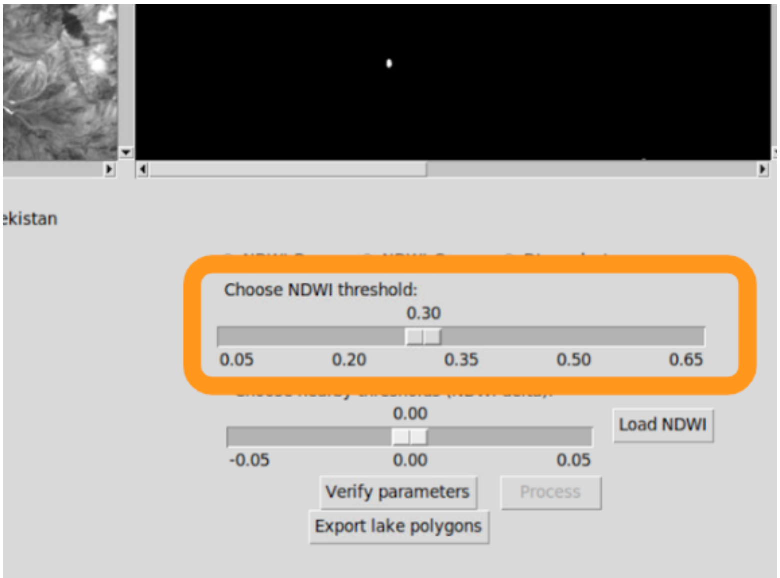


Figure 7. Selecting year, month, and date

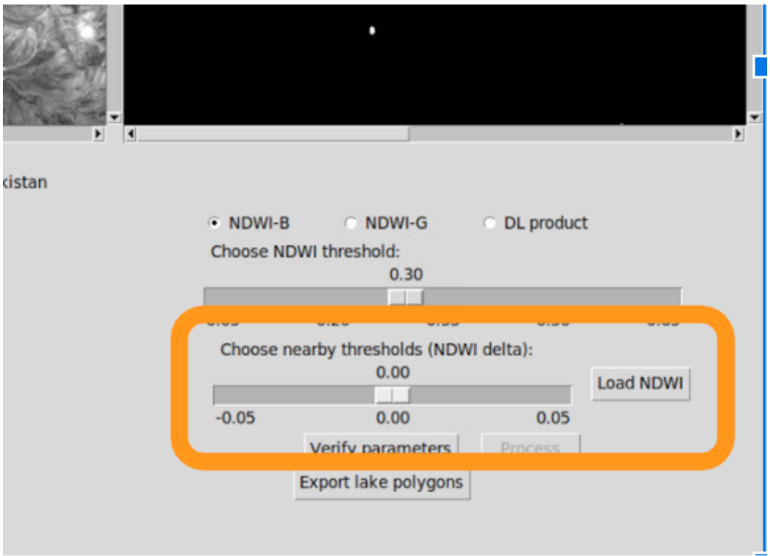
NDWI threshold (applicable only for NDWI-B and NDWI-G). If the product chosen is either NDWI-B or NDWI-G, the corresponding *threshold (T)* parameter can be set using the "Choose NDWI threshold" scale bar, refer to Fig. 8a. Any value between 0.05 and 0.65 can be set using this bar (granularity = 0.05). The lake mapping result for the chosen ROI, date, NDWI product, and threshold can then be generated by clicking the *Process* button, see Fig. 9a. Once the result is generated and visualised for threshold *T*, the results for nearby thresholds (Threshold +/- delta) can be visualised using the "Choose nearby thresholds (NDWI delta)" scale bar and "Load NDWI" button, see Fig. 8b. Note that the "*Load NDWI*" button needs to be clicked to visualise the new results after the threshold delta (*d*) value is selected using the "Choose nearby thresholds (NDWI delta)" scale bar. This threshold adjustment can be done at a granularity of 0.01. The effective threshold value will be: $T + d$

Some examples are as follows:

- Threshold (*T*) = 0.30, delta (*d*) = 0.03 (effective threshold = 0.33)
- Threshold (*T*) = 0.30, delta (*d*) = -0.02 (effective threshold = 0.28)



a) *Scale bar* to choose the NDWI threshold



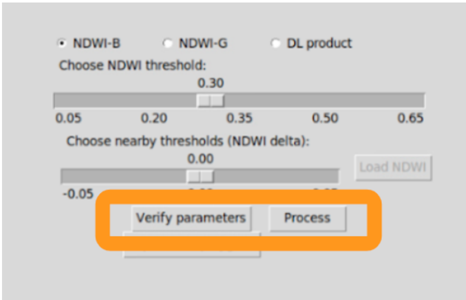
b) *Scale bar* and *Load NDWI* button to adjust the chosen NDWI threshold

Figure 8. Setting the NDWI threshold

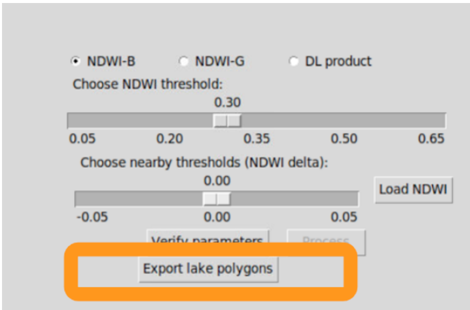
***Verify parameters* and *process*.** To generate the results for a chosen set of parameters (country, year, month, date, product etc.), click the the *process* button, see Fig. 9a. The *process* button will be active only when the correct parameters are selected and verified. To check if the right parameters were chosen, click the *verify parameters* button prior to clicking the *process* button, refer to Fig. 9a. If the *process* button remains inactive even after clicking the *verify parameters* button, check the *log window* for warnings, update and verify the parameters again until the process button becomes active, refer also section 5.

