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Non-climatic factors affecting glacier mass balance (on the example of avalanche nourishment)

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Motivation

- Glacier mass balance is affected by non-climatic factors such as topography, debris cover and geometric parameters of glaciers themselves, avalanche activity, volcanism, etc.

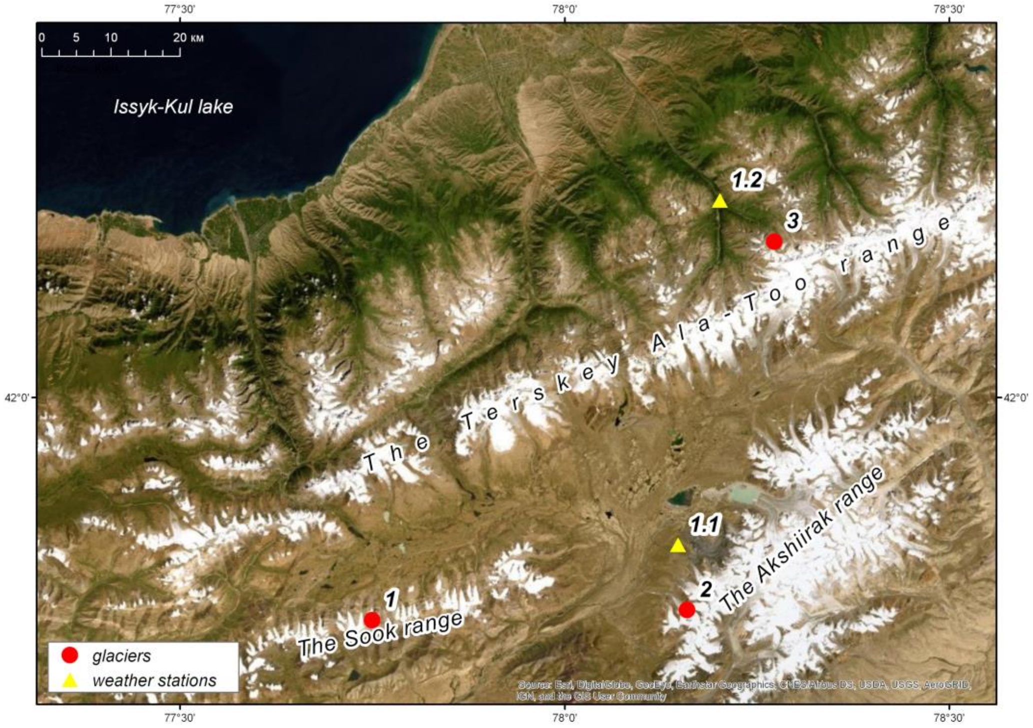
- **Which non-climatic factors affect the glaciers mass balance? Avalanches?**

- The contribution of snow avalanches to the snow accumulation on a glacier is still among the least studied components of the glacier’s mass balance which is related to poor avalanche data availability and difficulties in obtaining such data on most of mountain glaciers.

- We propose a possible approach for the numerical assessment of snow avalanche contribution to accumulation at mountain glaciers based on DEM and weather data analysis using GIS and numerical modeling of snow avalanches using RAMMS.

- **Glaciers show a direct response to climate changes. Is it always the case?**

The Inner Tien Shan



Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

1.Batysh Sook Glacier (1.11 km^2) (3900-4450 m a.s.l.)

2.Glacier №354 (6,38 km^2) **(3780-4620 m a.s.l.)**

Photos by CAIAG

3.Karabatkak Glacier (2,5 km^2) (3350-4780 m a.s.l.)

The proposed approach was first tested on three glaciers in Kyrgyz Republic.

Weather stations:
1.1 – Kumtor-Tian-Shan (3660 m a.s.l.)
1.2 – Kizil-Suu (2555 m a.s.l.)

A case study was realized for 2015/2016 balance year.

Study area

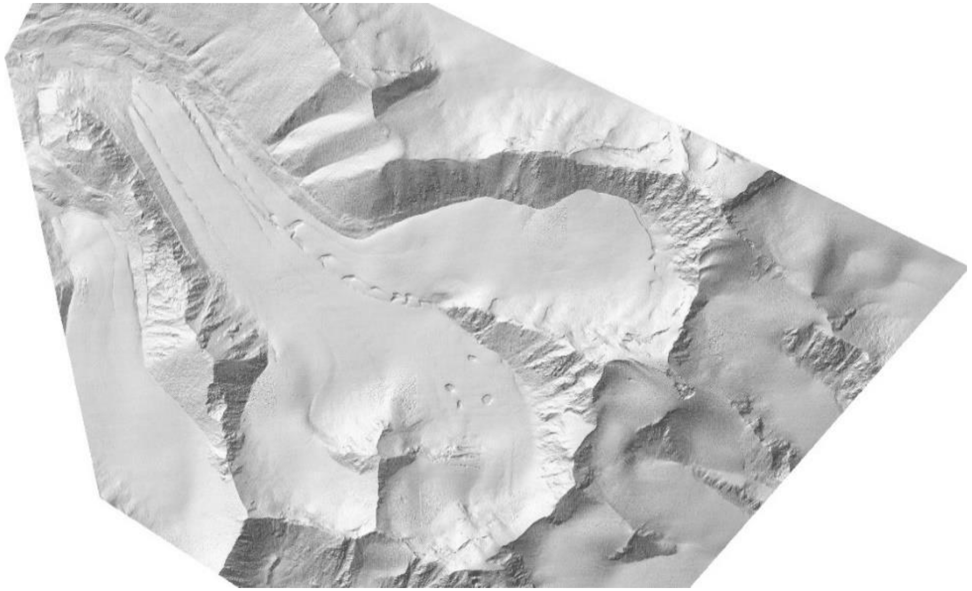
Possible approach

1/Topography analysis

Input:

