Climate change impact on the mountain environment in Peruvian Andes and Tien Shan Mountains in Kyrgyzstan

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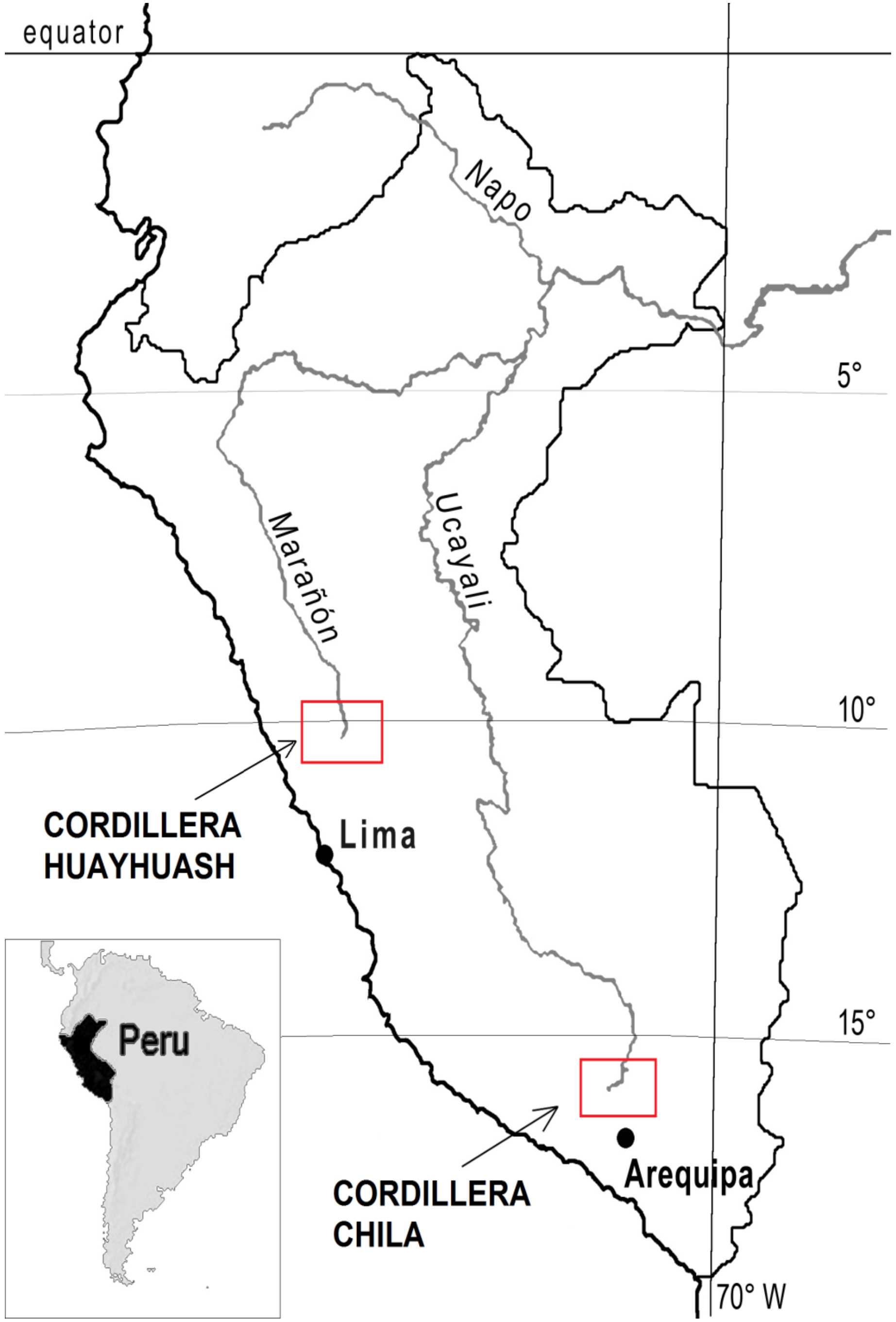


New research project - funded by the Czech Science Foundation

"Natural Hazards of the Amazon River Sources Territory Caused by the Global Climate Change"

STUDY AREA

The Peruvian Western Andes (Cordillera Occidental) – altitudes higher than 5000 m

→ The watershed between Pacific and Atlantic Oceans

1. **Cordillera Huayhuash** (10 S.)
2. **Cordillera Chila** (15 S.)

– distance N-S about 1000 km.

Comparing of two areas:

1. Marañon River headstream area (humid) - mountain steppe ***páramos***
2. Ucayali – Apurímac (Amazon) headstream area (arid) – mountain steppe ***puna***

Western hillsides:

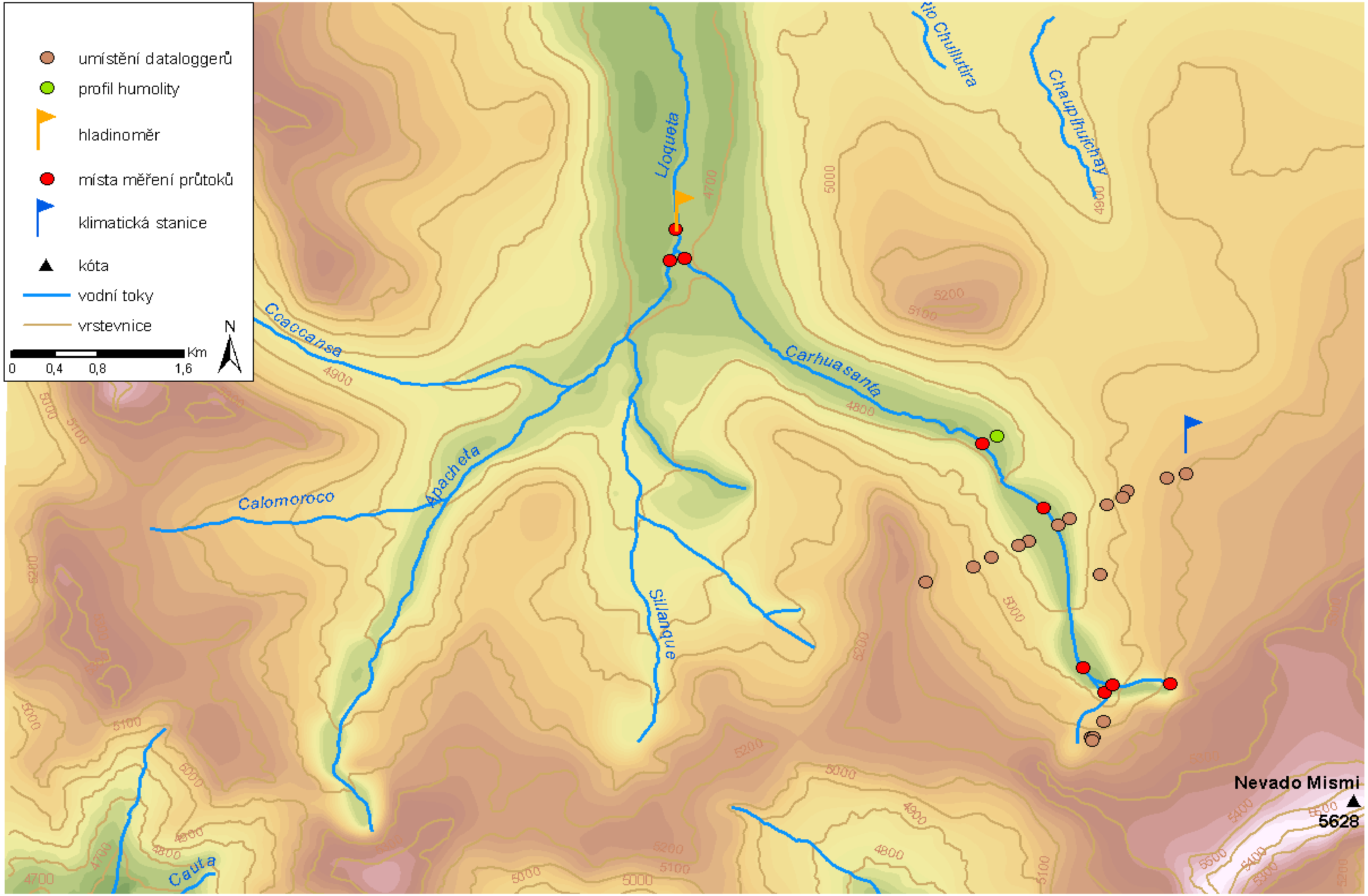
Costa – zone along the Pacific coast (aridity growth to the south) → desert area and vegetation of type ***lomas*** *in fog layer* ***garúa***.

- periodical effect El Niño (El Niño – Southern Oscillation): temperature increase → heavy rain → natural disaster (increase of glacier melting, debris flows - *huaycos*, outburst of glacial lakes, floods, landslides). Specially strong El Niño in 1982/83, 1997/98 and 2016/2017

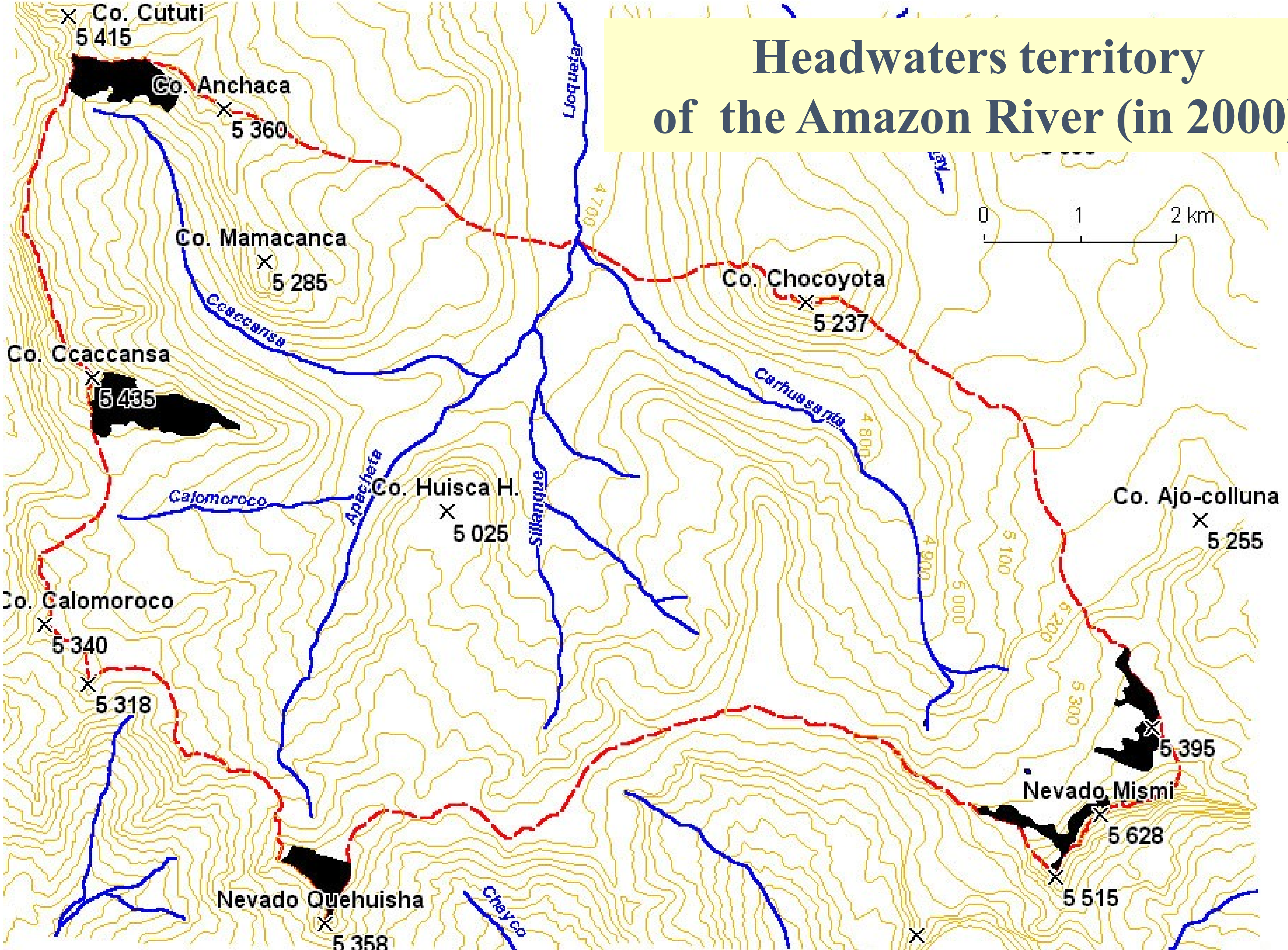
Oriental hillsides and the tableland: humidify – under the influence of trade wind from Atlantic ocean