Some tips:

- Before verifying the parameters and processing, confirm that the chosen ROI (map window) matches with the country selected
- For DL and NDWI products, if no S2 image is found on the date chosen, the *process* button will be inactive, but a list of available images will be shown in the *log window*. Re-select one of the available dates from the list and click the *verify parameters* button for the *process* button to be active.



a) *Verify parameters* and *process* buttons



b) Export lake polygons button

Figure 9. Some toolbox buttons

Exporting vector shape files. The processing time depends on the chosen ROI size, the computer configuration etc. Once the processing is complete, the "*Export lake polygons*" button will be active, see Fig. 9b. Click that button to generate the detected lake outlines as shape (.*shp*) files. For more details on the toolbox outputs, refer to Section 7.

Monitoring lake dynamics (applicable only for NDWI-B and NDWI-G products)**.** For monitoring the temporal dynamics of the glacial lake(s) in the region of interest, the previous satellite imageries available and corresponding results can be visualised in the *satellite image window* and *results window* respectively by sliding the "Choose previous sat imagery" timeline scale bar, see Fig. 10. The number of previous imagery that can be monitored can be configured using the "*TL_BAR_SPAN*" parameter in
C:\Users\<username>\Documents\Toolbox\notebooks\misc\parameters.py
For example, the toolbox visualised in Fig. 10 has *TL_BAR_SPAN=3* where up to three previous (available and stored in the correct folder as described in section 2.3) satellite imagery and

corresponding results can be visualised.

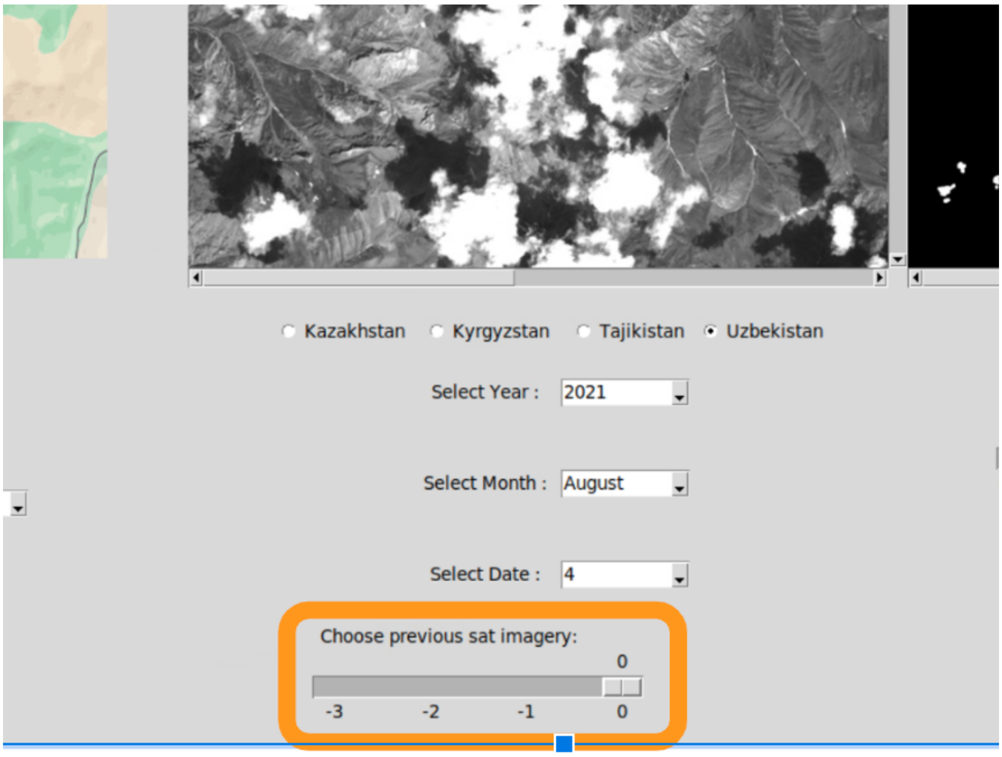


Figure 10. Lake dynamics monitoring scale bar

Section 4. How to select the correct ROI?

Follow the steps shown in Fig. 11 to select the correct ROI and to generate the lake mapping results. While choosing the ROI, we recommend the user to navigate to inside the correct pilot site (for the country chosen) using the map window.