1. Batysh Sook Glacier – DEM (1 m) received from the the eBee UAV, July 2016 (Gindraux, Hergarden, 2016)
2. №354 Glacier – DEM (1 m) received using GeoEye-1 stereo survey 29.07.2012 (Petrakov et al., 2016)
3. Karabatkak Glacier – DEM (30 m) received using ALOS World 3D (30 m) and High Mountain Asia DEM (8 m).

Using GIS technologies in combination with DEM, the potential avalanche release zones have been indicated and analyzed with respect to topographic characteristics.



Hillshade №354

Slope, deg.	Aspect							
	S	SW	W	NW	N	NE	E	SE
25-30	4,1	5,5	7,6	12,3	13,8	9,3	6,1	4,2
30-35	17,4	29,3	42,5	55,6	65,8	46,2	31,7	19,2
35-40	22,1	40,5	60	84,3	95,2	66	45,8	24,7
40-45	16,6	30	50	60	84	56	40,2	20,3
45-50	6,4	11,5	21,8	31,2	41,6	25,6	16,3	5,7
50-55	1,6	3,1	6,4	10	13,3	7,6	4,2	2,1
55-60	0,6	1,1	2,5	4,5	4,8	2,8	2	0,6

Frequency of snow avalanches depending on the slope and aspect, amount of avalanches per 100 years (Kharitonov, 1979)

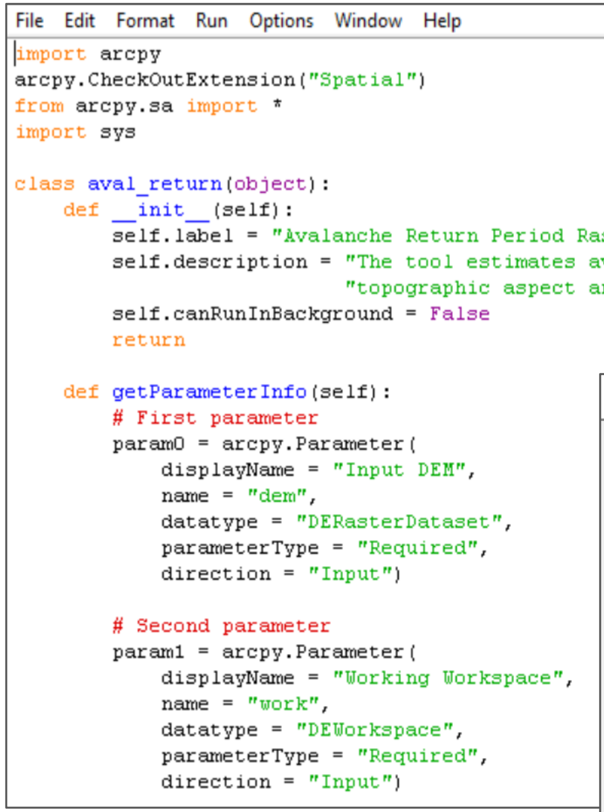
1/Topography analysis

Possible approach

Geoprocessing:

Topographic characteristics were derived from the DEM in order to automatically define the frequency of avalanches (or their return period) in the potential release zones using regional dependency of Kharitonov (1979) based on the analysis of 4972 avalanches recorded in different parts of Central Asia.

The Python Script was developed for the automatic identification of frequency of avalanches in the release zones on Tien Shan.



