ASSESSMENT OF GLACIER LAKES DEVELOPMENT IN CENTRAL CAUCASUS

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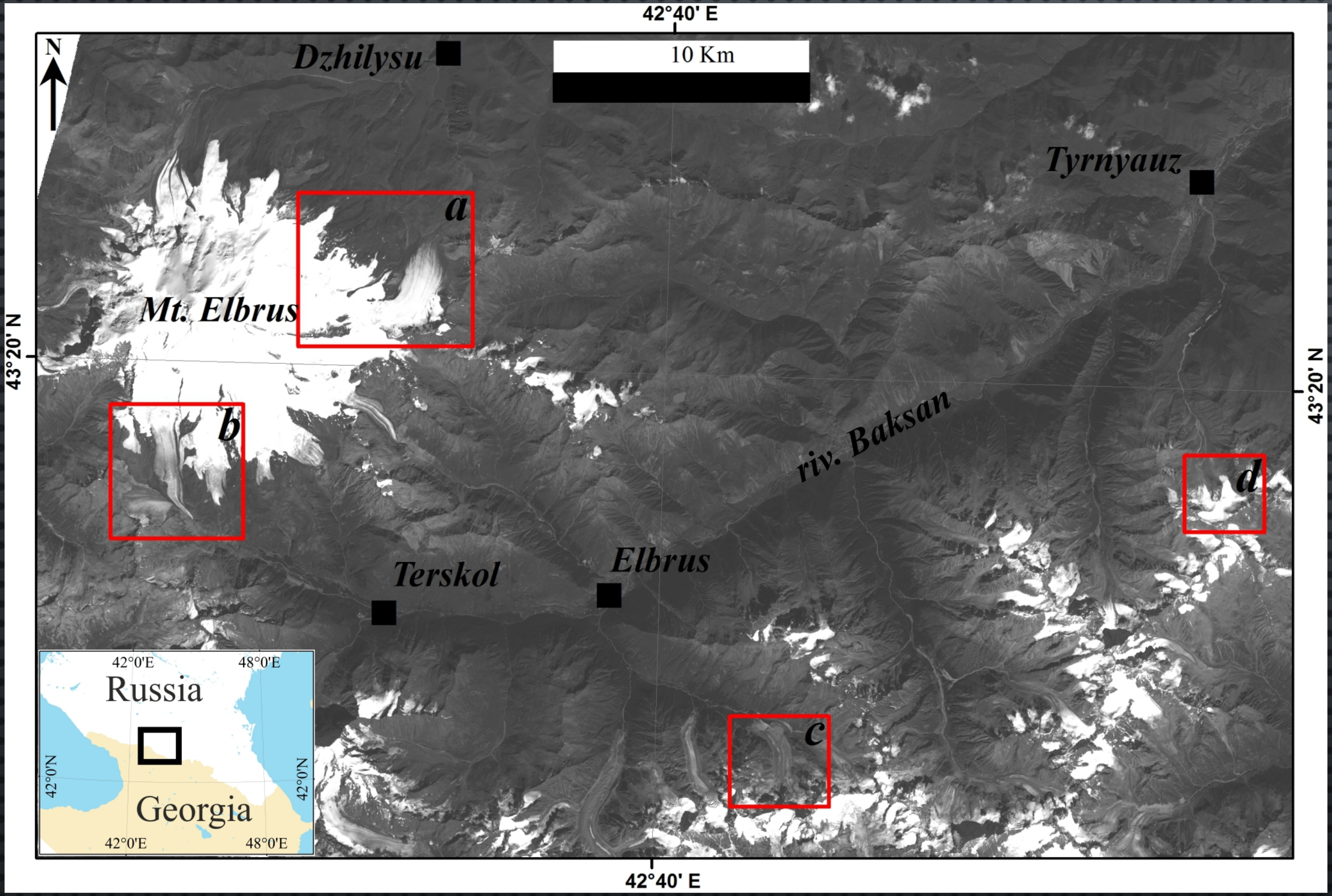
Area of interest: Elbrus area, Caucasus