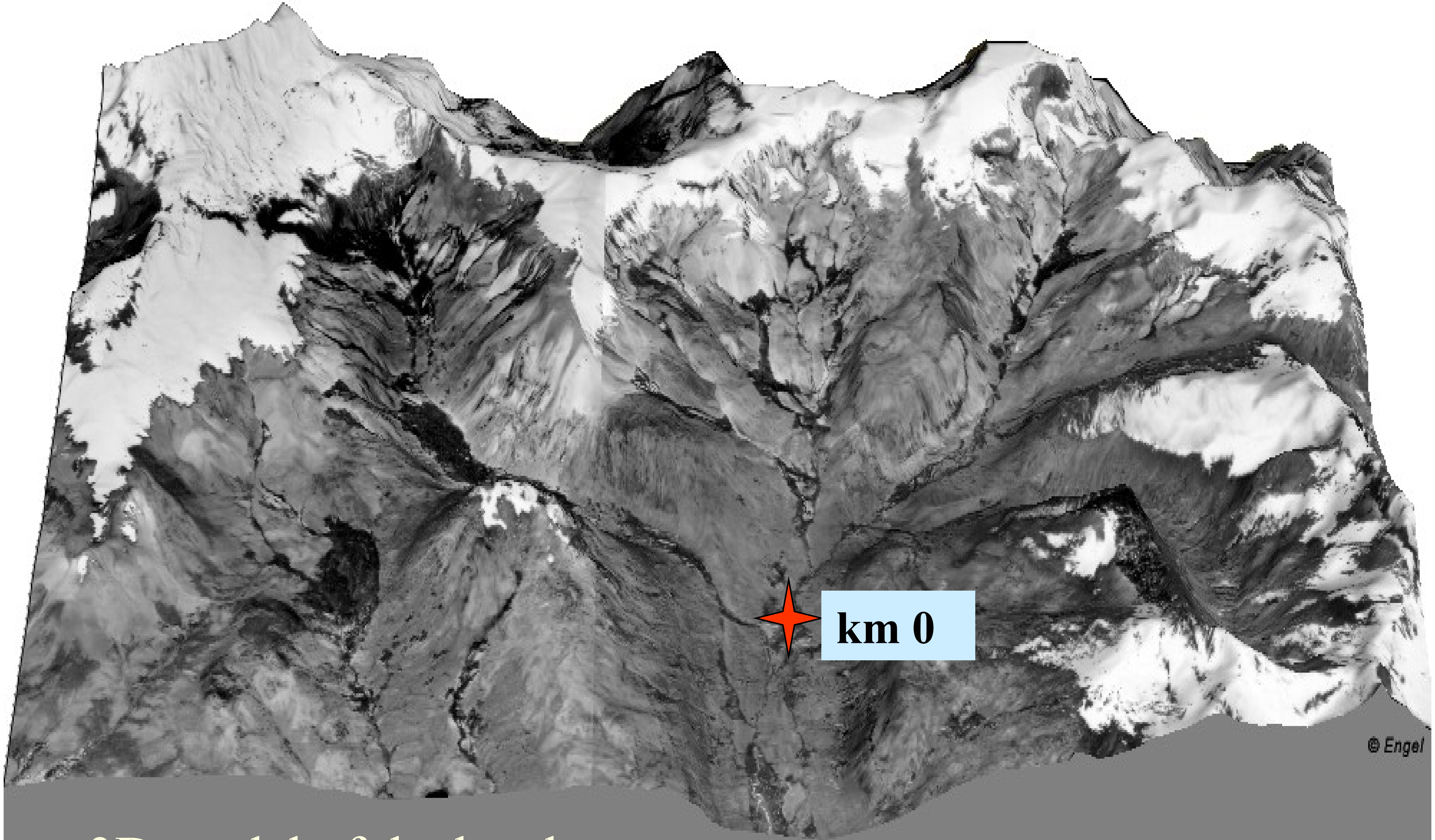

ECUADOR
Rio Amazonas
PERU
BRAZIL
Rio Marañon
LIMA
Rio Ucayali
BOLIVIA
Arequipa
Amazon source area

Headwaters territory of the Amazon River



Headwaters territory of the Amazon River (in 2000)





3D model of the headwater territory of the Amazon river

Laguna Bohemia – left source of the Carhuasanta River

Right headwaters stream of the Carhuasanta River

Glaciation in 2000

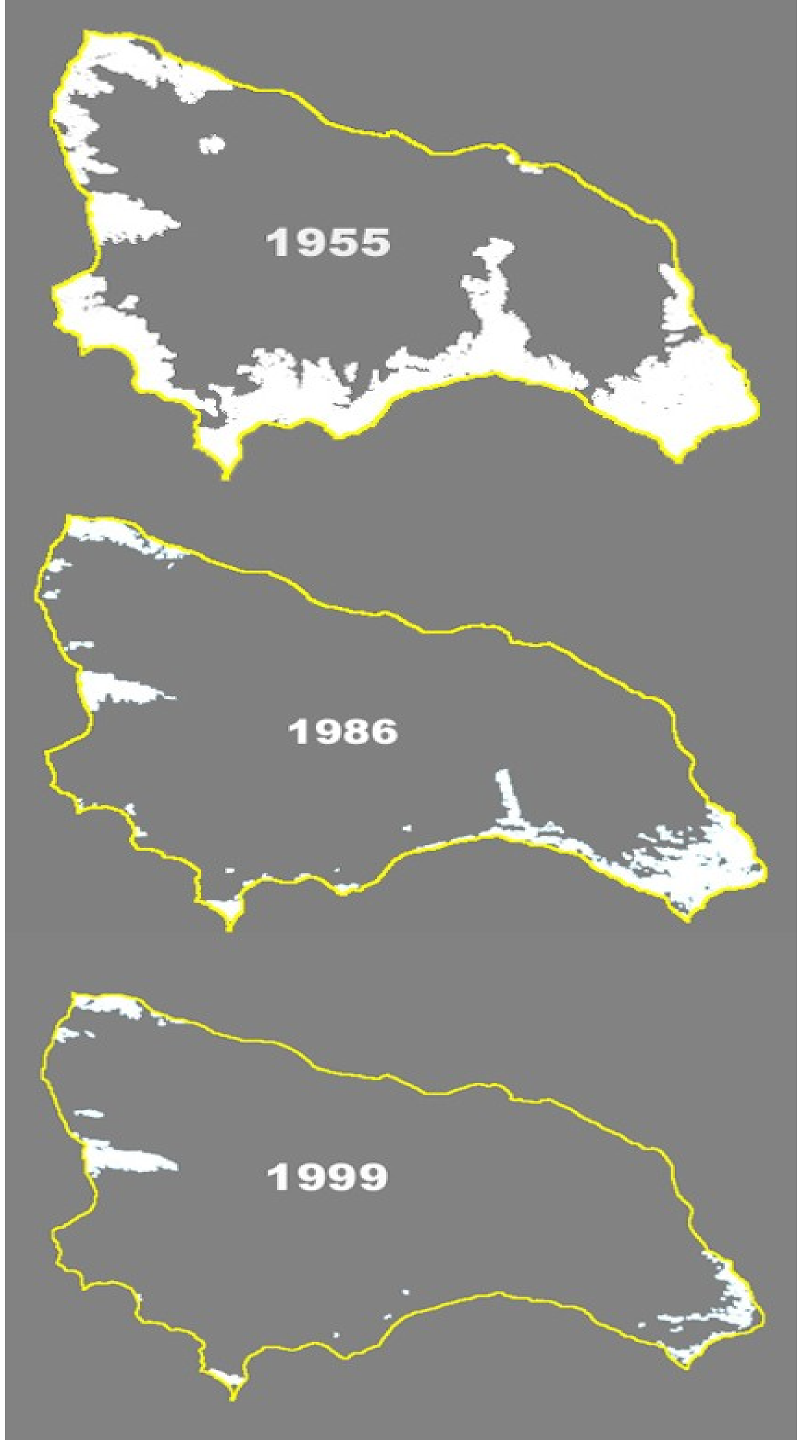
The glaciation was restricted to the highest parts of mountain ranges in the eastern part of the Cordillera Chila. There are four glaciers in the catchment area of the Carhuasanta and Apacheta rivers that extend over a ***surface of 1.54 km²*** out of total 57.15 km².

The snowline altitude varies from 5250 to 5300 m.

Over the 20th century, the glaciers of an observed area have undergone rapid retreats: **glaciers experienced a 60 % decrease in surface area since 1955.**

Glaciers disappeared from 2000 to 2007 completely and fields of perennial snow persisted in the highest areas only

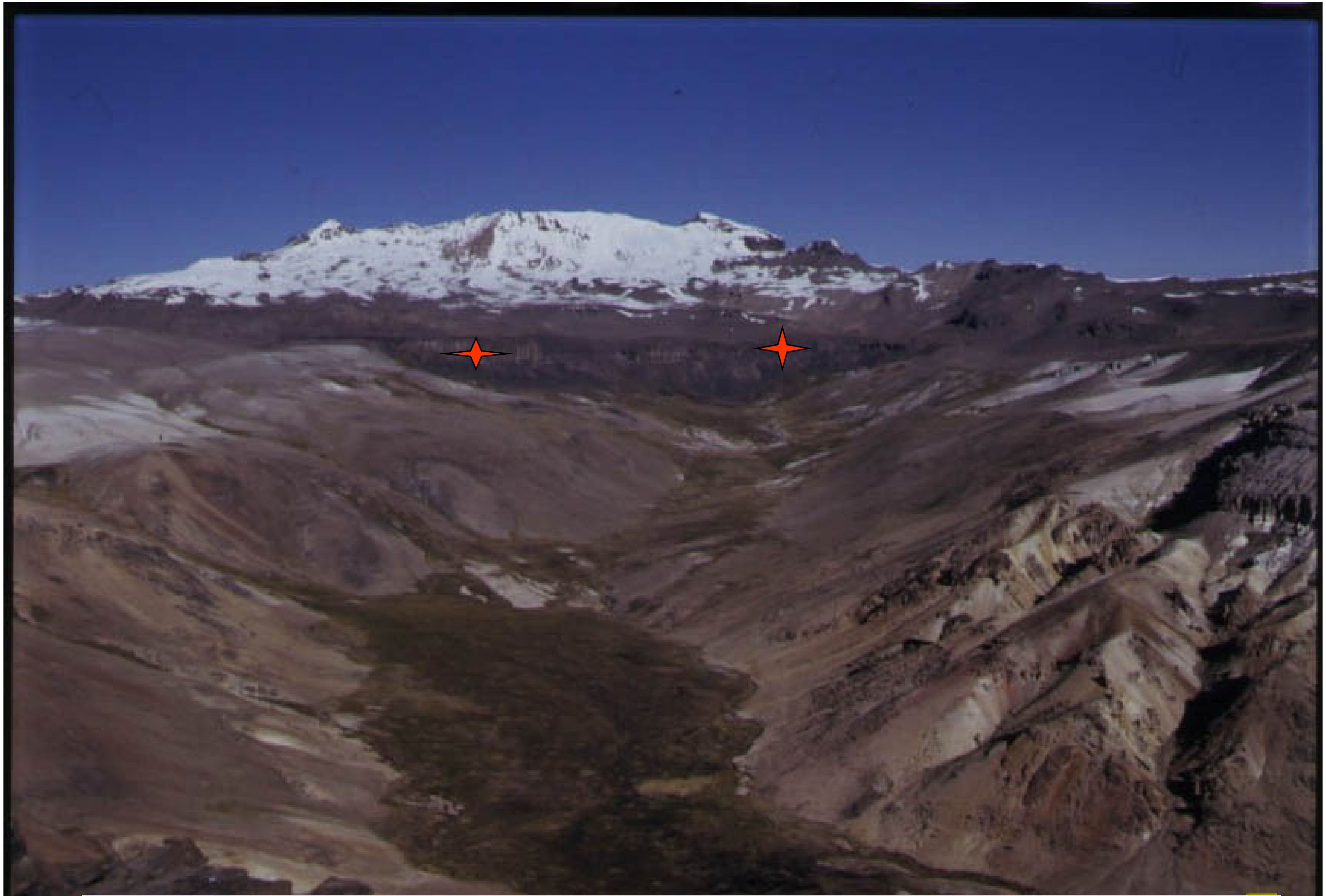
Glacier retreat since 1955 to 1999



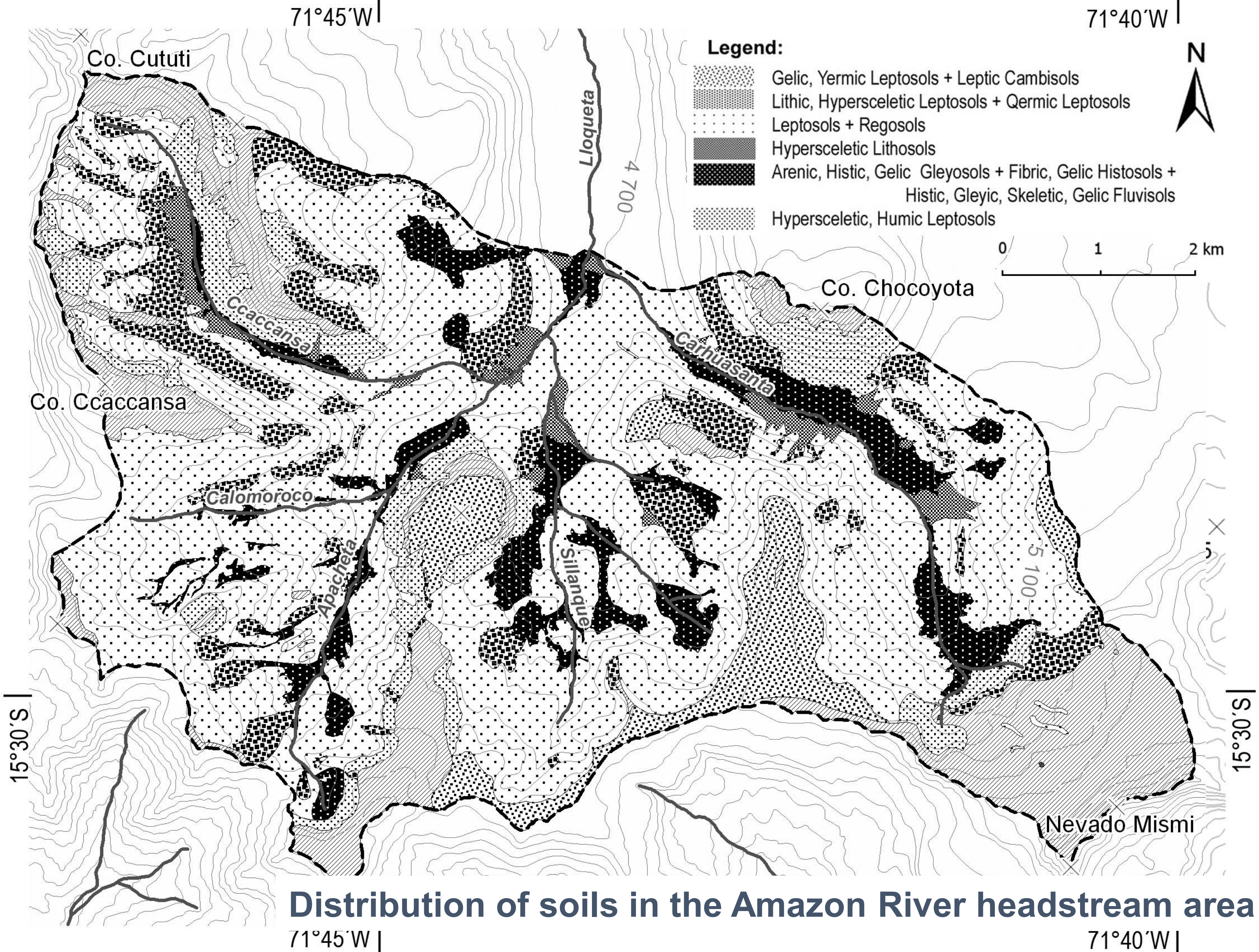
Glaciers dynamic in the Amazon River headwaters territory since 1955 to 2000

Glacier	Area [km^2]		Difference %	Max. alt. [m]	Min. alt. [m]	Orientation
	1955	2000				
Mismi	0.57	0.45	21	5628	5250	NW
Chayco	0.72	-	100	5200	5150	NW
Quehuisha	0.97	0.20	79	5358	5250	N
Calomoroco	0.42	-	100	5340	5200	NE
Ccaccansa	0.66	0.51	23	5435	5250	S
Cututi	0.50*	0.38	24	5360	5200	S
Total	3.84	1.54	60	5628	5150	