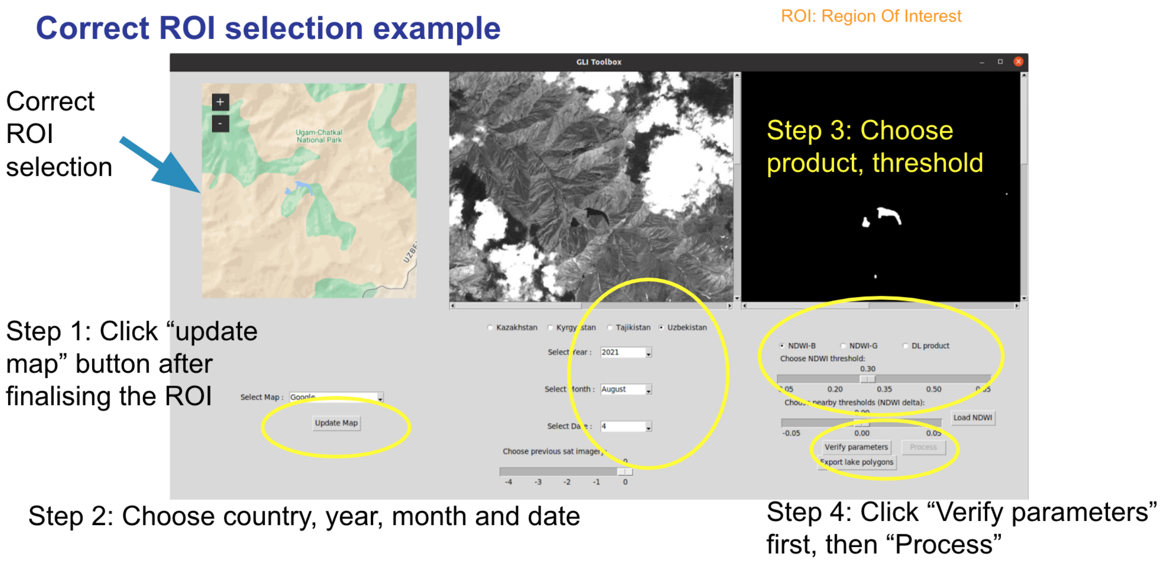
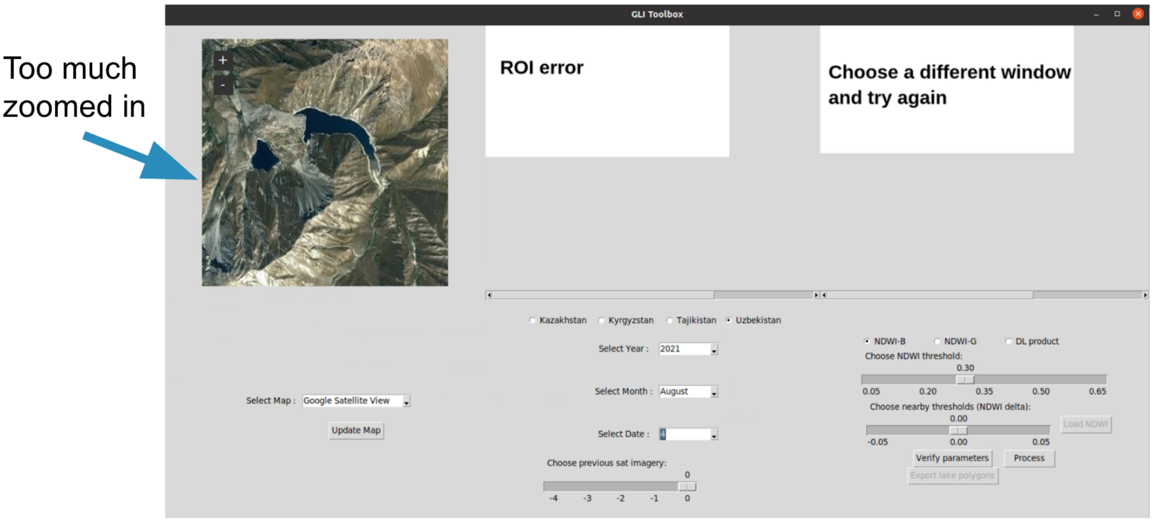


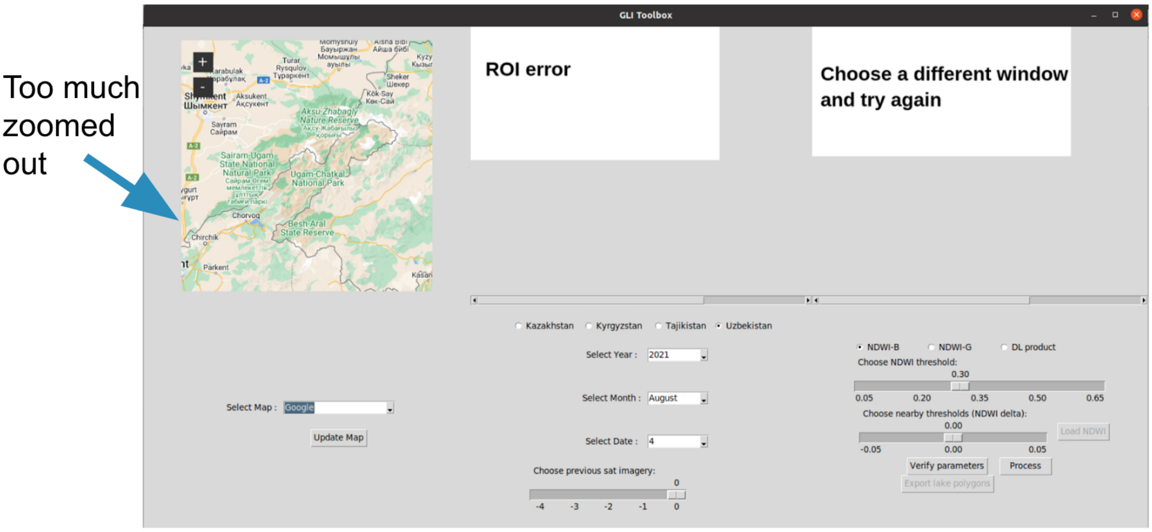
Figure 11. Steps to generate the lake mapping results

There are several ways the ROI selection can go wrong. The toolbox and log window will throw errors in such cases. Three cases are explained in Fig. 12.



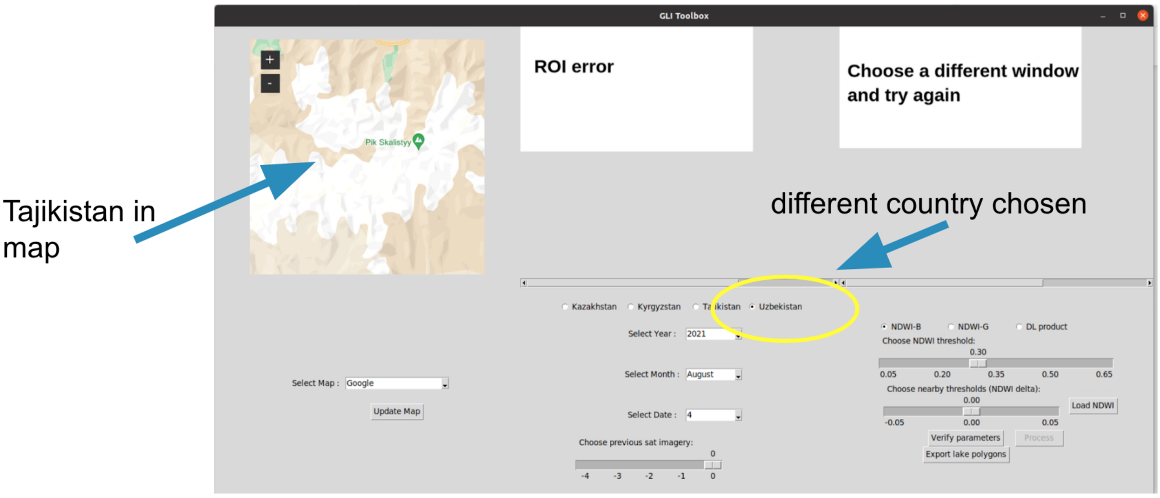
Log window error: "ROI too small, choose a bigger window and try again"