Data

GPR: a,b (**Kutuzov et el., 2019**), c (**this study**) and modelled: d (**Farinotti et al., 2019**) ice thickness; Pléiades, SPOT, SRTM DEMs and topo maps

Methods of bed overdeepenings detection:

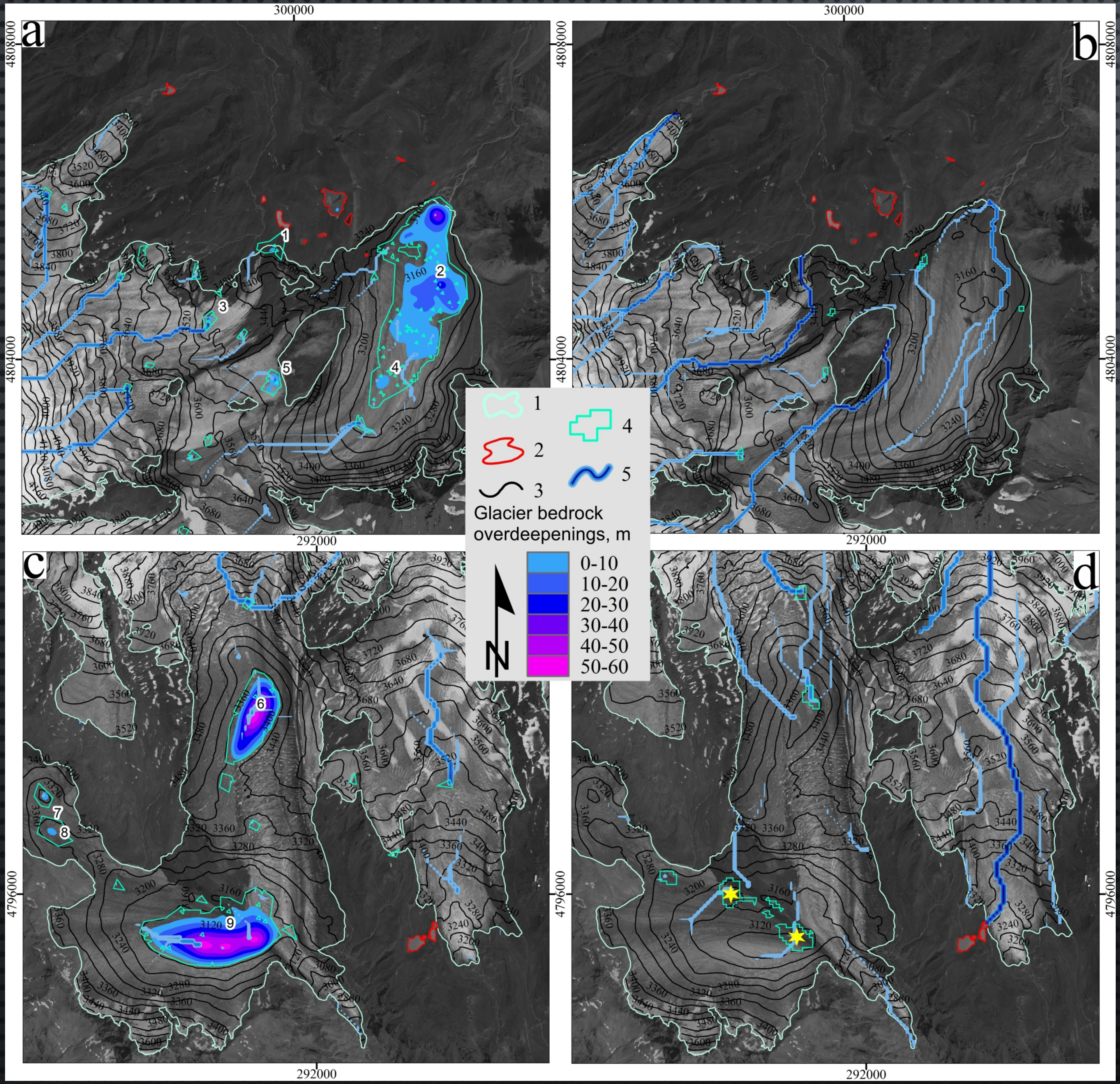
1. From **Linsbauer et al., 2016** by filling them with a standard geoinformatic hydrology tool in ARCGIS and bathymetry rasters construction
2. Calculating of hydraulic potential (**Copland and Sharp, 2000)** to find potential sites with subglacial lakes and model drainage network: $\boldsymbol{\phi = \rho_W g B + f \rho_i g (H - B)}$,