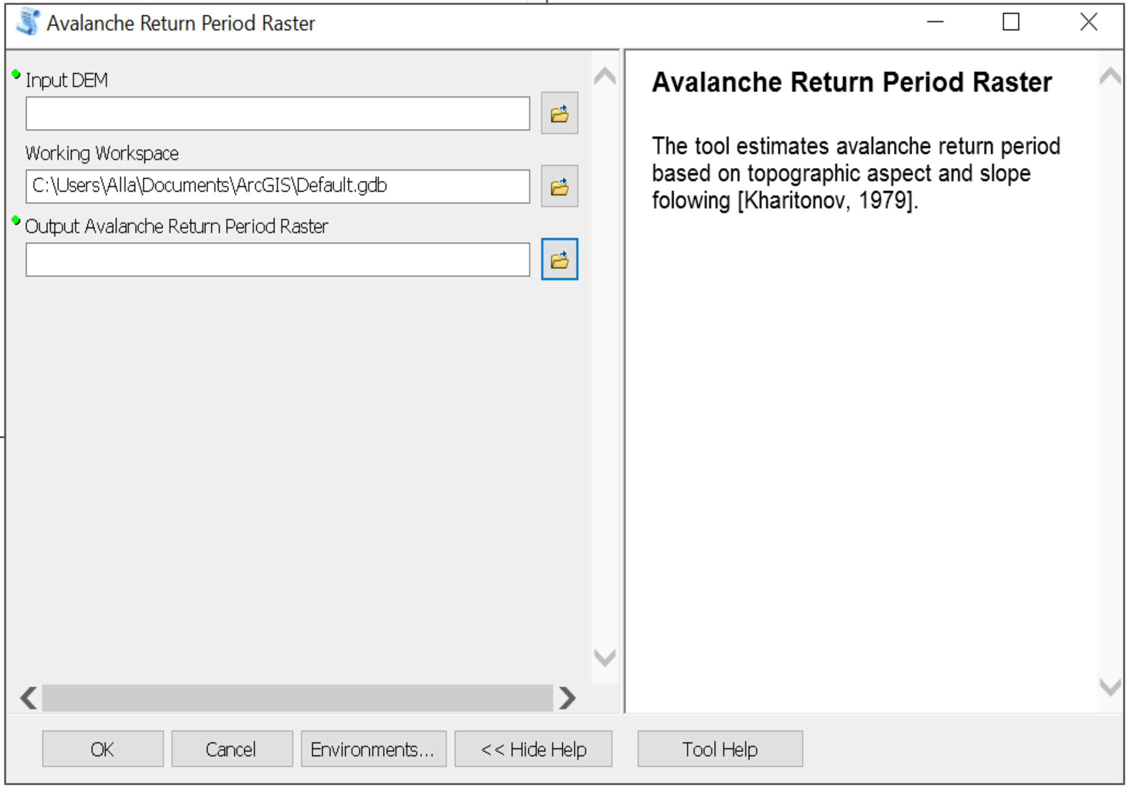
```
import arcpy
arcpy.CheckOutExtension("Spatial")
from arcpy.sa import *
import sys

class aval_return(object):
    def __init__(self):
        self.label = "Avalanche Return Period Raster"
        self.description = "The tool estimates avalanche return period based on "\
                           "topographic aspect and slope folowing [Kharitonov, 1979]."
        self.canRunInBackground = False
        return

    def getParameterInfo(self):
        # First parameter
        param0 = arcpy.Parameter(
            displayName = "Input DEM",
            name = "dem",
            datatype = "DERasterDataset",
            parameterType = "Required",
            direction = "Input")

        # Second parameter
        param1 = arcpy.Parameter(
            displayName = "Working Workspace",
            name = "work",
            datatype = "DEWorkspace",
            parameterType = "Required",
            direction = "Input")
```

Python script part



Input DEM

Working Workspace: C:\Users\Alla\Documents\ArcGIS\Default.gdb

Output Avalanche Return Period Raster

Avalanche Return Period Raster

The tool estimates avalanche return period based on topographic aspect and slope folowing [Kharitonov, 1979].

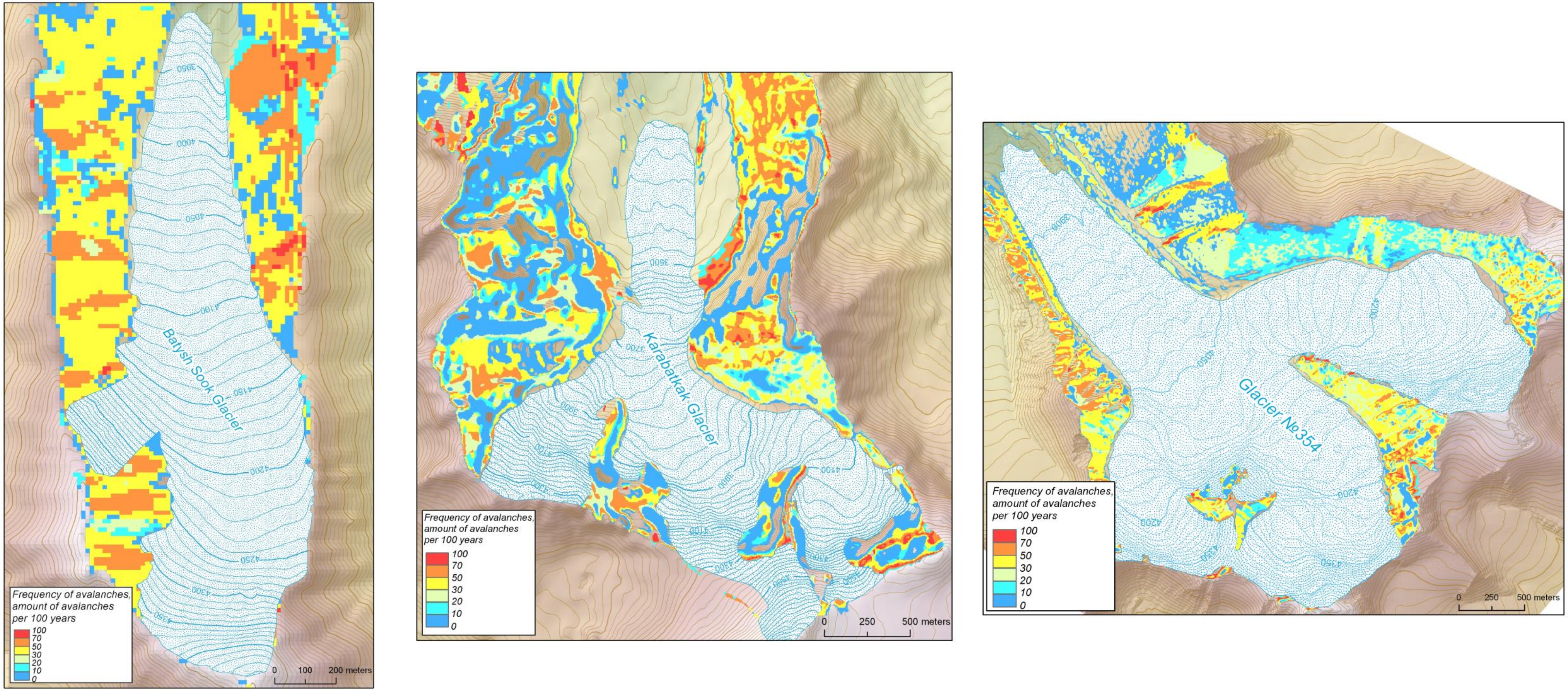
The developed geoprocessing tool in ArcMap.