a) Case 1: Too small ROI



Log window error: "ROI too big, choose a smaller window and try again"

b) Case 2: Too big ROI



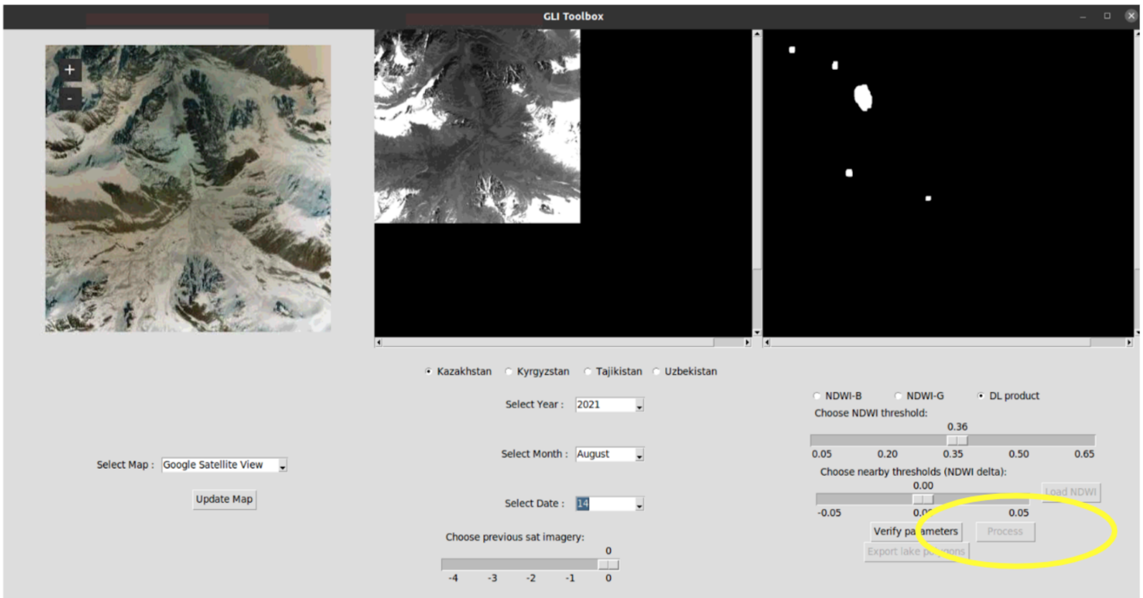
Log window error: “Chosen ROI outside the pilot site, choose ROI again”

c) Case 3: Chosen ROI outside the coverage area (pilot site)

Figure 12. Some wrong ROI selection examples

Section 5. Case: Inactive process button

Selecting and verifying the correct set of parameters is critical for the process button to be active**.** An example case of an inactive process button (even after choosing all the parameters) is shown in Fig. 13a. The corresponding output in the log window is displayed in Fig. 13b. Active process button after choosing the correct parameters (August 3 instead of August 14) is shown in Fig. 13c.

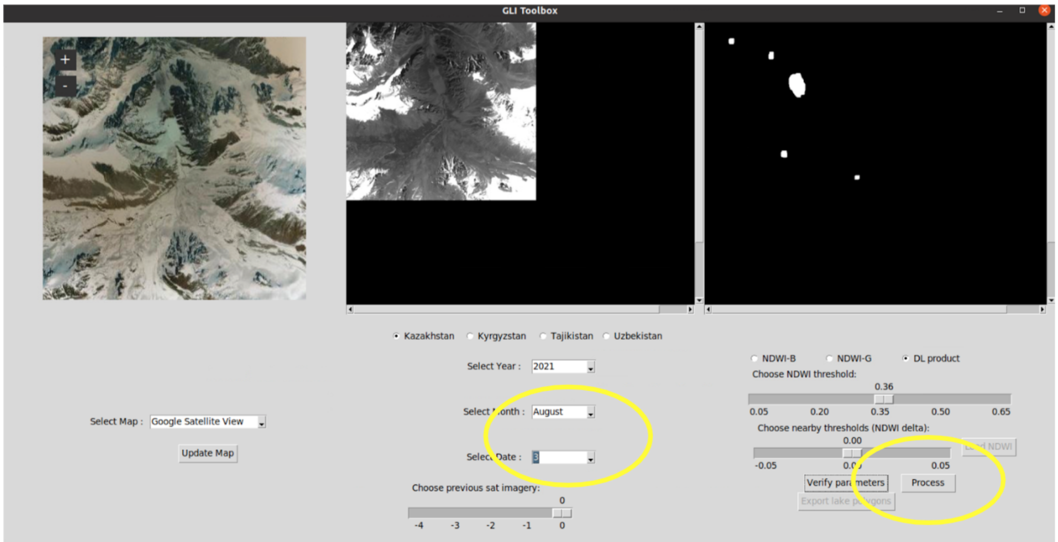


a) Example: inactive process button

```
Your selection:
Country:  Kazakhstan
Year:  2021
Month:  August
Date:  14
Product type: DL

For visualisation, no Sentinel-2 image found on this date. Try again with a different date
Some possible dates in current month ['20210803', '20210805', '20210808', '20210810', '20210813', '20210815', '202
10818', '20210820', '20210823', '20210825', '20210828', '20210830']
```