$\boldsymbol{\rho_w}$ and $\boldsymbol{\rho_i}$ - densities of water and ice, kg/m^3; ***g*** - gravity, *m*/sec^2; *B* - bed elevation, m; ***f*** is the subglacial water pressure as a fraction of ice-overburden pressure, ***H*** - surface elevation, m;

- Water flows from areas of high to areas of low hydraulic potential, and normal to the equipotential contours.
- Closed contours in the field of hydraulic potential indicate the existence of overdeepenings (when ***f***=0) and possible subglacial lakes (when ***f***=1).

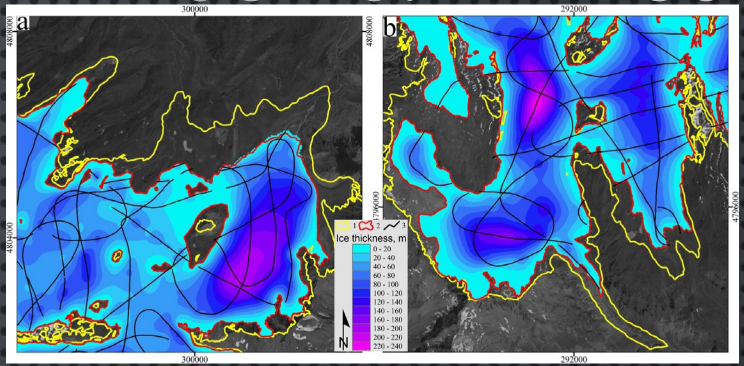
Both methods give very similar results. To minimize errors we used a criteria for overdeepenings selection based on DEMs resolution (3.2-30 m): the lower threshold of the potential lake area is assumed to be 1000 m^2.

- ESTIMATION OF THE LOCATION AND VOLUME OF THE POTENTIAL GLACIER LAKES BASED ON GROUND AND AIRBORNE GPR DATA, AS WELL AS RESULTS OF GLOBAL ICE THICKNESS MODELS.
- SELECTED GLACIERS ARE LOCATED ON THE NORTH-EASTERN (A) AND SOUTHERN (B) SLOPES OF ELBRUS AS WELL AS IN THE ADYL-SU (C) AND GERKHOZHAN-SU (D) VALLEYS.
- THERE ARE INFRASTRUCTURE FACILITIES IN THE VALLEYS BELOW THESE GLACIERS THAT CAN BE EXPOSED TO DANGEROUS IMPACTS IN CASE OF GLOFS