Kharitonov G.G. Calculation methods of the avalanche nourishment of glaciers. Materialy Glyatsiologicheskikh Issledovanii. Data of Glaciological Studies. 1979, 36: 155–159. [In Russian with English abstract].

Possible approach

1/Topography analysis

Results:



Frequency of avalanches in the avalanche release zones in the basins of the studied glaciers

2/Meteorological data analysis

Using meteorological observations from nearest weather stations and regional dependences (World Atlas of Snow and Ice Resources, 1997; Glaciation of Tien Shan, 1995), snow height has been re-calculated for the research areas and analyzed winter period.

The estimated snow height frequency turned out to be 50% during the winter season 2015/2016.

Estimated max. snow height during 2015/2016 balance year in avalanche release zones:
Batysh Sook Glacier – 62 sm
№354 Glacier – 84 sm
Karabatkak Glacier – up to 212 sm

Maximum snow height (H) frequency (P) according to the Tien Shan Kumtor station.

Oledeneniye Tyan Shanya. Glaciation of Tien Shan. Ed. M.B. Dyurgerov. Moscow: VINITI, 1995: 239 p. [In Russian].

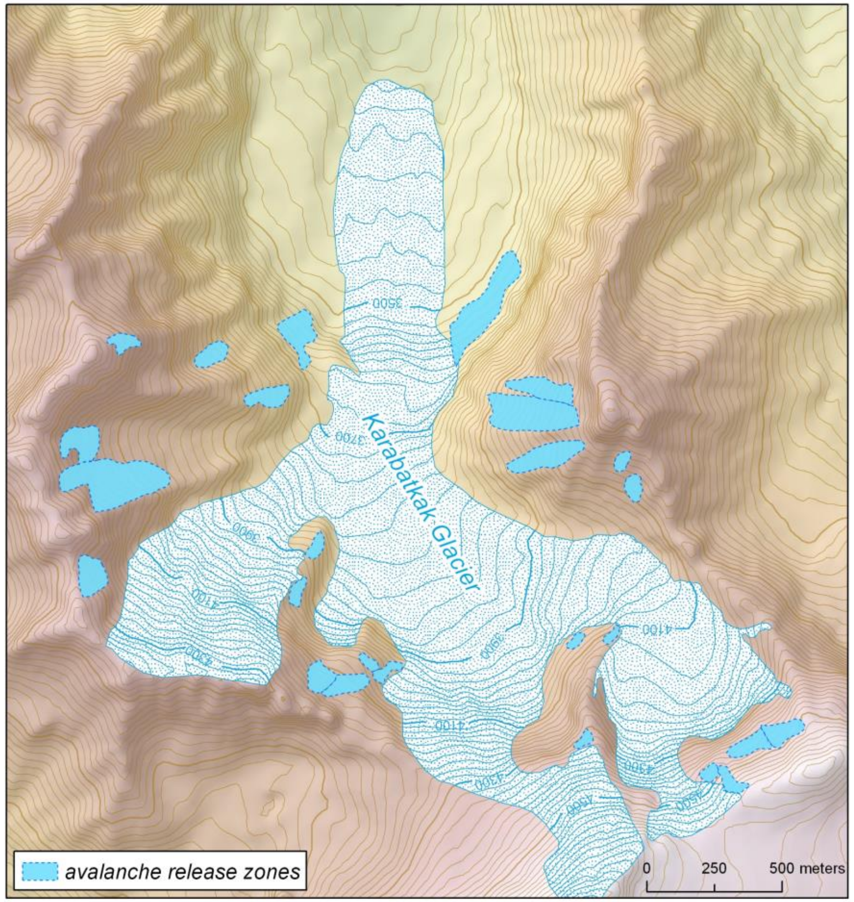
Atlas snezhno-ledovykh resursov mira. World Atlas of Snow and Ice Resources. Ed. V.M. Kotlyakov. Moscow: Institute of Geography, Russian Academy of Sciences, NPP «Kartographiya», 1997: 392 p. [In Russian and English].