b) Log window output



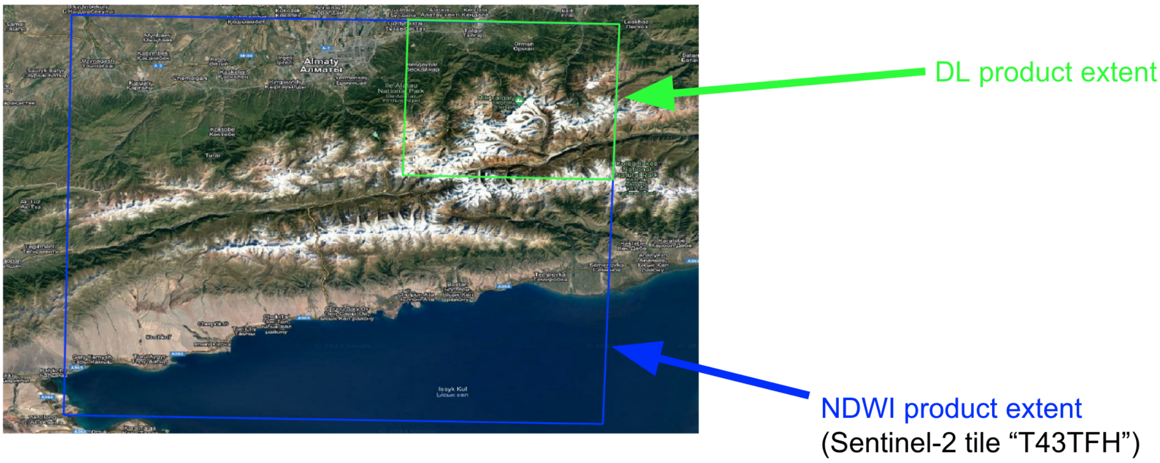
c) Active process button after choosing the correct parameters and clicking “verify parameters” button

Figure 13. Case: inactive process button

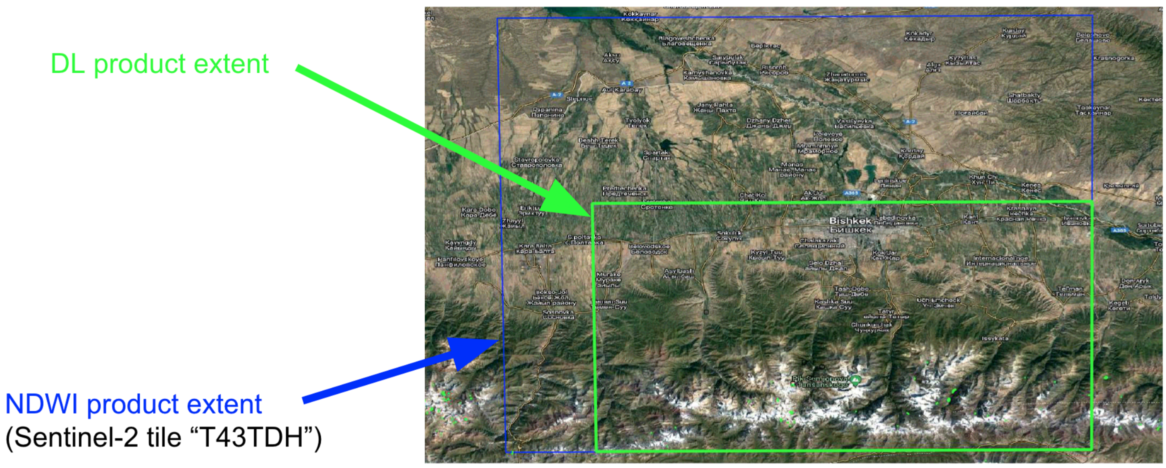
Section 6: Temporal and spatial coverage

Temporal coverage. For the four target countries, the toolbox can be used to detect glacial lakes in the pilot sites in the months of May to October 2021 (both inclusive). Refer also to Section 3 ("Selecting year, month and date") and Fig. 7.

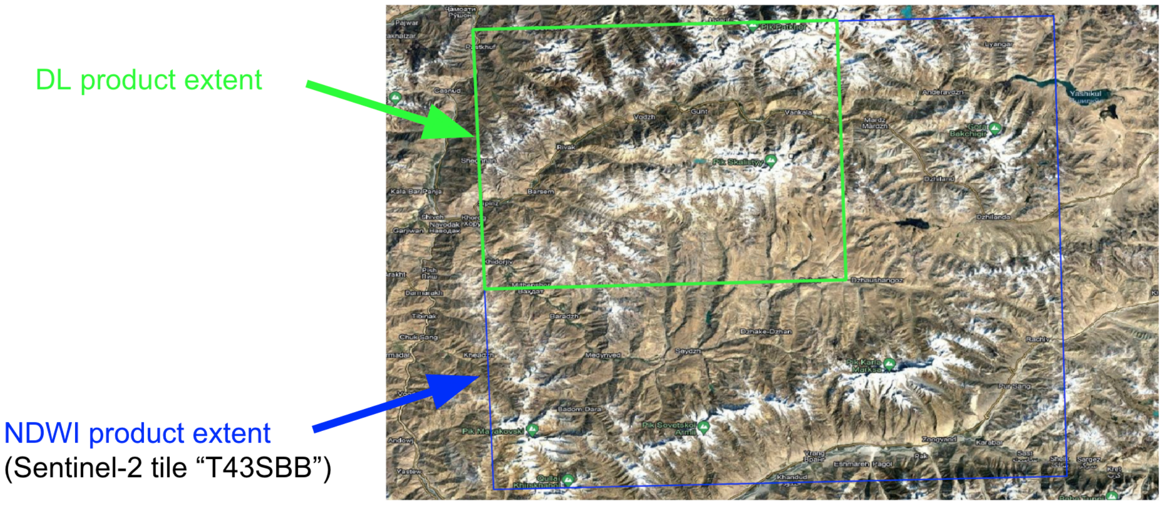
Spatial coverage. Fig. 14 shows the regions that can be monitored (in and around the pilot sites) using the NDWI (blue) and DL (green) products. The coverage for Kazakhstan, Kyrgyzstan, Tajikistan and Uzbekistan are shown in sub-figures 14a, 14b, 14c and 14d respectively.