The watershed between Pacific and Atlantic Oceans



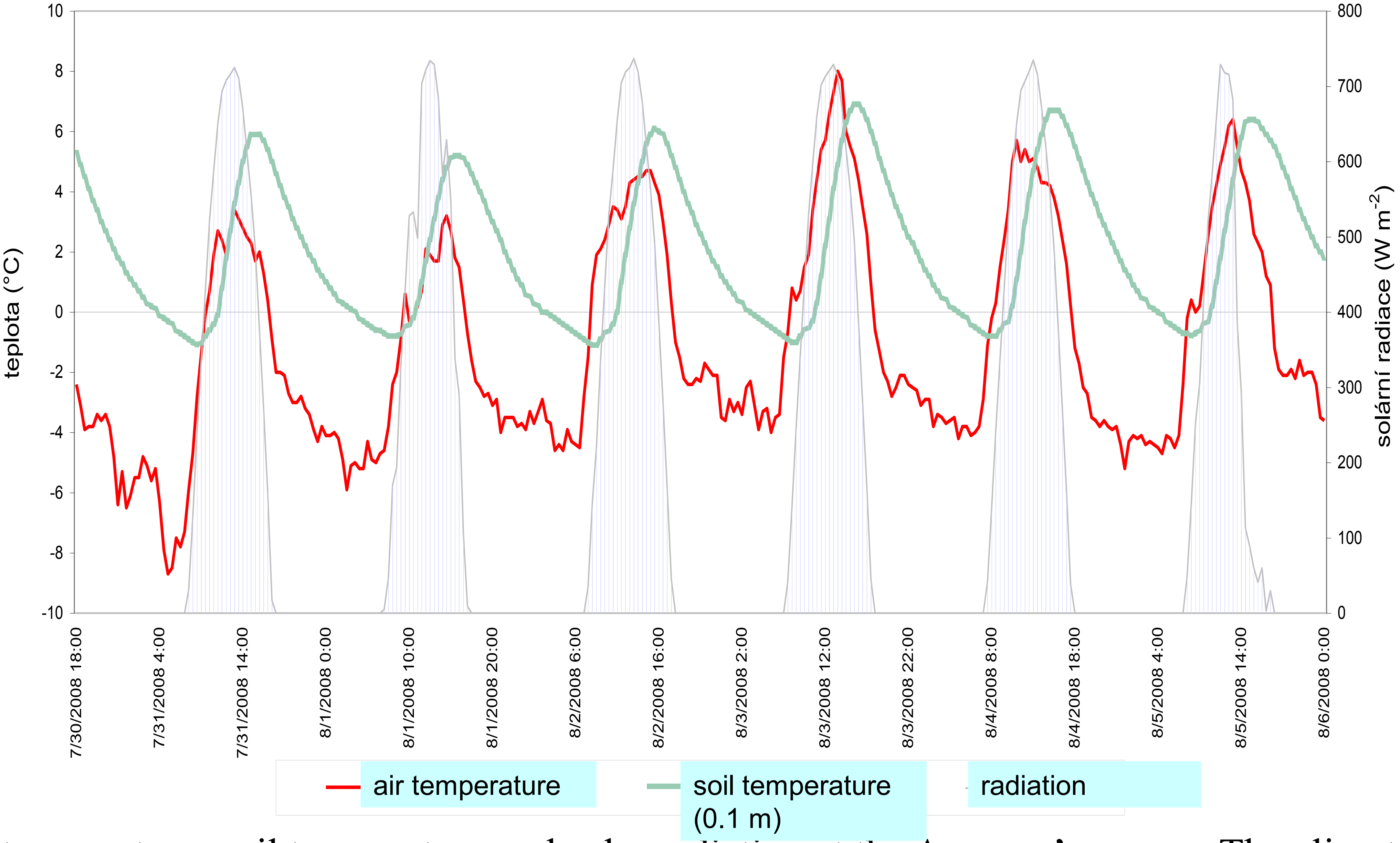
Carhuasanta River and Nevado Mismi (5628 m)



Distribution of soils in the Amazon River headstream area

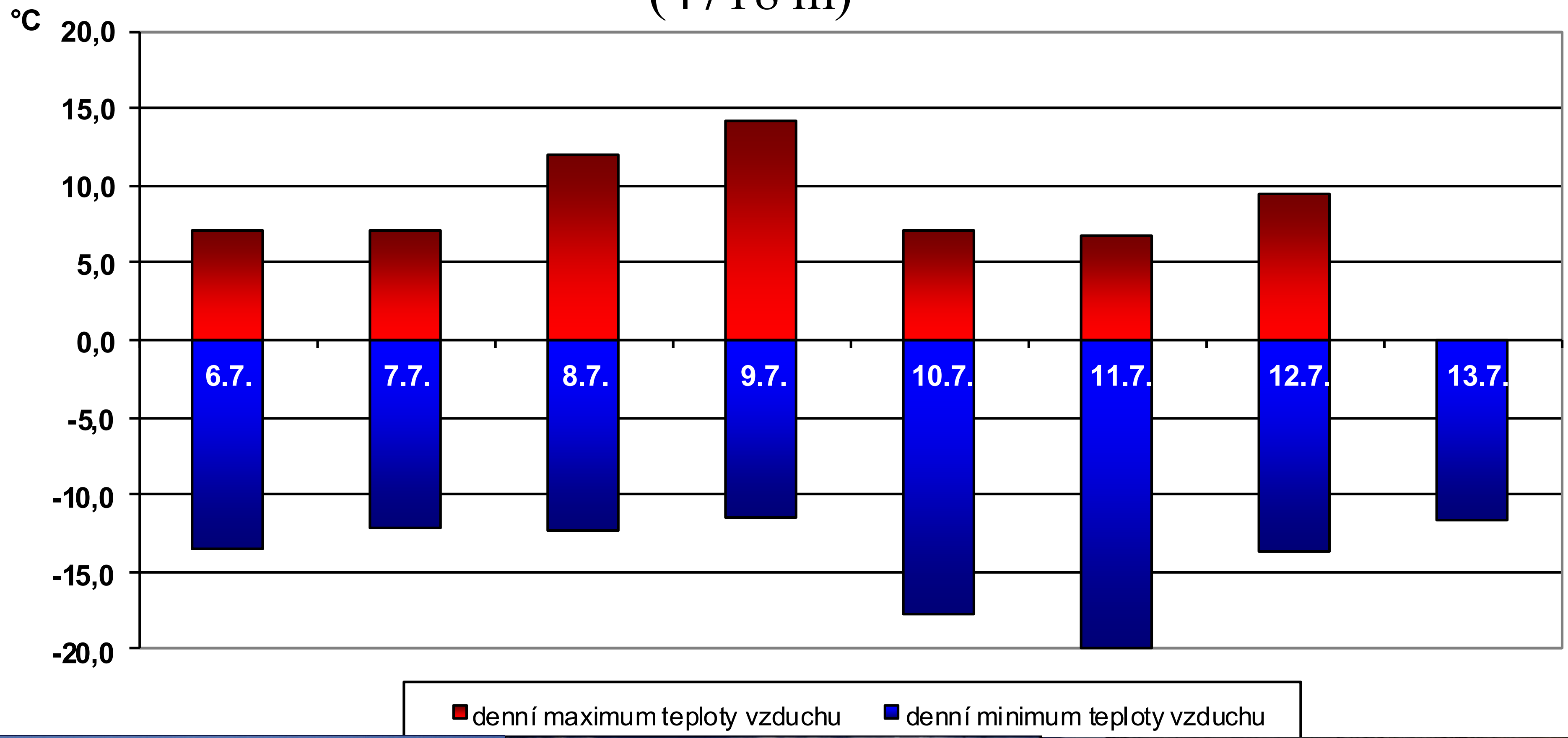
Die Talvegetation „Champa“ (Distichia muscoides)

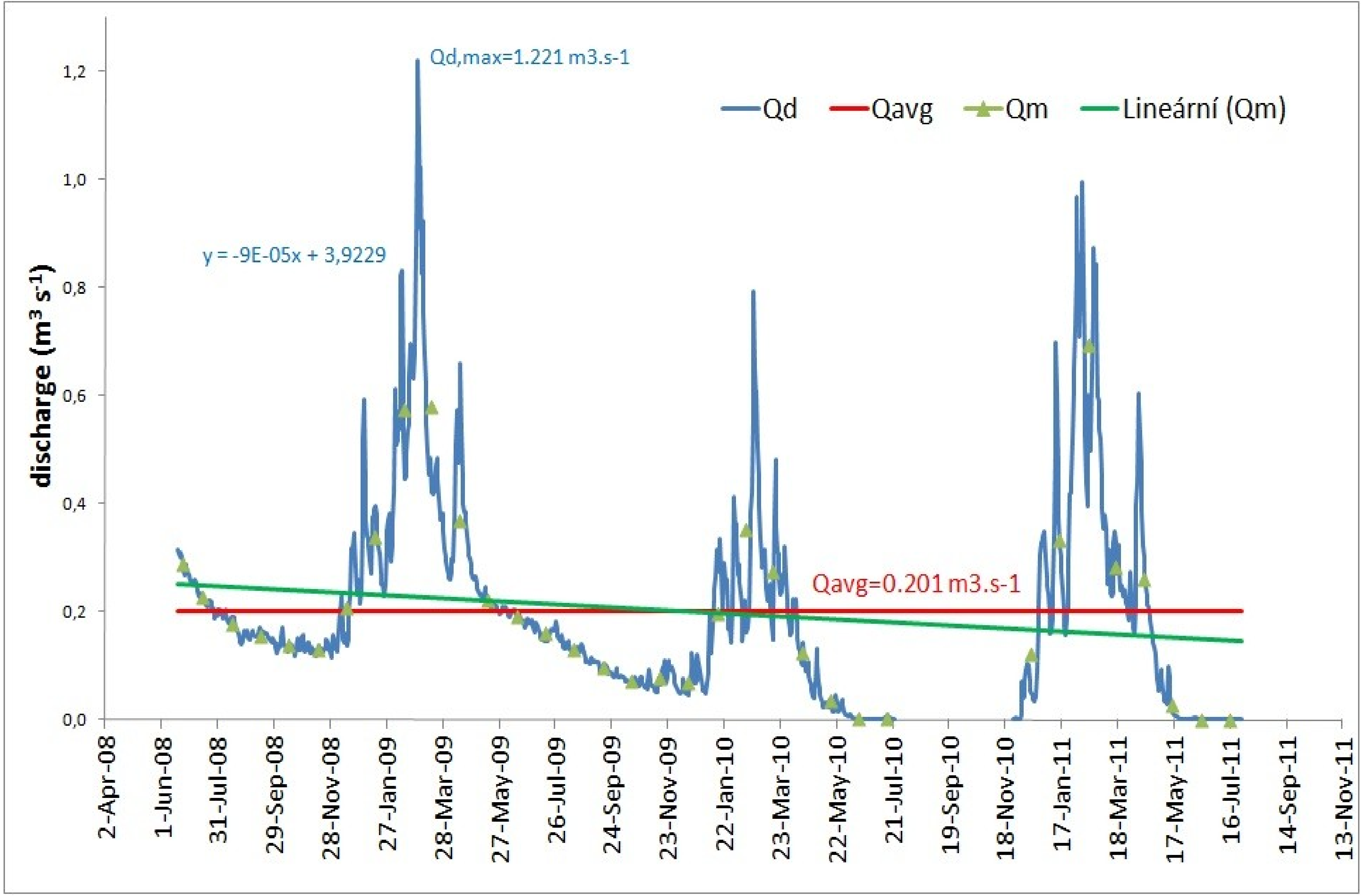
The climatic station at the Amazon’s source, located at 5075 m above sea level: it was **the highest located station in Peru**. In background Nevado Mismi (5628 m).



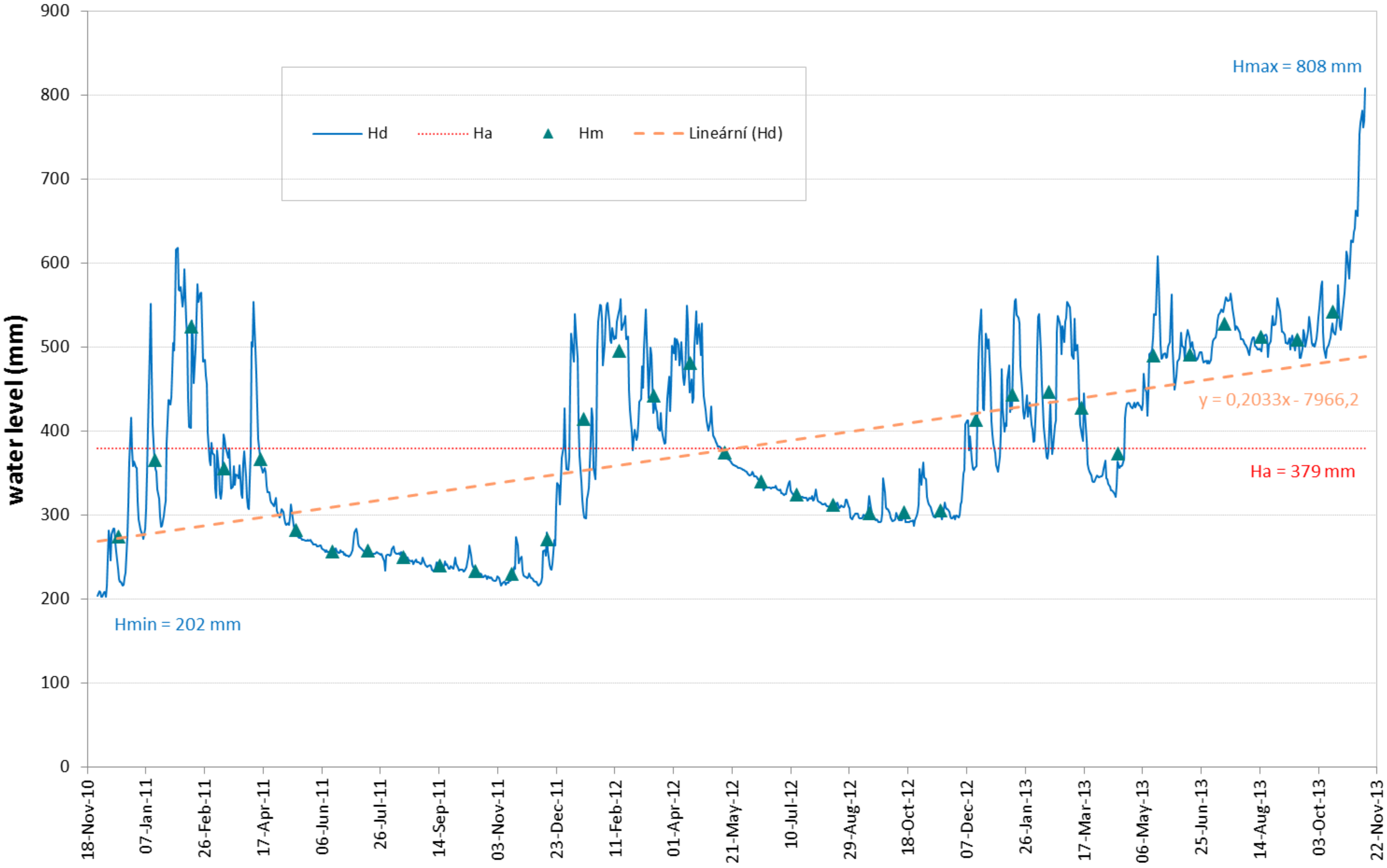
Air temperature, soil temperature and solar radiation at the Amazon's source. The climatic station of the Charles University in Prague (5075 m a.m.s.l., period 30.7. - 6.8. 2008.