RESULTS: ELBRUS

1 – glacier outlines1957
2 - glacier outlines 2017
3 – GPR profiles



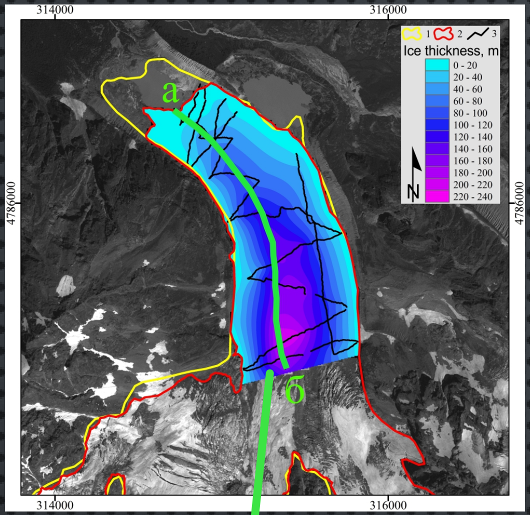
Based on Kutuzov et el., 2019 data

- Nine bedrock overdeepenings were found on selected glaciers and a subglacial drainage network was modelled (see Figure).
- The largest overdeepenings (№№ 2, 6 and 9) with an area of 1026, 195 and 415 x 10^3 m^2, respectively, are located on the bed of the Djikiugankez and Bolshoy Azau glaciers, with volume 7355, 4522 and 9380 x 10^3 m^3, respectively (see Figure a,c).
- Large modern subglacial lakes with an area of 42 and 51 x 10^3 m^2 could be located under Bolshoy Azau glacier (indicated by yellow stars at Figure d)

Overdeepenings (m) at the Elbrus glaciers bedrock according to radar data and reconstructed subglacial drainage network without glaciers (f = 0) (a, c) and with glaciers (f = 1) (b, d). 1 – glacier outlines in 2017; 2 – modern glacier lakes; 3 – contour lines of the glacier bedrock topography; 4 – bedrock overdeepenings; 5 – subglacial drainage pathways (color intensity indicates relative drainage area).