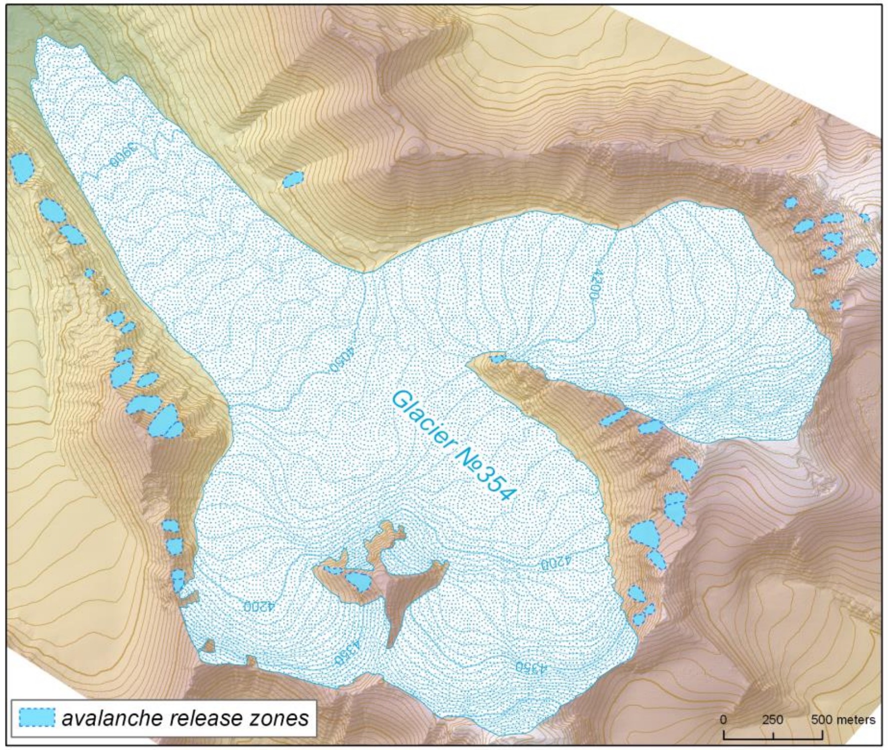
Possible approach

3/Avalanches volumes assessment

Possible approach

Mean area (m^2) of reconstructed avalanche release zones:
Batysh Sook — 10520;
Karabatkak — 15460;
№354 — 7570;





Reconstructed avalanche's release zones in 2015/2016

3/Avalanches volumes assessment

Avalanche snow fracture height coefficient (k) (Blagoveshenskiy, 1991)

Snow height (H), sm	Dry avalanches	Wet avalanches
20-30	0,6	0,8
30-40	0,5	0,7
40-60	0,4	0,6
60-80	0,5	0,6
80-100	0,6	0,6
100-150	0,6	0,6
150-200	0,5	0,5
200-300	0,4	0,4

Blagoveshchenskiy V.P. Opredelenie lavinnykh nagruzok. The definition of avalanches loads. Almaty: Gylym, 1991: 116 p. [In Russian].

As only a part of the total snow cover as usual participates in the avalanche formation, we computed 2 different scenarios of avalanches volumes: with the total release snow height and its part calculated according to (Blagoveshenskiy, 1991).

Volume of avalanches (V, m^3)*:*

$$V = kHF$$

F – area of avalanche release zone (m^2)

Glacier	k=0,5	k=1
Batysh Sook	39 000	78 000
№354	127 000	254 000
Karabatkak	329 000	658 000