The confluence of Carhuasanta and Apacheta rivers (4718 m)





Average daily and monthly discharges in the Lloqueta River (headwaters territory of the Amazon River) and line of trend of monthly discharges. Period: 24.4. 2008 – 16.7. 2011


Hd
Ha
Hm
Lineární (Hd)
Hmax = 808 mm
Hmin = 202 mm
Ha = 379 mm
y = 0,2033x - 7966,2
water level (mm)
900
800
700
600
500
400
300
200
100
0
18-Nov-10
07-Jan-11
26-Feb-11
17-Apr-11
06-Jun-11
26-Jul-11
14-Sep-11
03-Nov-11
23-Dec-11
11-Feb-12
01-Apr-12
21-May-12
10-Jul-12
29-Aug-12
18-Oct-12
07-Dec-12
26-Jan-13
17-Mar-13
06-May-13
25-Jun-13
14-Aug-13
03-Oct-13
22-Nov-13

Headwaters territory of the Marañon River

Durchflussmessungen in Rio Lloqueta

The new climatic station at the Amazon’s source, located at 5280 m a. s. l.
The highest located station in Amerika (5 280 m n.m.), from November 2016.

Cordillera Huayhuash, Nevado Yerupaja (6617 m)

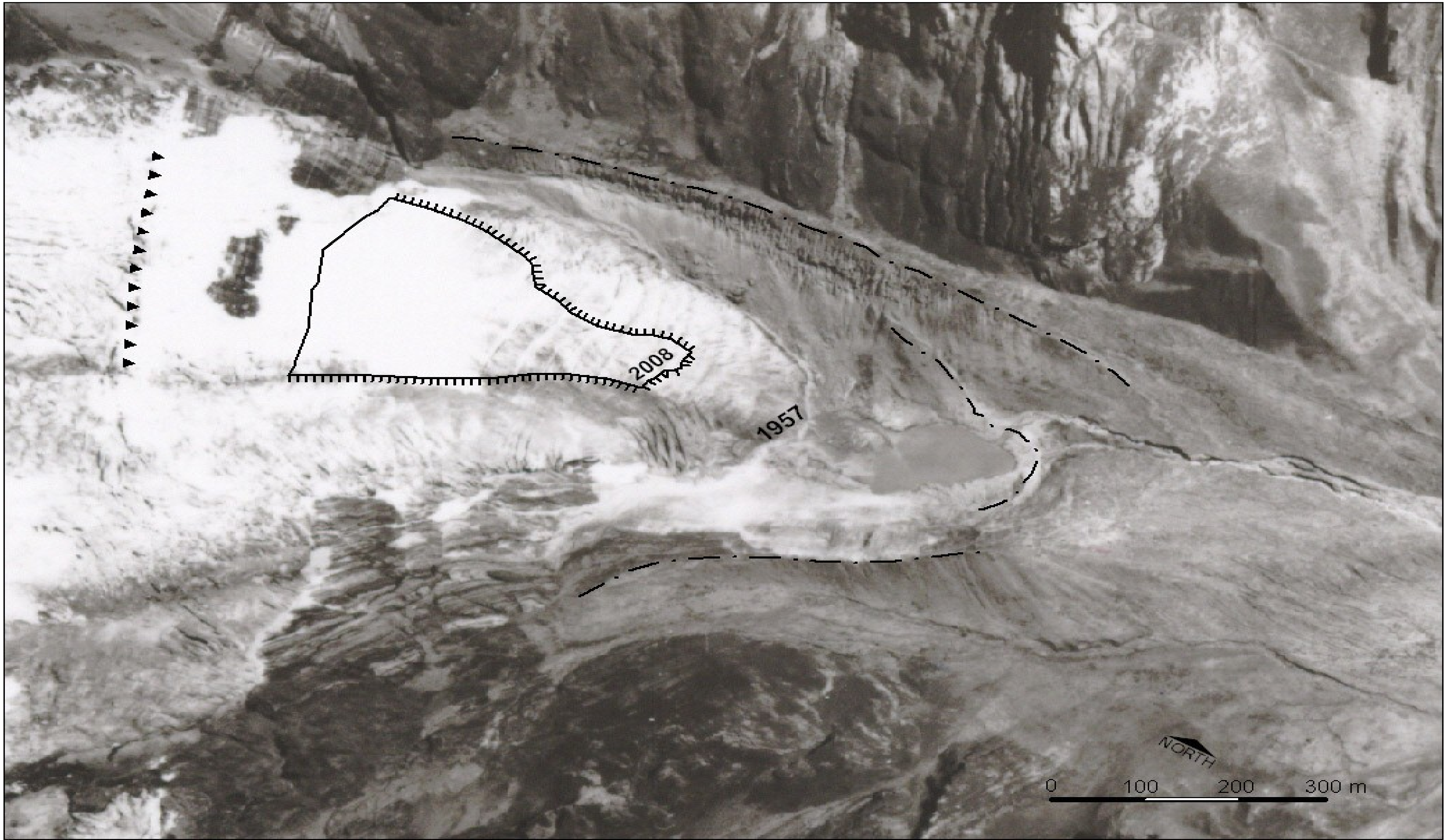

Cordillera Huayhuash
De NASA - http://earthobservatory.nasa.gov/IOTD/view.php?id=8924, Dominio público

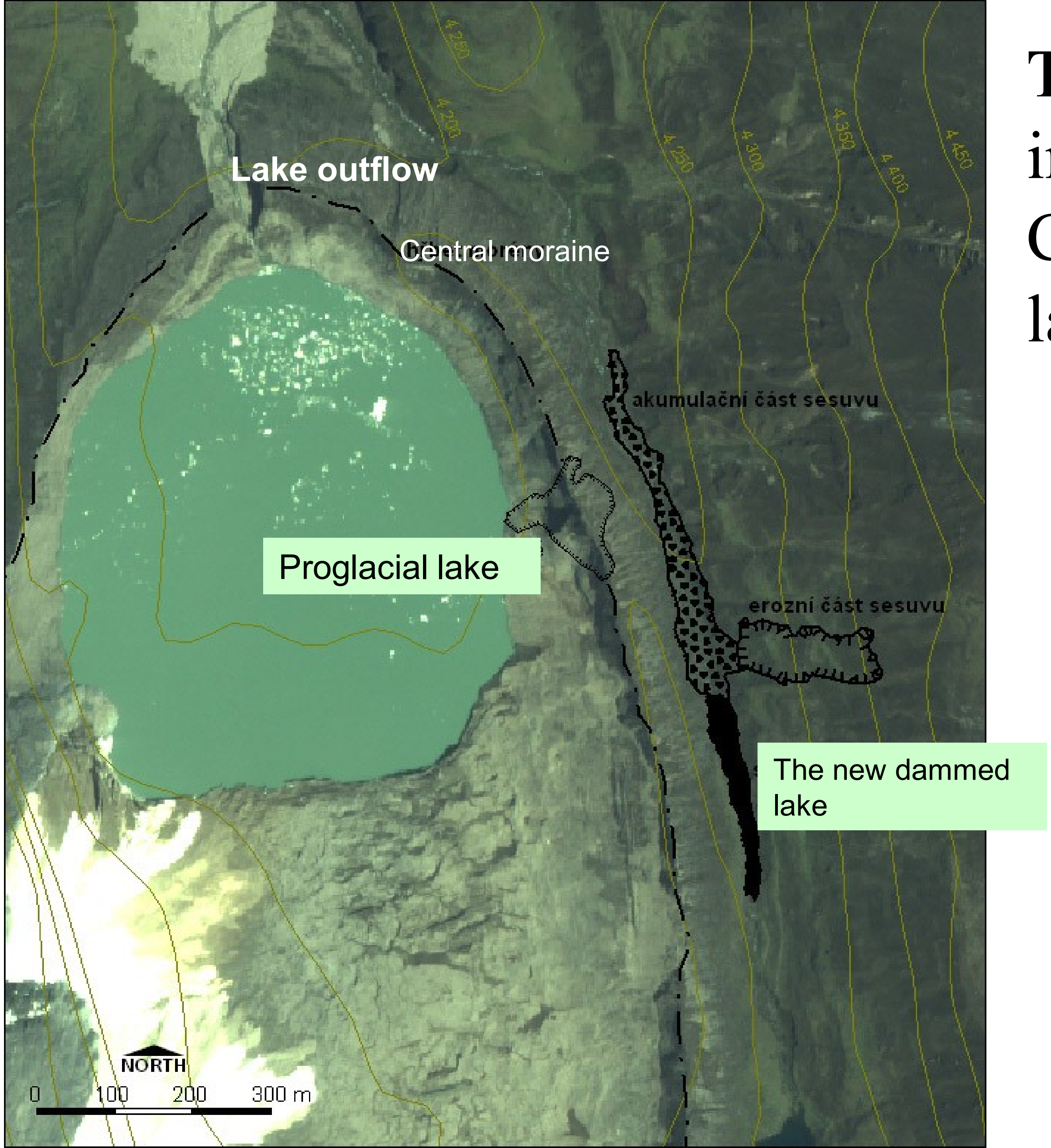
Proglacial Cangrajanca Lake

Dangerous Cangrajanca lake with periodical outburst. The lake basin is filled from the Yerupaja glacier.

Yerupaja glacier retreat (1957 – 2008)

Total retreat: 230-350 m, annual retreat: 4 – 7 m.





The relief changes
in the valley of Carhuacocha river after lanslide from 8.3. 2009

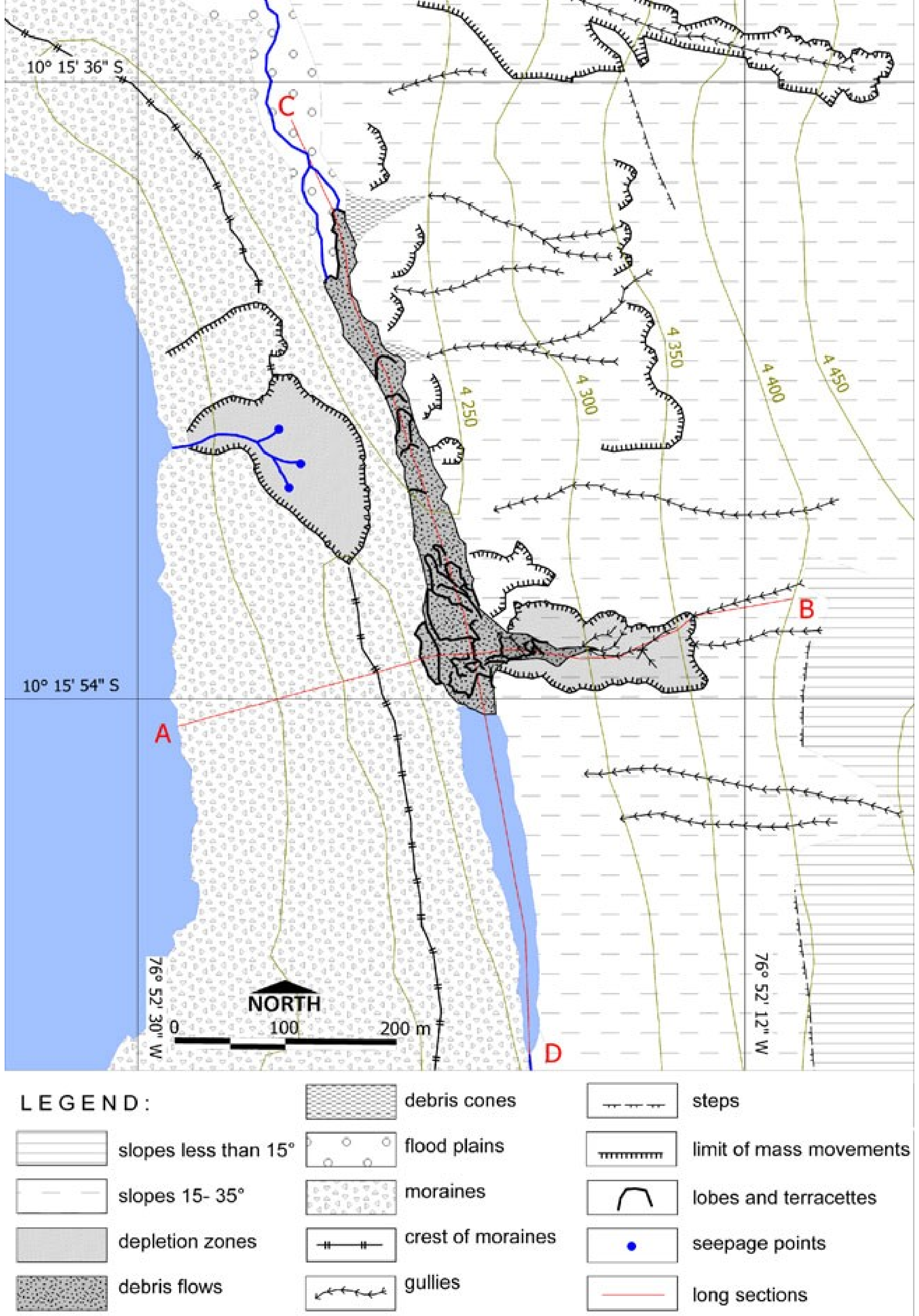
Rainfall-related debris flows in Carhuacocha Valley

The debris flow was triggered by cumulative rainfall combined with an extreme precipitation event:

- From the end of January to the beginning of March 2009, the Cordillera Huayhuash experienced abnormally high precipitations at exceeded 270mm.