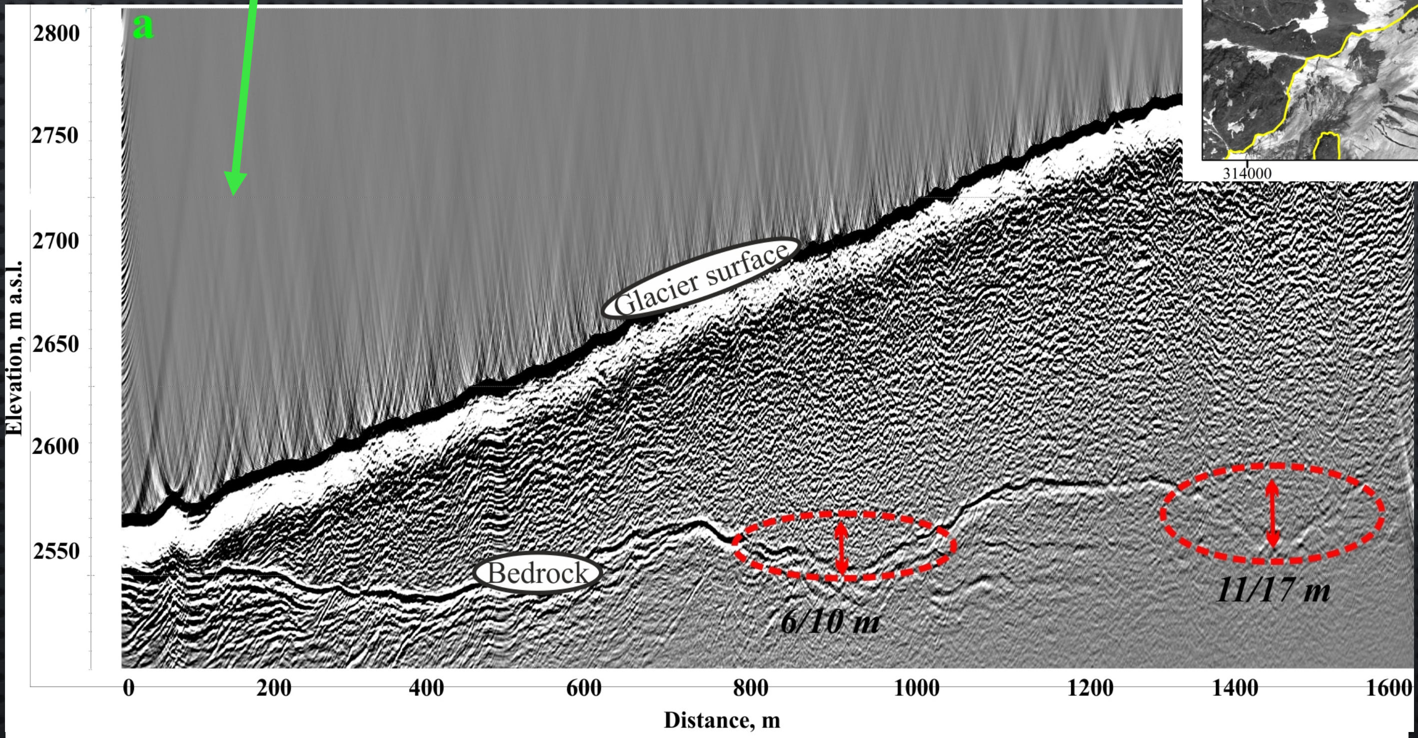
RESULTS: GLACIER BASHKARA

Ice thickness measurements in 2010 и 2017, ~30 km GPR profiles

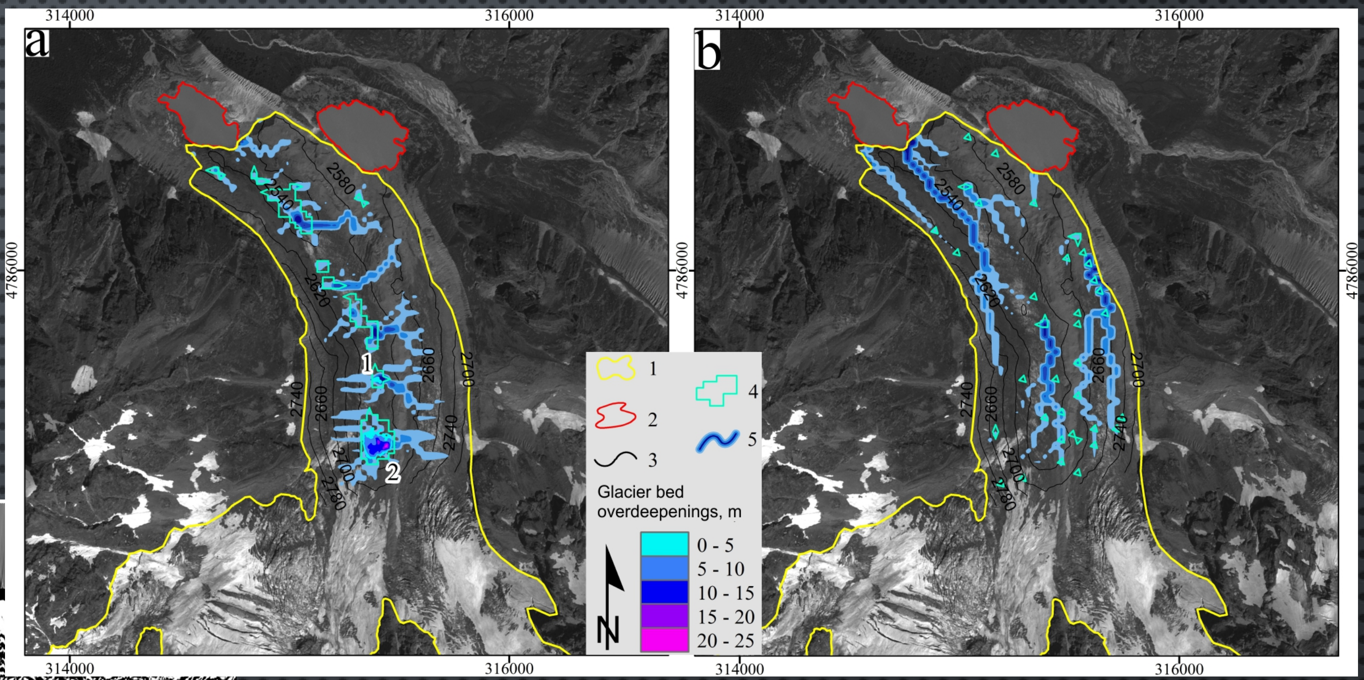