Total volume (m^3) of avalanche drifted snow during 2015/2016 balance year

Possible approach

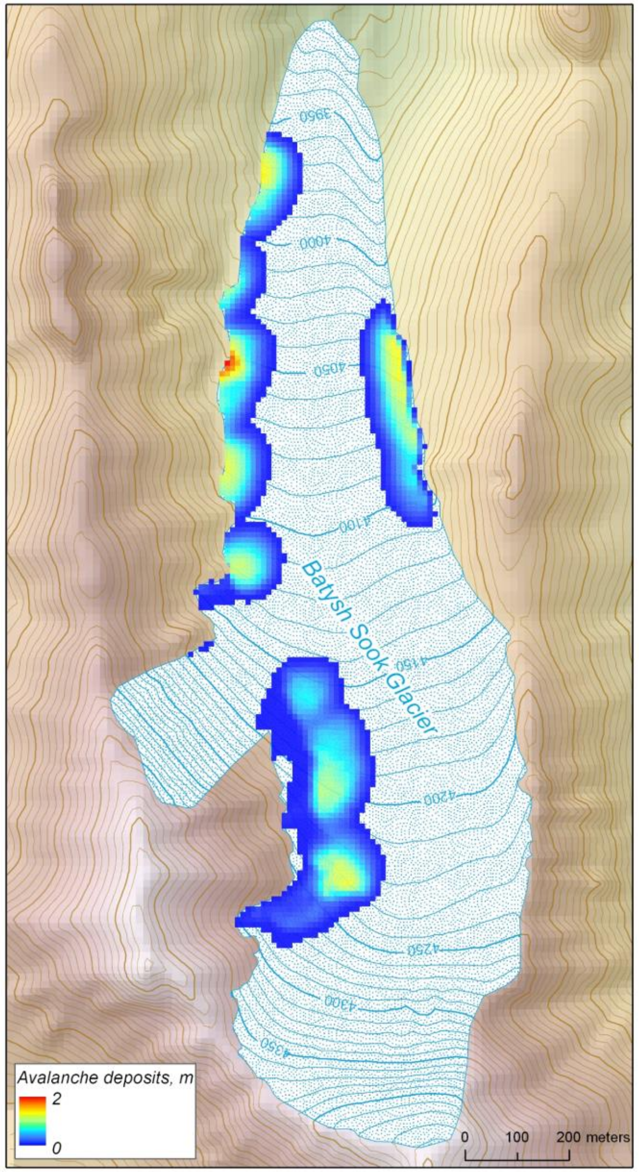
Possible approach

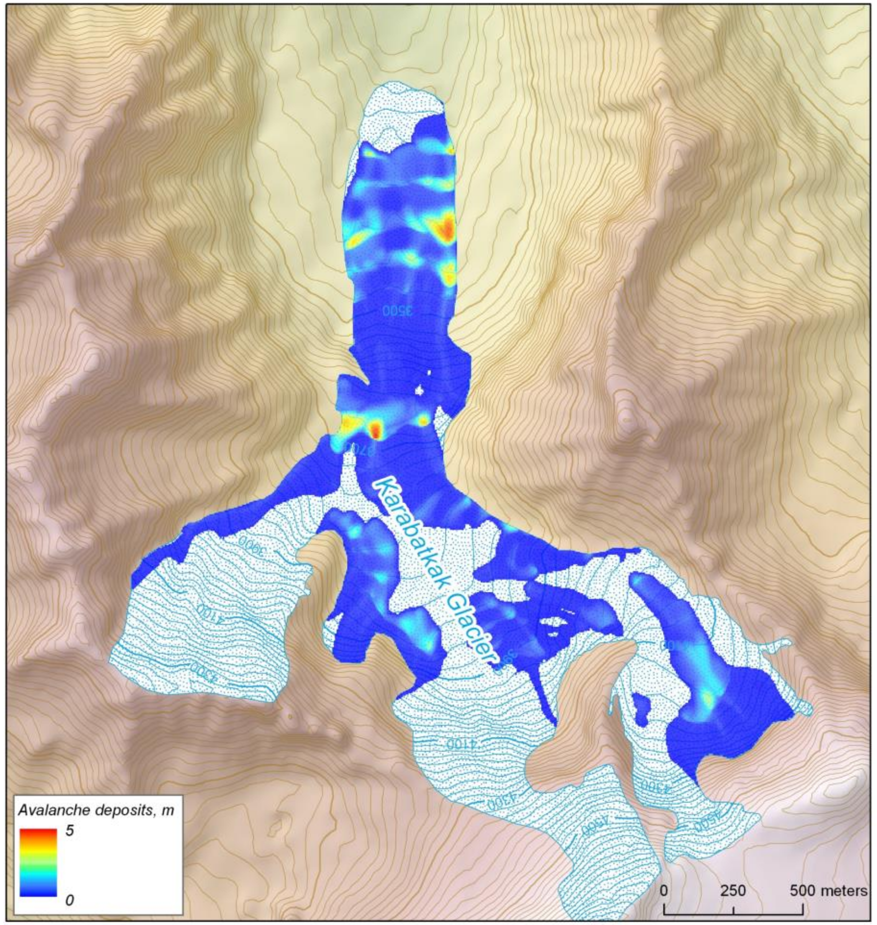
4/Numerical simulation of avalanches using RAMMS

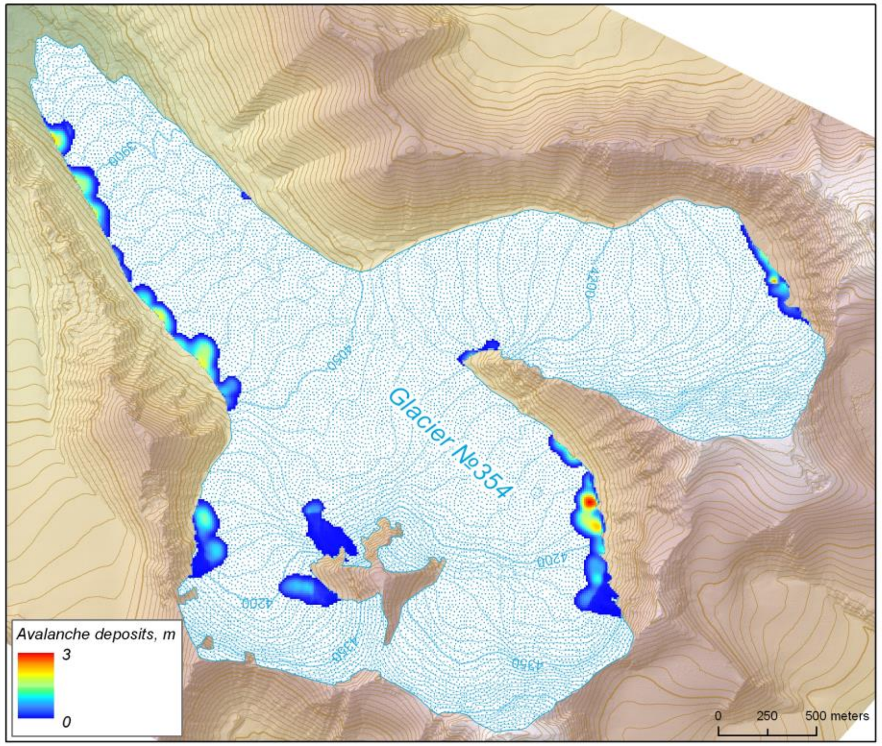
We performed the numerical simulation of avalanches that were most probably released during the winter period 2015/2016 using RAMMS (Christen et al., 2010)

http://ramms.slf.ch/ramms/

RAMMS simulation results (run out distances and deposition heights) can be compared with field measurements.