- The annual precipitation at the nearby Cajatambo station (distance 25 km) is **563 mm**.
- From January 25 to March 7 – 270 mm
- 10 days prior to flow – 56,2 mm
- 24 h prior to flow – 18,4 mm


F
D
A
C
B
E
The new lake (E) damed by
the landslide (A,B,C,D)



New hydrographic situation after landslide:

→ water percolated through the moraine dam of Cangrajanca Lake

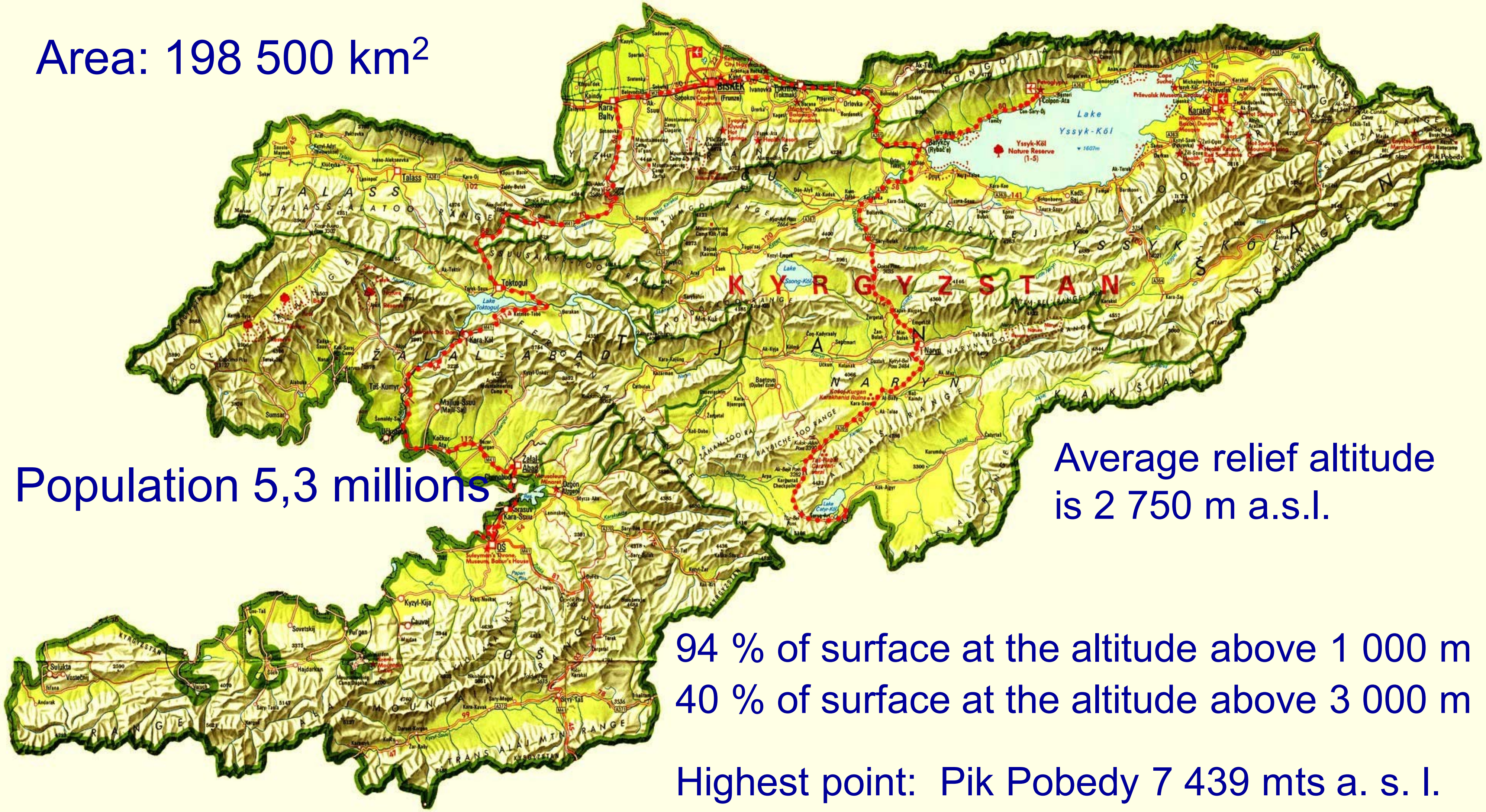
→ lateral moraine disturbed by groundwater erosion

Lateral moraine: disturbed by groudwater erosion

Conclusions

- The monitoring has confirmed **a falling trend in the flow rate**, following the retreat of area glaciers.
- At present, the **Cordillera Chila** mountain range no longer has any glaciers. The last of them melted between 2000 and 2007.
- The **Cordillera Huayhuash** mountains show a relatively slow retreat of valley glaciers in comparison with the neighboring Cordillera Blanca range → since 1957, glaciers have retreated at an average annual rate of 4 to 7 m, summary by 230 to 350 m.
- Systematic measurements of soil temperatures have shown an absence of long-term frozen soils in locations up to 5150 m above sea level.
- The lower boundary of the zone of mountain permafrost is, therefore, located higher than the literature indicates for this area.

Kyrgyz Republic



Area: 198 500 km^2

Population 5,3 millions

Average relief altitude is 2 750 m a.s.l.

94 % of surface at the altitude above 1 000 m

40 % of surface at the altitude above 3 000 m

Highest point: Pik Pobedy 7 439 mts a. s. l.

Projects of the Czech Development Cooperation

- Monitoring of high-mountain glacial lakes and protection of population against catastrophic consequences of floods caused by moraine dam failure (2004-2007).

- Risk analysis and limiting the consequences of high-mountain lake dam failure (2007-2010).

Project funded by NATO SPS

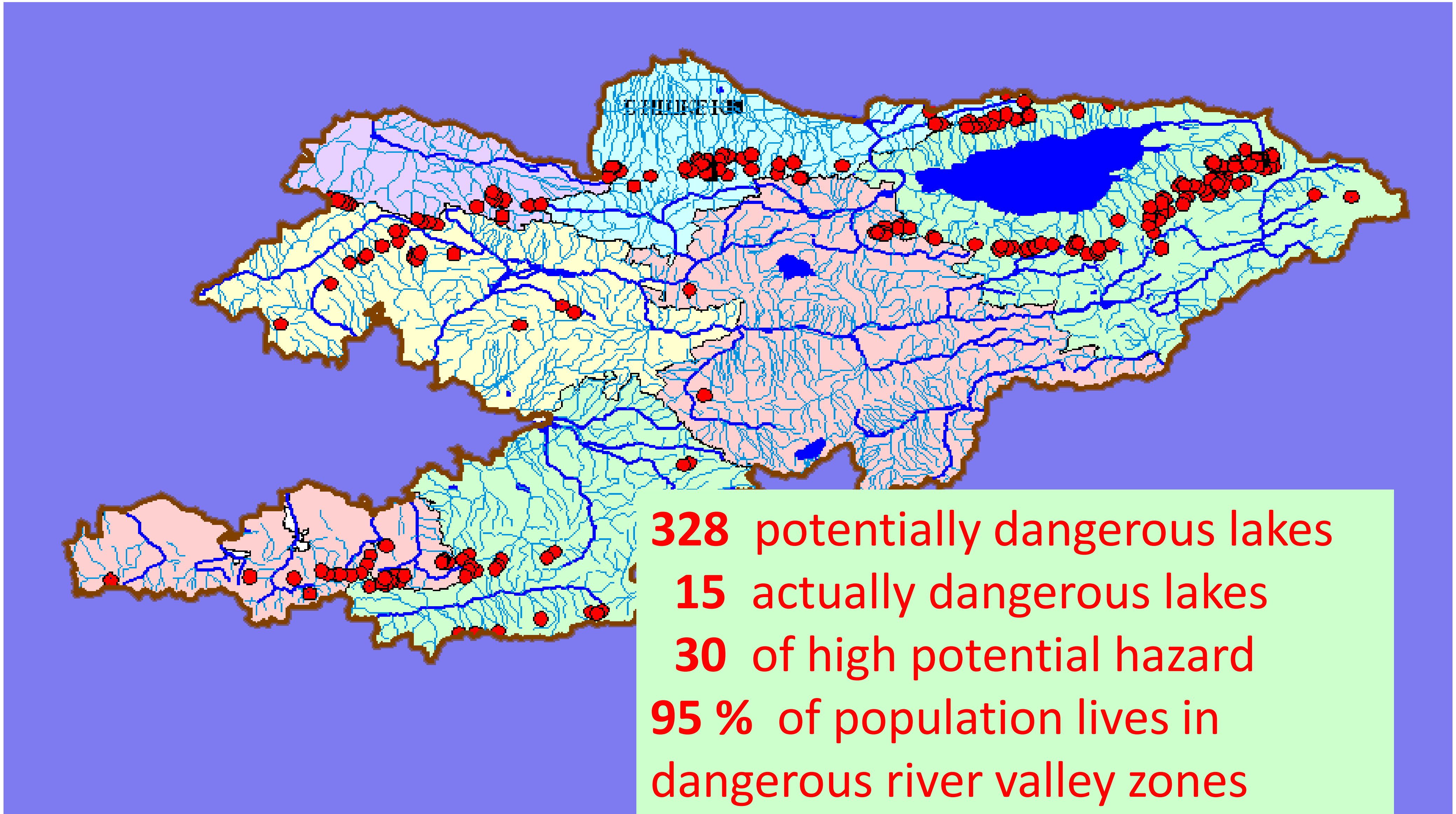
- Glacier hazards in Kyrgyzstan: implications for resource development and water security in Central Asia (2012-2013)

Natural hazards in Kyrgyzstan

The hazardous alpine lakes in Kyrgyzstan

1923 lakes covering more than 0.1 km²

100 lakes more than 1 km²



328 potentially dangerous lakes

15 actually dangerous lakes

30 of high potential hazard

95 % of population lives in dangerous river valley zones

Lakes after outburst

Outburst thermokarst lake in Shakhimardan (1998)

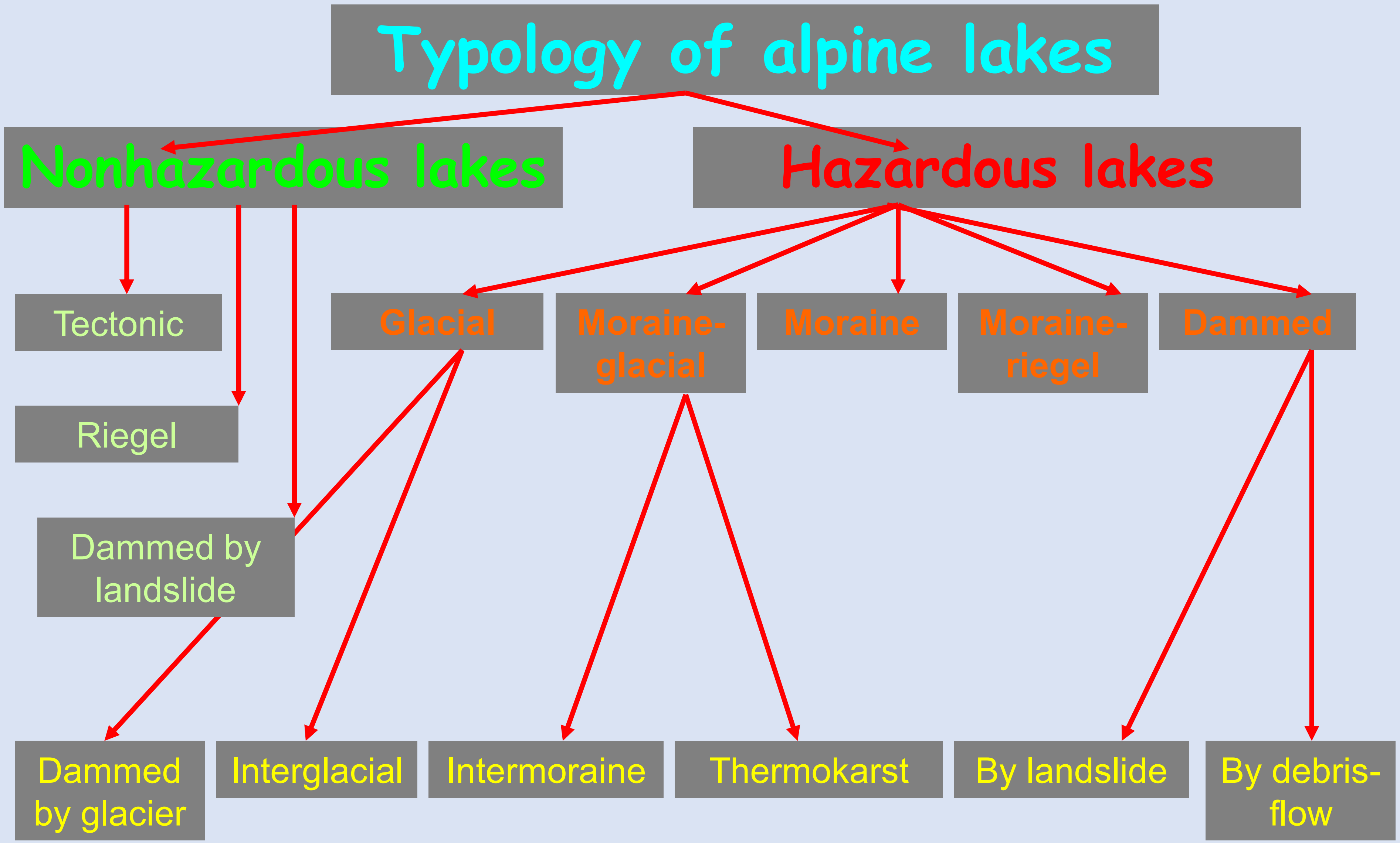
Outburst of Zyndan glacial lake, 24th of 2008