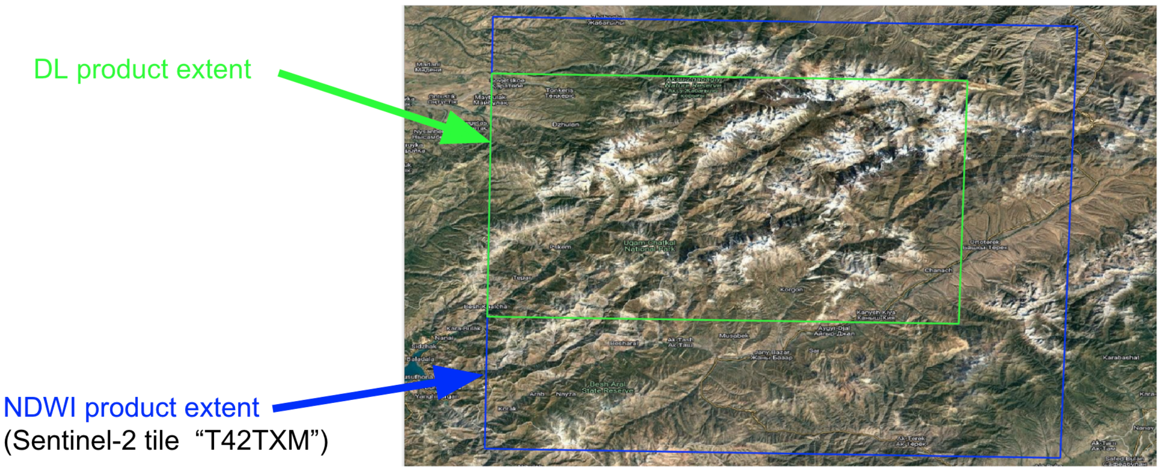
a) Spatial coverage: Kazakhstan



b) Spatial coverage: Kyrgyzstan



c) Spatial coverage: Tajikistan



d) Spatial coverage: Uzbekistan

Figure 14. Regions near the pilot sites in the four target countries that can be monitored using the toolbox

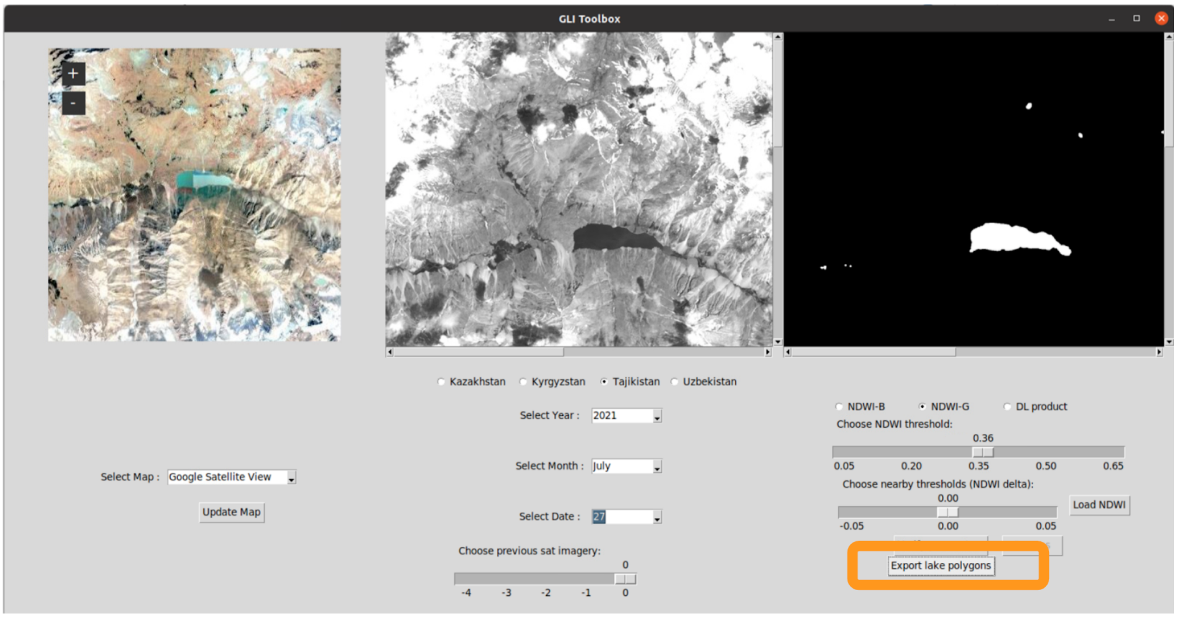
Section 7: Toolbox outputs

The toolbox outputs can be generated by clicking the "Export lake polygons" button, see Fig 15a. Refer also to Section 3 ("Exporting vector shape files"). The outputs will be generated in the folder:
C:\Users\<username>\Documents\Toolbox\notebooks\lake_monitoring\