1 – glacier outlines 2000; 2 - glacier outlines 2017; 3 – GPR profiles

Mean/max ice thickness of measured part: 75.5 / 215 m. Ice volume: 88 x 10^6 m^3



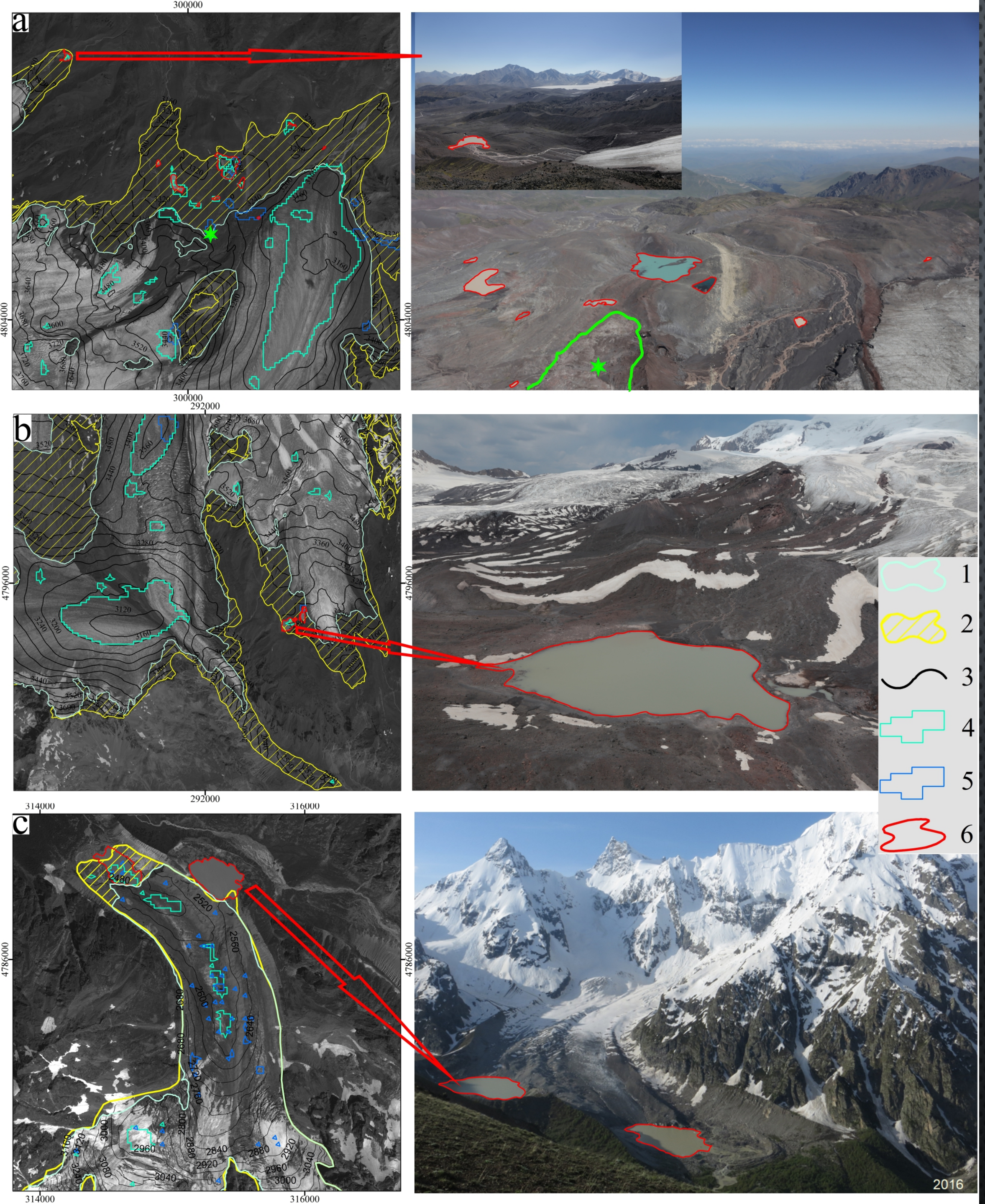
An example of a processed radargram obtained on the Bashkara glacier in 2017. Red ovals indicate bed overdeepenings, where water can accumulate. Numbers indicate med/max depth of bedrock overdeepenings along radar profile