Genetic classification of lakes

- Monitoring of the mountain lakes in Kyrgyzstan was aimed mainly at evaluation of dam stability with regard to the risk of lake rupture and consequent occurrence of flood and stone flows ("sels").
- Genetic types of lakes in high mountain regions of Kyrgyzstan (according Jansky, Sobr and Yerokhin 2006):

  tectonic, glacier, morainic-glacier, morainic, lakes

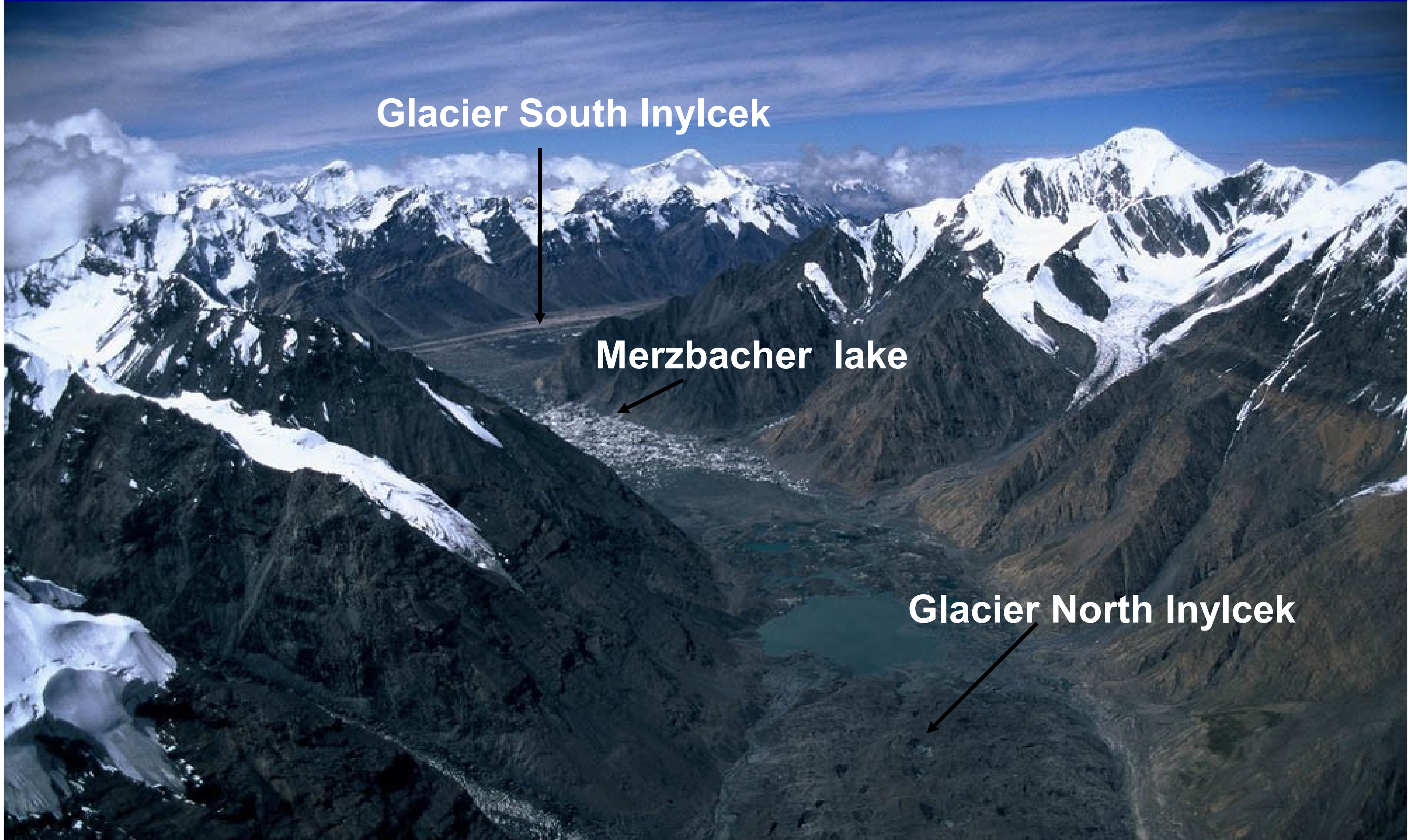
  dammed by a rock step and lakes dammed by a landslides


Typology of alpine lakes
Nonhazardous lakes
Hazardous lakes
Tectonic
Riegel
Dammed by landslide
Glacial
Moraine-glacial
Moraine
Moraine-riegel
Dammed
Dammed by glacier
Interglacial
Intermoraine
Thermokarst
By landslide
By debris-flow


Tectonic lakes
Issyk - Kul

Glacial (proglacial) lakes:

dammed by a glacier, situated directly in the body of a glacier or in the moraine on its contact

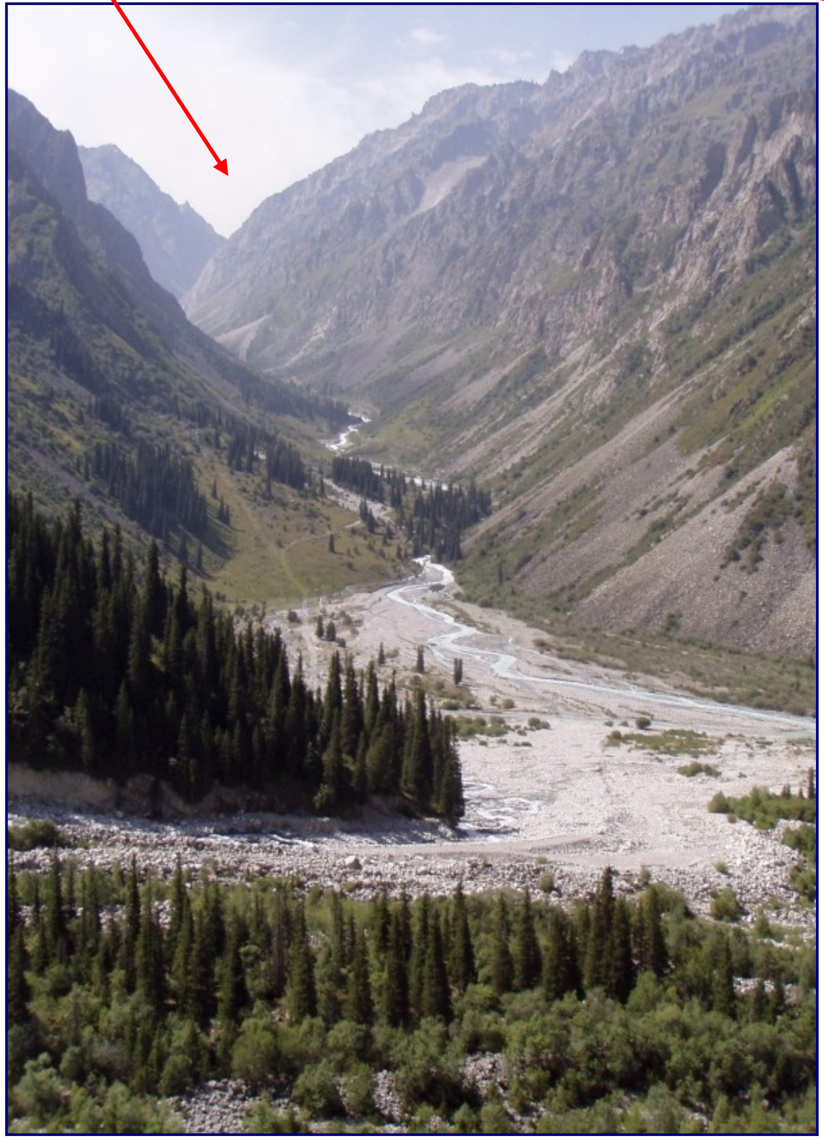


Intraglacier lakes:

formed in hollows of glaciers, mostly in places of large icefalls with a complicated system of underground canals


periodical Ak-Sai lake

Stone flow (sel) after rupture of Ak-Sai lake in 1985 and 2014



Morainic-glacier lakes:

a) subtyp – lakes of intramorainic depressions

This type is developing in basins of intramorainic depressions after retreat of a glacier

Morainic-glacier lakes:

b) subtyp

lakes of thermokarstic depressions

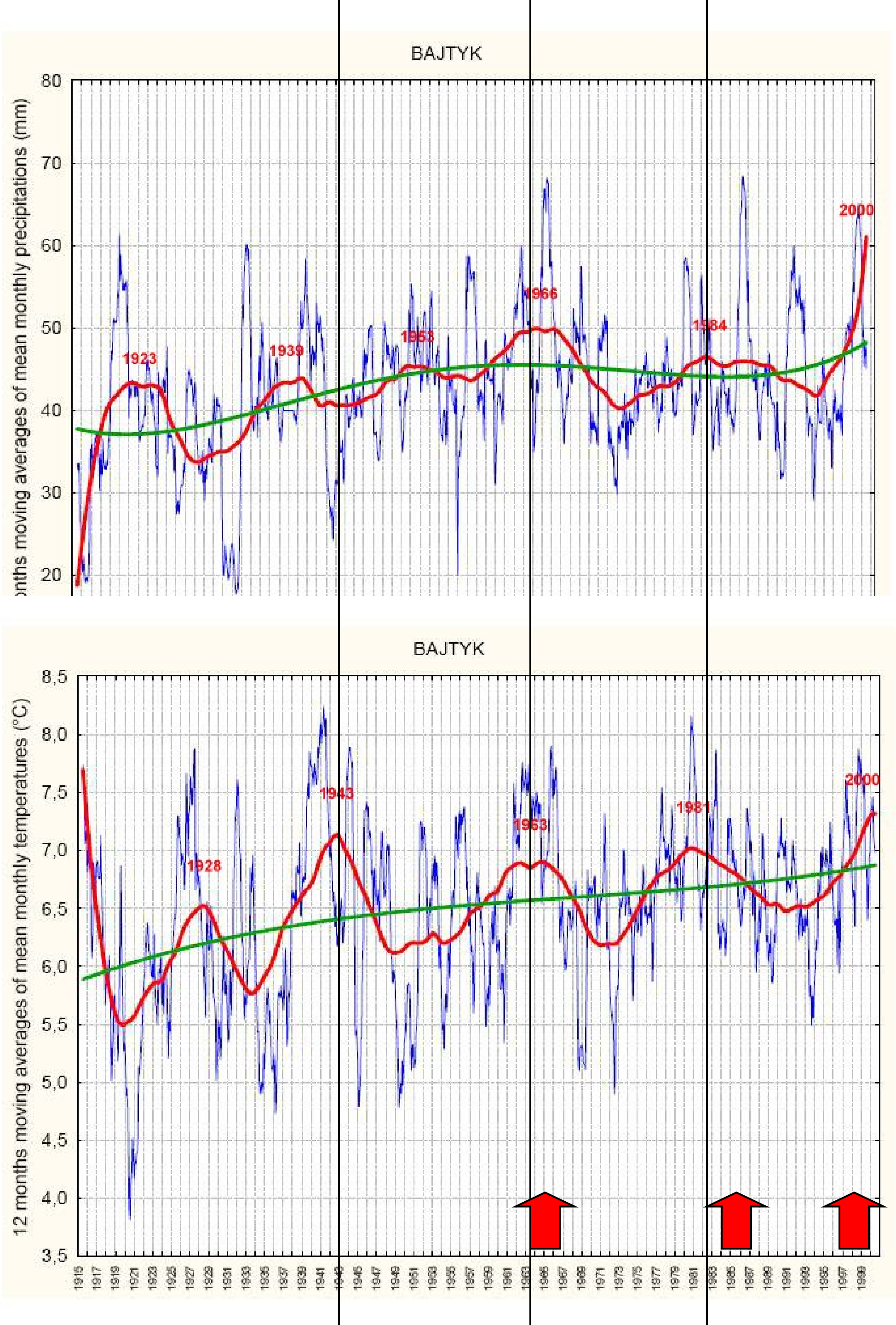
Lakes dammed by a landslides:

large volume → therefore rupture is very dangerous

Koltor lake: Superficial outflow after intensive precipitation

Koltor lake – new trouble

Erosion furrow
at outer side of lake dam



Development of precipitations and temperature

Baytyk station 1 579 mts a.s.l.

Precipitations:

15 years cycle until 1966,
Change to 20 years cycle.
Steep increase since middle of nineties.

Temperature:

Regular 20 years cycle.

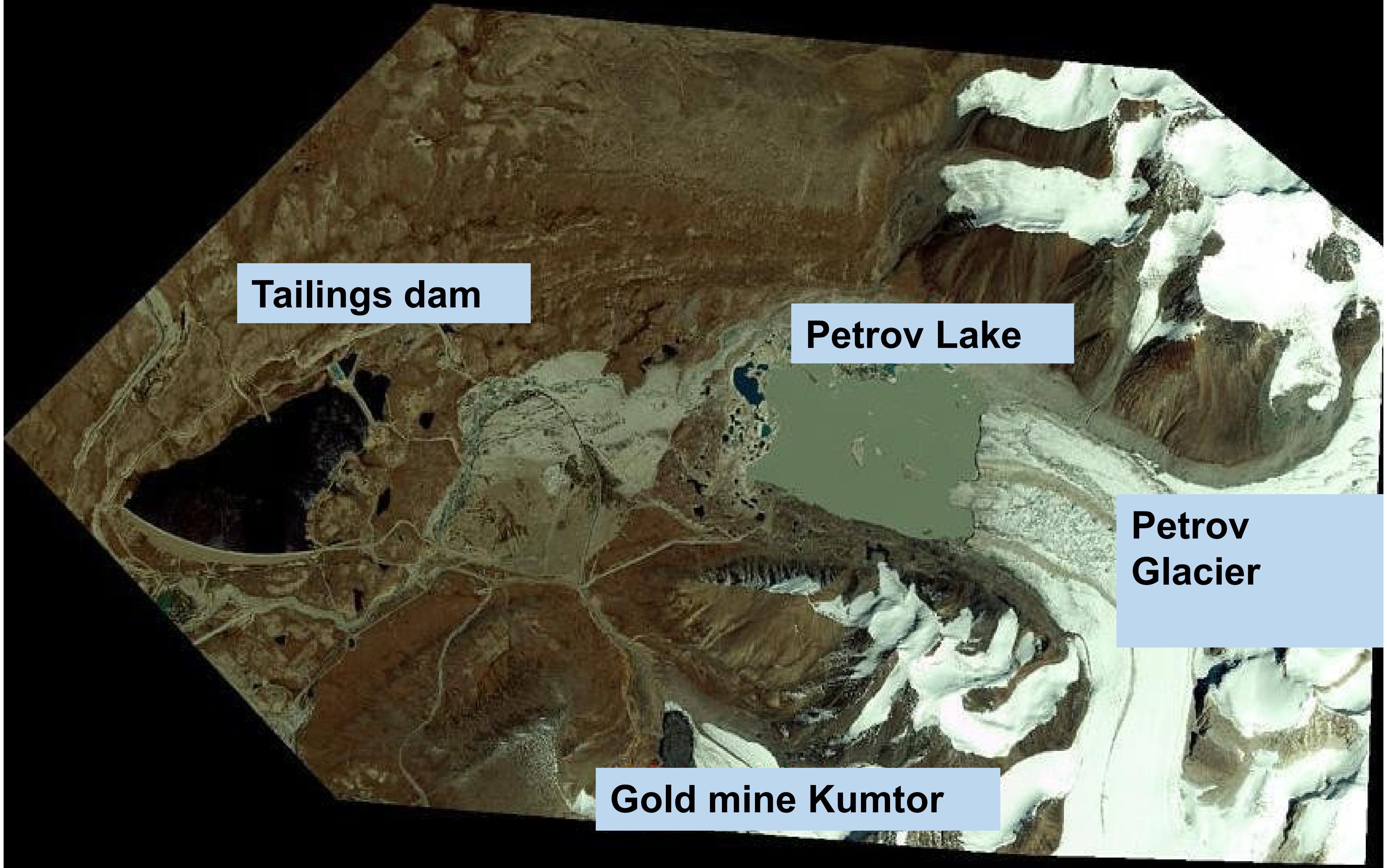
Clear correlation between precipitations and temperature
In the middle of sixties and eighties