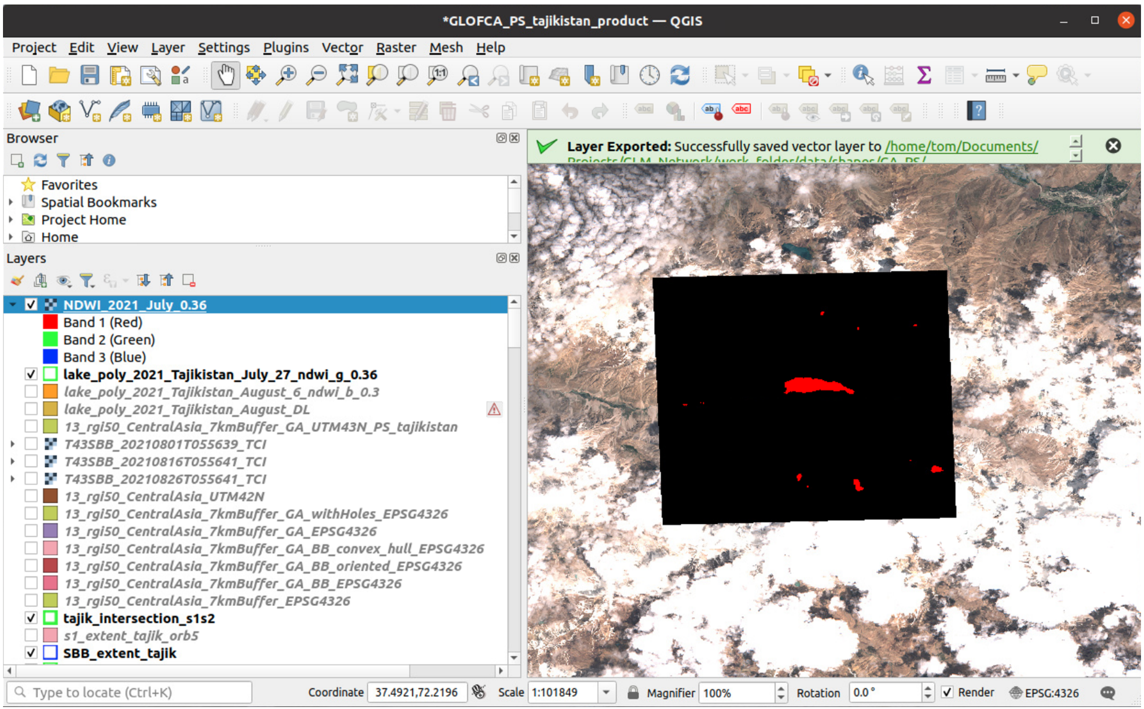
Both vector (*.shp* files) and raster (*.tif* file) outputs are generated, see Fig. 15c and 15b respectively. The detected lake outlines in vector format will be automatically saved in the folder:
C:\Users\<username>\Documents\Toolbox\notebooks\lake_monitoring\lake_polygons\<country>

The corresponding results in raster format (.tif) will be stored in the folder:
C:\Users\<username>\Documents\Toolbox\notebooks\lake_monitoring\rasters\<country>

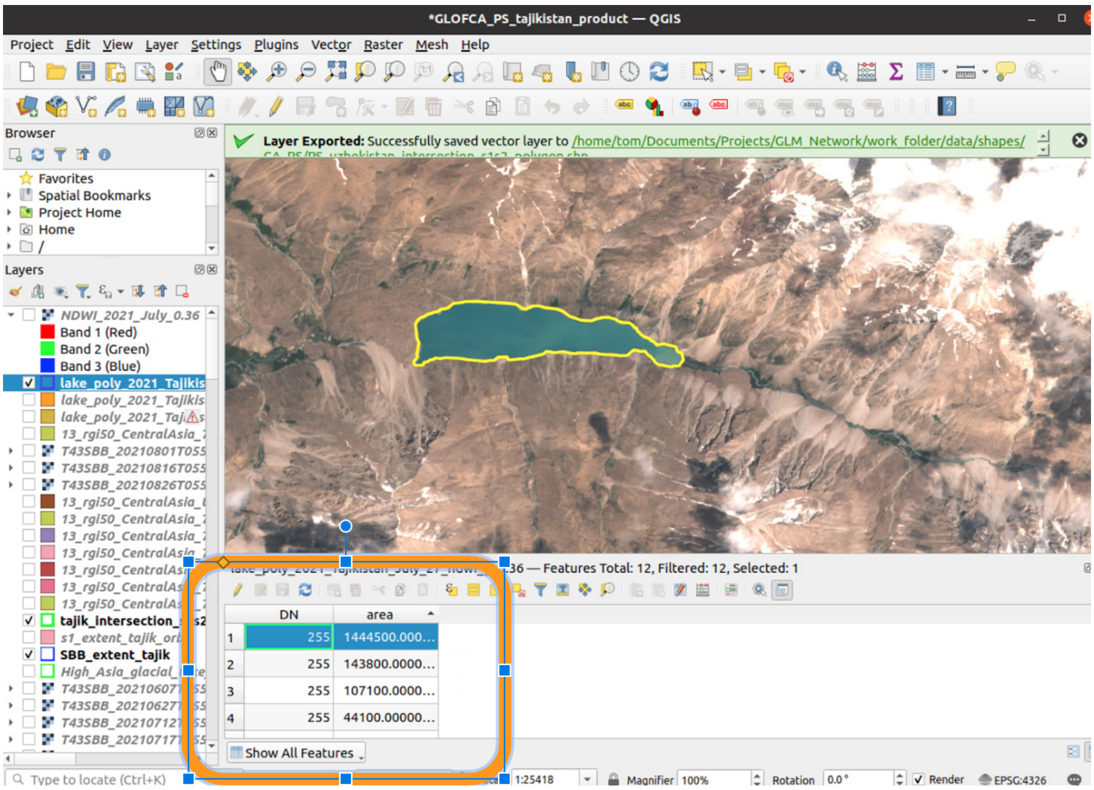
The *.shp* and *.tif* results thus generated can be imported and visualised in GIS software such as QGIS, ArcGIS etc. for further analysis. The *.shp* file also includes the area (in m^2) of the detected lakes and can be accessed using the "Open Attribute Table" in QGIS, see the highlighted part in Fig 15c.



a) "Export lake polygons" button to generate the outputs



b) Example raster output (*.tif* format, visualised in QGIS software)



c) Example lake outline vector (polygon, *.shp* format, visualised in QGIS software). Also, the attribute table showing the area (in m^2) of the detected lakes is highlighted

Figure 15. Toolbox outputs

Section 8: Toolbox extension and application to other years

The toolbox allows monitoring of glacial lakes in the pilot sites during the summer months in 2021, refer to Section 6 for more details. Follow the instructions below to apply the toolbox to other years (for example, 2025) or to different months in 2021 (for example, November):

- Code modification:
  - in *mainWindow.py*, *createComboBox* function, modify the *boxchosen['values']* for
    - *box_type=='Year'* to include a new year
    - *box_type=='Month'* to include a new month
- Data download (for NDWI product):
  - Download the Sentinel-2 tiles for the new month(s)/year(s), refer also Section 2.1
  - Create a new folder for each new year and store the corresponding Sentinel-2 data (see also Section 2.3) in the newly created folder. For example, for Kazakhstan, the new data for year 2025 should be downloaded and stored in:
    C:\Users\<username>\Documents\Toolbox_Data\2025\Kazakhstan\Sentinel-2\all_tiles\
- Computation of DL results:
  - Download the Sentinel-2 tiles and Sentinel-1 orbits for the new month(s)/year(s), refer Sections 2.1 and 2.2
  - Generate the DL product for the new month(s)/year(s) in the UZH PC and transfer the results to the computer on which the toolbox is installed