Overdeepenings (m) at the Bashkara glacier bed according to radar data and reconstructed subglacial drainage network without glacier (*f* = 0) (*a*) and with glacier (*f* = 1) (*b*). *1* – glacier outlines in 2017; *2* – modern glacier lakes; *3* – contour lines of the glacier bedrock topography; *4* – bedrock overdeepenings; *5* – subglacial drainage pathways (color intensity indicates relative drainage area).

The largest overdeepening located in1.5 km from glacier front have area 14 000 m^2 and volume 100 000 m^3 (2 times less than volume of the modern lake Lapa (left one). In the field of hydraulic potential when f = 0 nine closed contour lines are found, 2 of them correspond to those found by the first method.

RETROSPECTIVE MODELLING

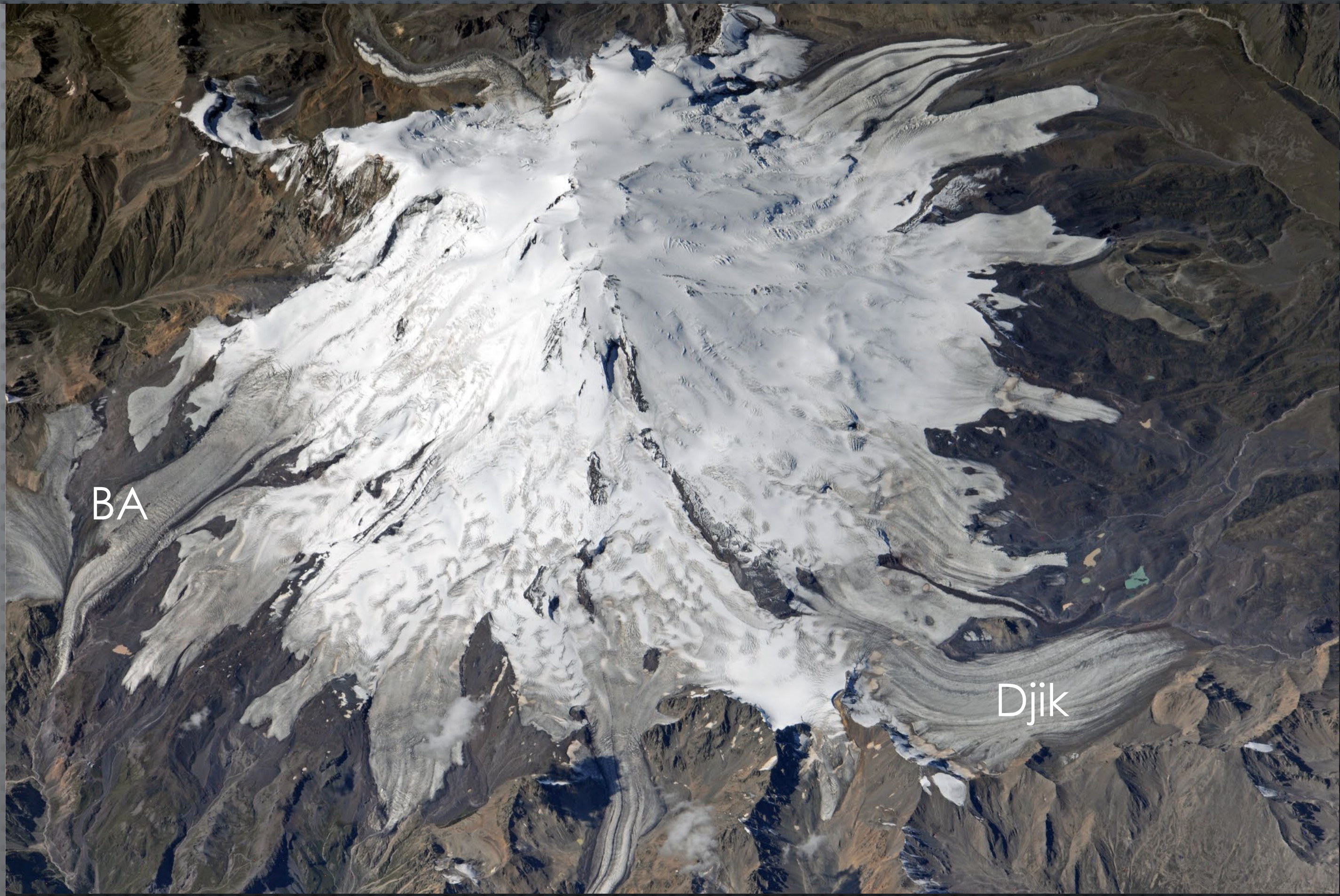


- The methodology was tested by retrospective modeling of Bolshoy Azau and Djikiugankez glaciers bed topography using 1957 topographic map.
- Seven existing lakes were predicted by the hydraulic potential in the areas where glaciers disappeared by 2017. Six overdeepenings on Djikiugankez glacier bed as of 1957 are currently absent, which might be related to the model uncertainties and the original DEMs errors, as well as to possible filling of lakes by sediments.
- Retrospective modeling of the Bashkara glacier bed topography based on SRTM DEM (2000) showed significant growth potential of the existing lake Lapa.

Position of reconstructed bedrock overdeepenings under glaciers: Mikelchiran and Djikiugankez (a); Bolshoy and Maliy Azau (1957) (b); Bashkara (2000) (c).
1 – glacier outlines in 2017; 2 – parts of glaciers that disappeared from 1957/2000 to 2017; 3 – contour lines of the glacier bedrock topography; 4 – bedrock overdeepenings without glaciers (f = 0); 5 – bedrock overdeepenings with glaciers (f = 1); 6 – modern glacier lakes (also highlighted on photographs). Green star and outline on (a) show lake that broke through on 11.08.2006.

CONCLUSION

- WHEN STUDIED GLACIERS MELTED AT LEAST 11 NEW LAKES WITH TOTAL AREA OF ABOUT 1.7 KM^2 AND AN AVERAGE DEPTH OF 8 M WILL FORM.
- THE DEEPEST LAKE (56 M MAX/23 M MEAN) WILL BE FORMED AT THE ABLATION ZONE OF BOLSHOY AZAU GLACIER WHILE THE LARGEST IN AREA (1 KM^2) ONE WILL APPEAR AT THE DJIKIUGANKEZ SNOUT (40 M MAX/7.2 M MEAN)
- SIMULATION SHOWED THAT SUBGLACIAL LAKES MAY EXIST UNDER BOLSHOY AZAU GLACIER.
- DETAILED GROUND-BASED RADAR SURVEY PLANNED FOR SUMMER 2020 WILL ENABLE THE ASSESSMENT OF SIZE AND VOLUME OF POTENTIAL SUBGLACIAL LAKES.



THANK YOU FOR ATTENTION