Highest number of disastrous outbursts in 1965-70, 1983-88, 1997-99

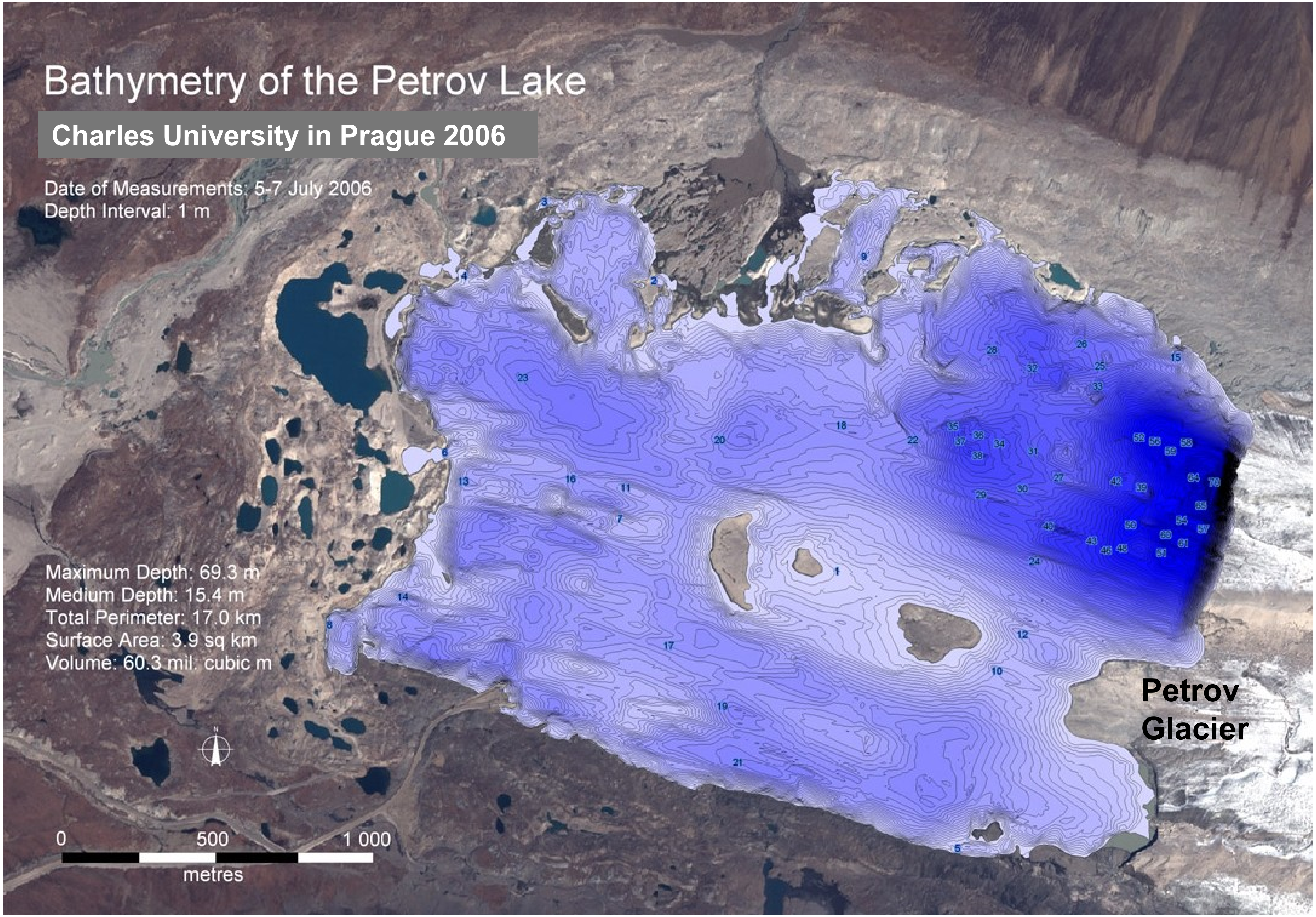
Petrov lake:
an extremely dangerous evolution

Petrov lake :
an extremely dangerous evolution

- **Moraine-glacial lake:** developed in basin of intramorainic depression after retreat of Petrov glacier.
- Is located in the foreground of the same-called glacier on the north-western slope of Ak-Sijrak massive in southern Tien-Shan.
- The moraine-glacial lakes **are considered as the most dangerous type including 47 % of listed lakes.**
- **Petrov glacier** is 69.8 km^2 large and 23 km long.

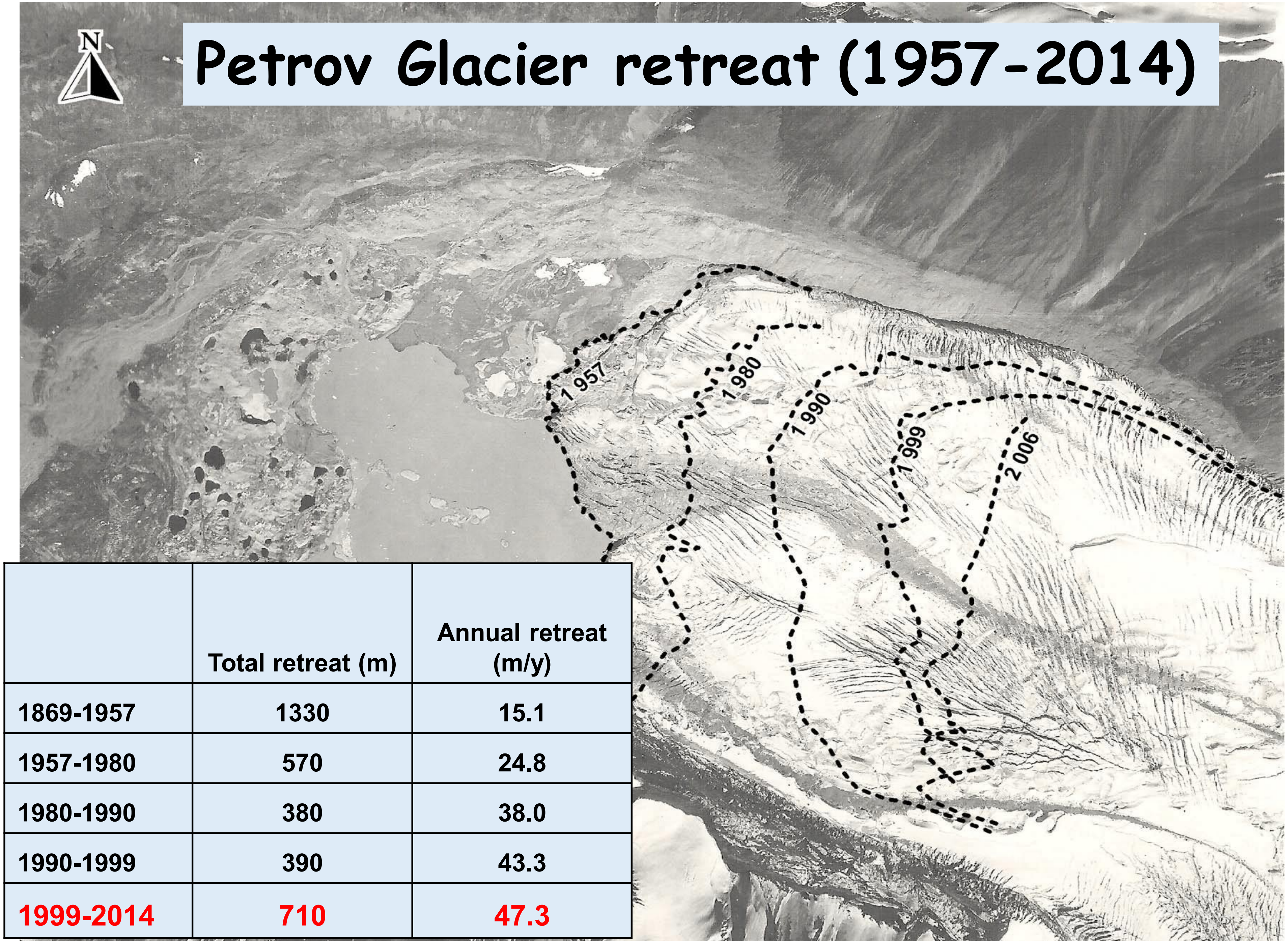


Satelite image of the Petrov Lake area (QuickBird 2003)


Bathymetry of the Petrov Lake
Charles University in Prague 2006
Date of Measurements: 5-7 July 2006
Depth Interval: 1 m
Maximum Depth: 69.3 m
Medium Depth: 15.4 m
Total Perimeter: 17.0 km
Surface Area: 3.9 sq km
Volume: 60.3 mil. cubic m
0
500
1 000
metres
Petrov
Glacier

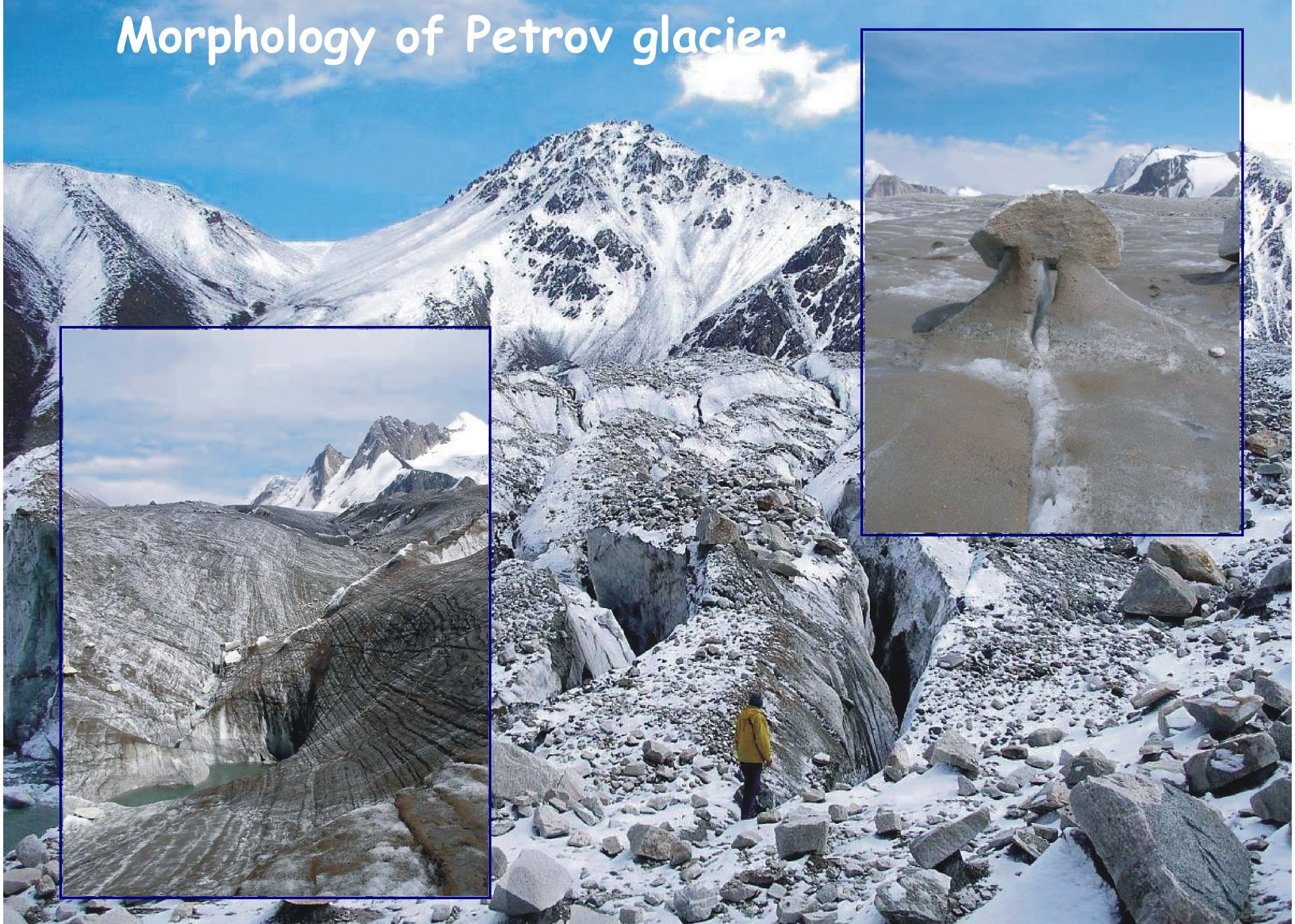

bathymetry

Petrov Glacier retreat (1957-2014)