Section 9. Toolbox extension and application to other regions

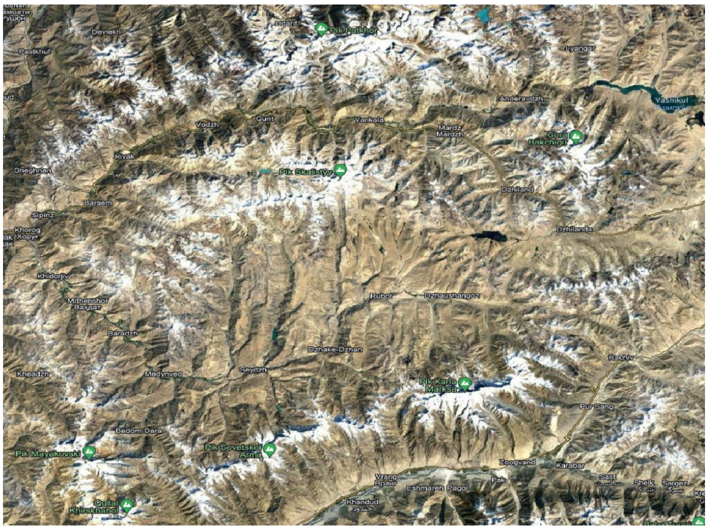
Only the pilot sites in four target countries (see Section 6 for details) can be monitored using the toolbox. Redesign of the toolbox is needed to monitor new target regions. At present, the toolbox can generate results only for regions that lie within the boundaries of a single Sentinel-2 tile (for the NDWI product) and a pre-defined S1 orbit (that covers the pilot site). Design and implementation of a new image stitching functionality in order to accommodate the multiple tiles (Sentinel-2) and orbits (Sentinel-1) that cover the new target regions, is needed. Additionally, download and provide the Sentinel-2 and Sentinel-1 data for the new region as input to the toolbox. In addition, the DL product needs to be generated (in UZH PC) for the new regions and transferred to the computer on which the toolbox is installed.

Section 10. NDWI

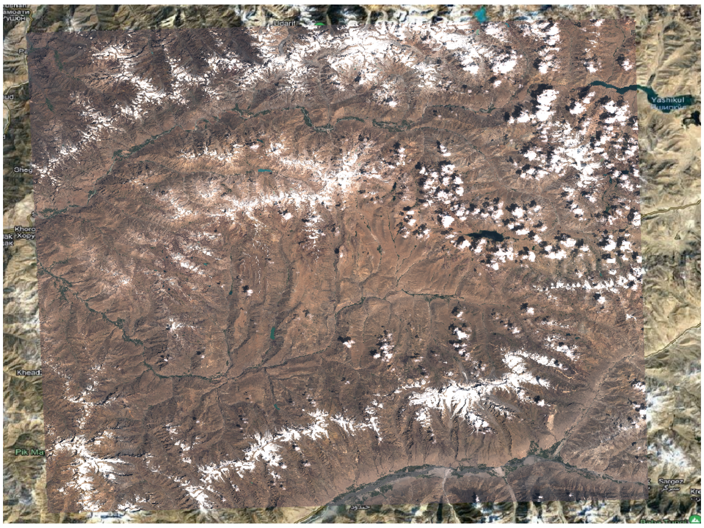
Water bodies can be mapped using NDWI (Normalised Difference Water Index). An example NDWI-G product for the tile T43SBB is shown in Fig 16.

For more details on NDWI-G index, refer to
S. K. McFEETERS (1996) The use of the Normalized Difference Water Index (NDWI) in the delineation of open water features, International Journal of Remote Sensing, 17:7, 1425-1432, DOI: 10.1080/01431169608948714

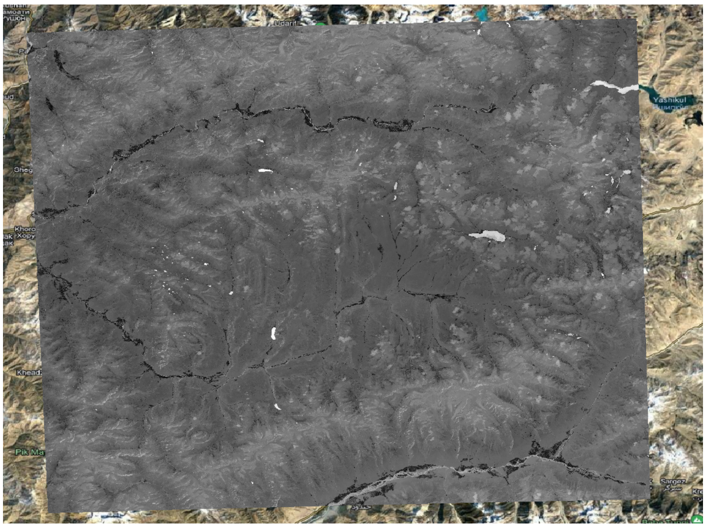
For more details on NDWI-B, refer to
Huggel, C., Kääb, A., Haeberli, W., Teysseire, P., Paul, F., 2002. Remote sensing based assessment of hazards from glacier lake outbursts: a case study in the Swiss Alps. Can. Geotech. J. 39, 316–330. https://doi.org/10.1139/T01-099



a) Region in and around the Sentinel-2 tile T43SBB (as in OpenStreetMap)



b) The T43SBB True Colour Image (TCI, L1C, 06 Aug 2021) overlaid on OpenStreetMap



c) NDWI-G (T43SBB, 06 Aug 2021, L1C)

d) Thresholded NDWI-G (T >= 0.28) product

e) Thresholded NDWI-G (T >= 0.36) product

Figure 3. Example water body mapping results for the Sentinel-2 tile T43SBB (06 Aug 2021).