Avalanche accumulation fields on the research glaciers in 2015/2016 reconstructed using RAMMS

5/Evaluation of snow avalanches contribution share

Possible approach

Winter balance (*Bw*, mm w.e.) in 2015/2016

Batysh Sook	+ 214
№354	+ 406
Karabatkak	+ 550

V – avalanche nourishment, mm w.e.

$$\boldsymbol{v = \frac{V}{B_w} * 100} \ (\%)$$

Results:

The estimated share of snow avalanche contribution to the accumulation on the research glaciers during the 2015/16 balance year turned out to be (of the total accumulation):

- Batysh Sook – 7,4±2,5%;
- № 354 – 2,2±0,7%;
- Karabatkak – 10,8±3,6%

The proposed approach can be applied in other regions where DEMs, regular meteorological observations are available as well as data on the regional avalanche formation factors.

Proposed approach for the numerical estimation of snow avalanches contribution into accumulation on glaciers:

1) Topography analysis:

- DEM analysis; definition of potential avalanche release zones that can provide avalanche drifted snow on the glacier;
- definition the frequency of avalanches from the potential avalanche release zones using regional dependences on local topography.

2) Meteorological data analysis:

-definition of the maximum snow height and its frequency in the avalanche release zones during the analyzed winter period.

3) Snow avalanches volumes assessment during the analyzed winter period:

-indication of the avalanche release zones considering the snow height frequency during the analyzed winter period;

-determination of the avalanche fracture height in the most probably active release zones during the analyzed winter period;

-avalanches volumes assessment.

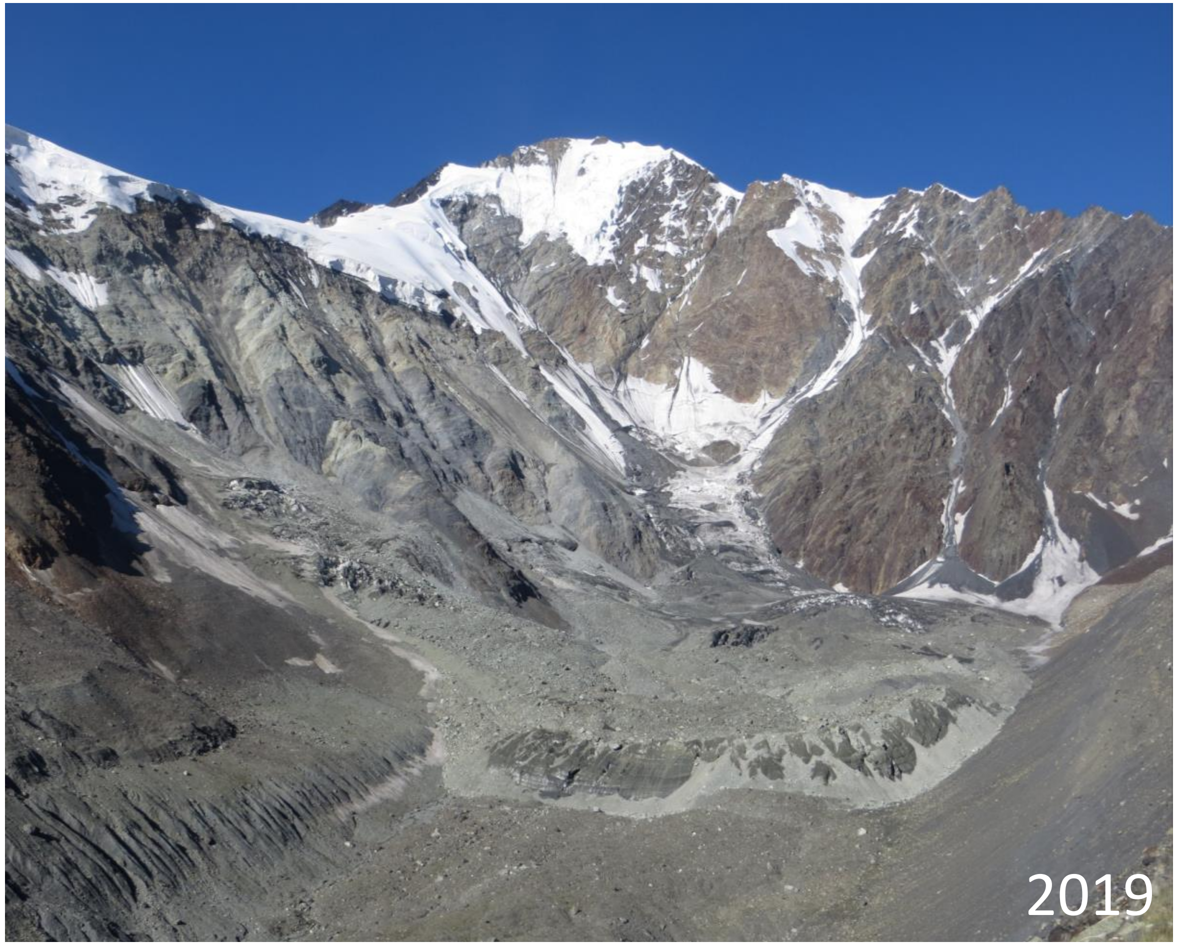
4) Numerical simulation of avalanches:

- evaluation of snow avalanches characteristics (run out distances, deposition heights) using numerical modeling (RAMMS);
- comparison of numerical simulation results with field observations or remote sensing data.