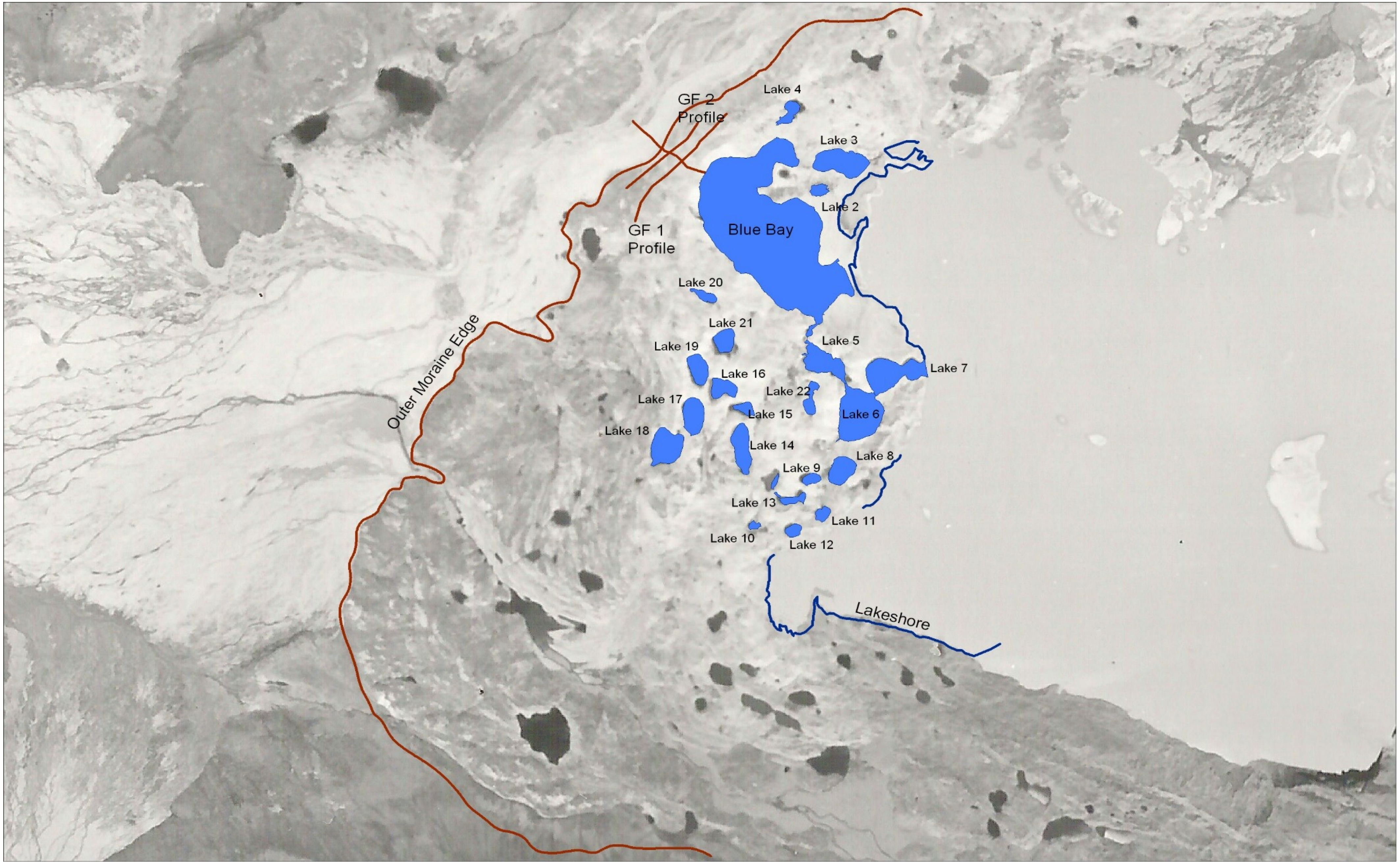


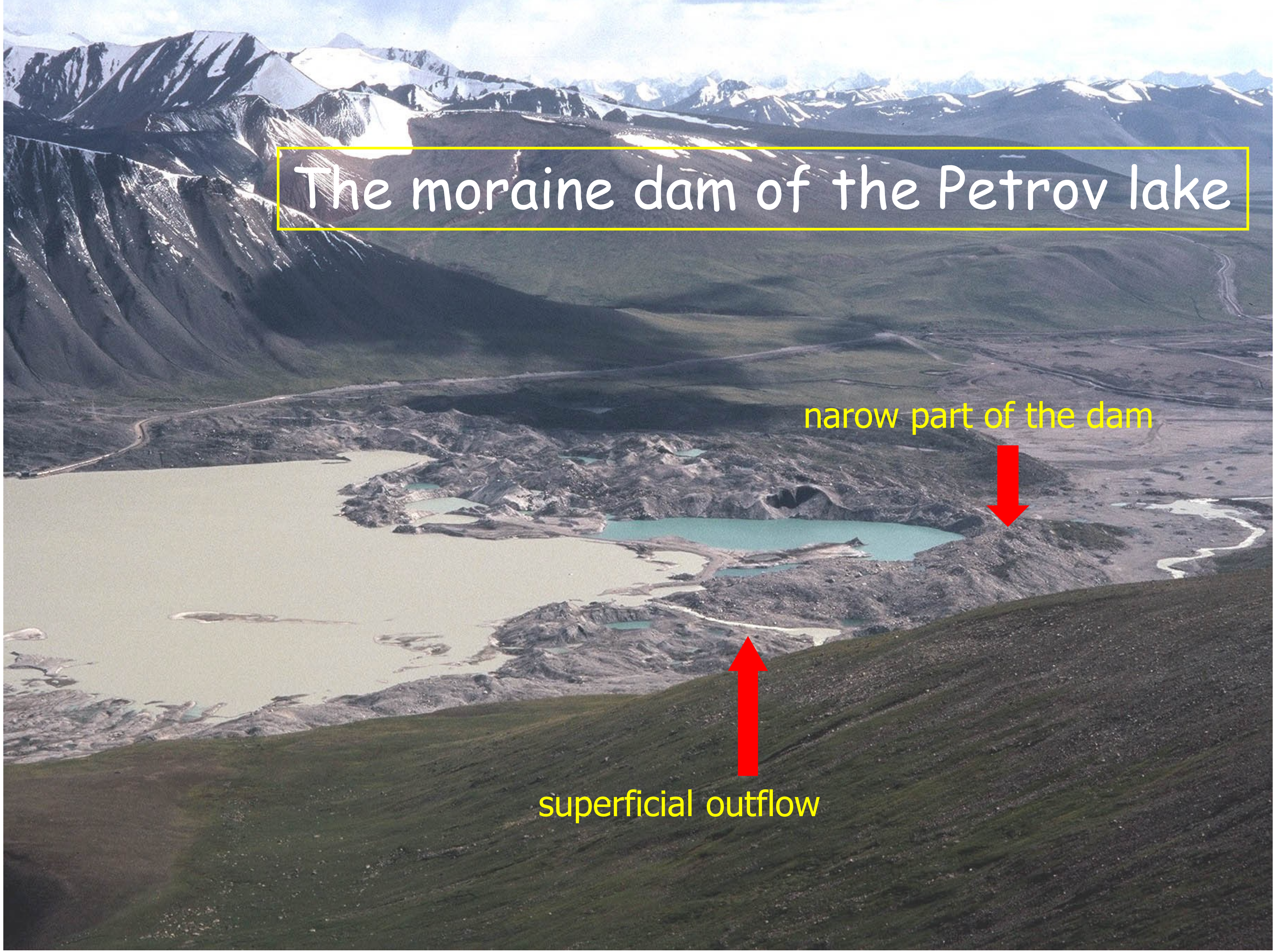
	Total retreat (m)	Annual retreat (m/y)
1869-1957	1330	15.1
1957-1980	570	24.8
1980-1990	380	38.0
1990-1999	390	43.3
1999-2014	710	47.3

Morphology of Petrov glacier



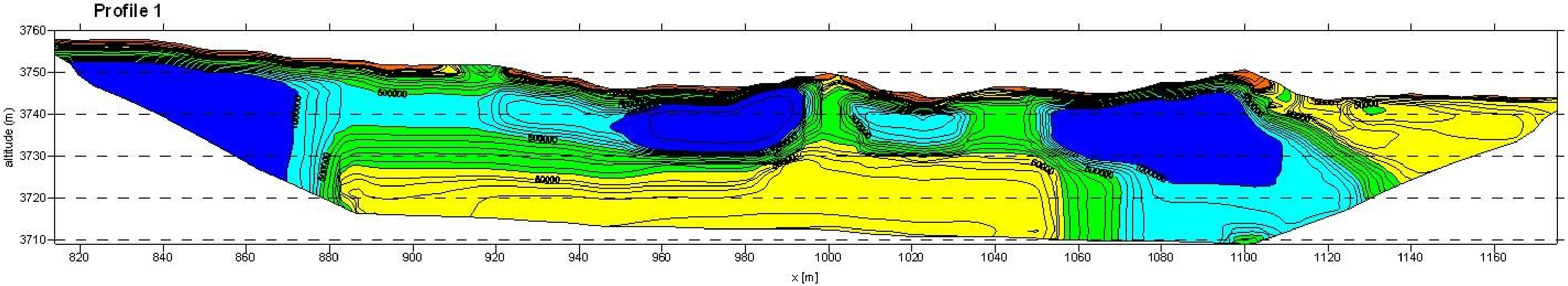
The lakes of thermokarstic depressions

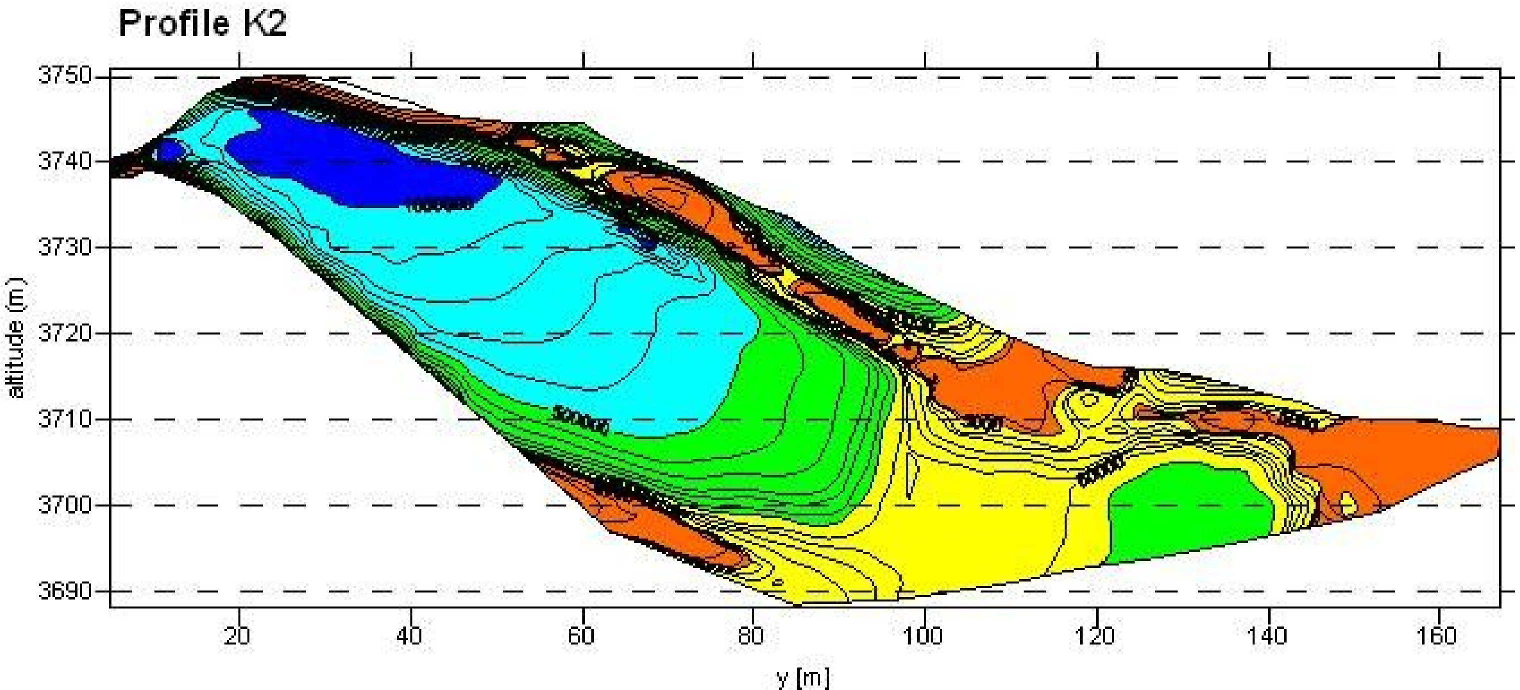



The moraine dam of the Petrov lake
narow part of the dam
superficial outflow

Geophysical survey of Petrov lake dam

Resistivity tomography





Conclusions I

- The thermokarst processes caused by melting of the buried ice in the moraine dam of the Petrov lake most danger and very dynamic development.

- The surface area and volume of the retained water in the Petrov lake increase considerably.
- *Enlarging of the lake size and volume* together with *weakening of moraine stability* causes an extremely dangerous situation which could result in a large-scale natural catastrophe.

- In the case of the dam rupture the storage facility of highly toxic waste on the territory of the gold mine Kumtor could be washed out.


Glacial complex Adygine
Adygine research station


Adygine research station
3 700 mts a.s.l.

Klimatická stanice Adygine, 3700 m n.m., se satelitním přenosem, instalace červenec 2017

Research and monitoring station Adygine

The research programme of the station is aimed at:

- Monitoring of hazardous lakes
- Meteorological observations
- Hydrological measurments
- Glaciological research
- Other researches (geological, botanical etc.)



GENERAL CONCLUSIONS

- Retreat of most of glaciers at the heights of 3 500–4 000 mts a. s. l.
- Development of new lakes after frontal part of retreated glacier tongue
- Short life-time of recently appeared lakes, few years or even months
- Negative influence of current climatic changes:
  - increase of evolution dynamics,
  - more chaotic development of glacier complexes,
  - decreasing of ice core mass inside the moraine,
  - higher water outflow from melting glaciers and discharge variability of glacial rivers.
- Higer risk level due to more intensive exploitation of mountain valleys

Publications

- JANSKÝ, B., ENGEL, Z., ŠOBR, M., YEROKHIN, S., BENEŠ, V., ŠPAČEK, K. (2009): **The Evolution of Petrov Lake and Moraine Dam Rupture Risk (Tien-Shan, Kyrgyzstan)**. Natural Hazards, Springer, 50, No. 1, pp. 83 -96.
- JANSKÝ, B., ENGEL, Z., ŠOBR, M. (2010): **Outburst flood hazard: Case studies from the Tien - Shan Mountains, Kyrgyzstan.** Limnologica, Limnologica-Ecology and Management of Inland Waters, 40(4), 358-364.
- ENGEL, Z., ŠOBR, M., EROKHIN, S. A. (2012): **Changes of Petrov Glacier and its proglacial lake in Akshiirak massif, central Tien Shan, since 1977.** Journal of Glaciology, International Glaciological Society, 58(208), 388-398.
- FALATKOVA, K., ŠOBR, M., KOCUM, J., JANSKY, B. (2014): **Hydrological regime of Adygine lake, Tien Shan, Kyrgyzstan.** Geografie, 119(4), 320–341

In preparation:

JANSKÝ, B., ŠOBR, M. edit.: The Lakes of Kyrgyzstan. Monography, Elsevier, 2019.

The scientists have
a hard live…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