5) Evaluation of snow avalanches contribution into glacier accumulation.

Central Caucasus

Kolka Glacier (1.2 km², 3000-3850 m a.s.l.)



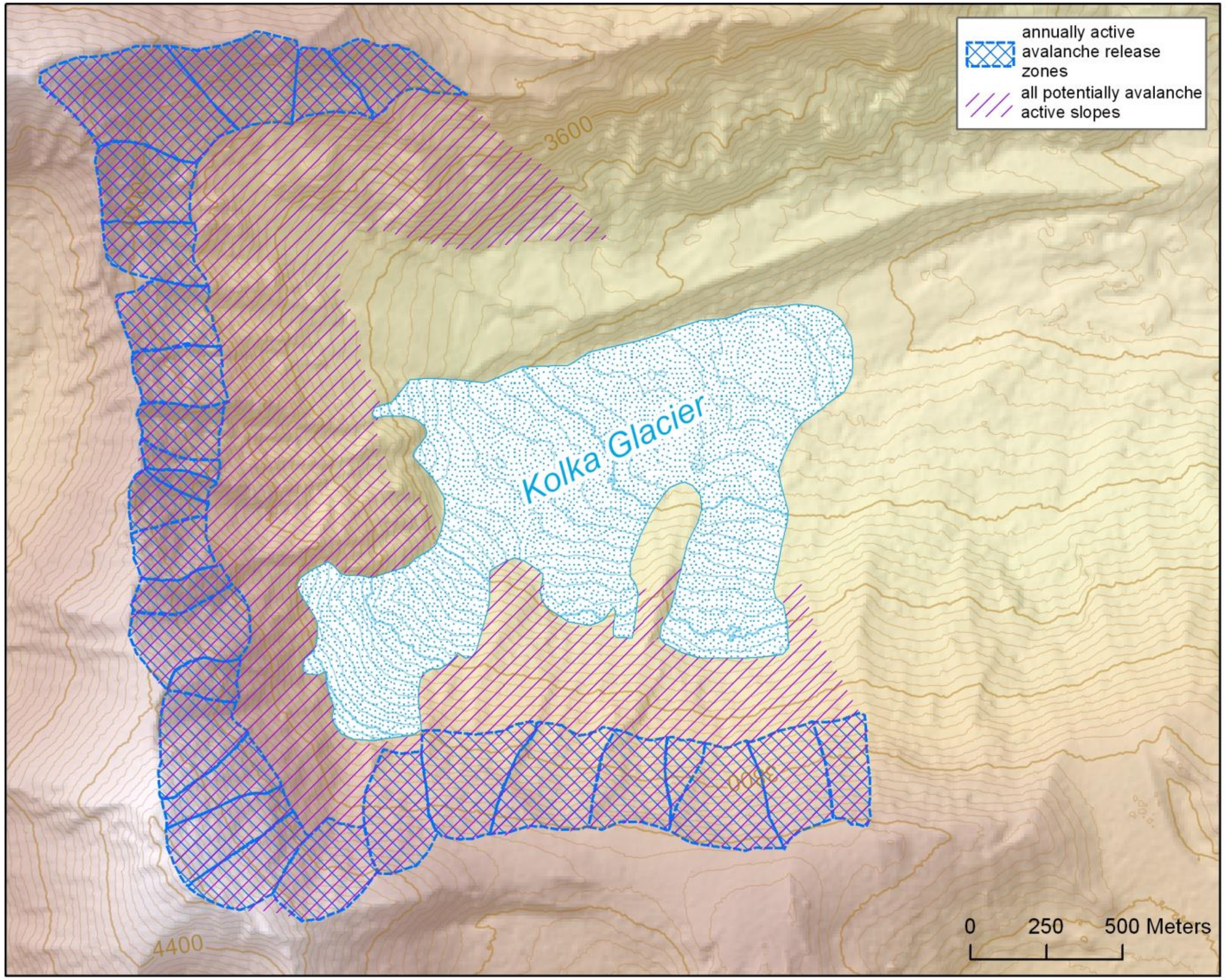
The Kolka Glacier, which rushed down the Genaldon valley on September 20, 2002 (North Ossetia), is now recovering after this catastrophe.

The role of snow avalanches in the Kolka Glacier nourishment

- In strong contradiction to the benchmark glaciers in the Tien Shan, the Kolka glacier demonstrates rapid mass gain in the Caucasus. It might be explained by significant, up to 80% share of avalanche nourishment to glacier mass gain.

- Quick growth of the Kolka glacier contrasts sharply with decreasing of volume of the representative Caucasus glaciers (Djankuat and Garabashi) over the same period.

- Avalanches play central role in the Kolka glacier volume increase.



The end. Thank you very much!!!

The mass balance of glaciers with avalanches nourishment is not necessary following the trend in temperature and precipitation, but this factor can be quantified by numerical models of snow avalanches.


Mikhail Golubev | mg5642.livejournal.com

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