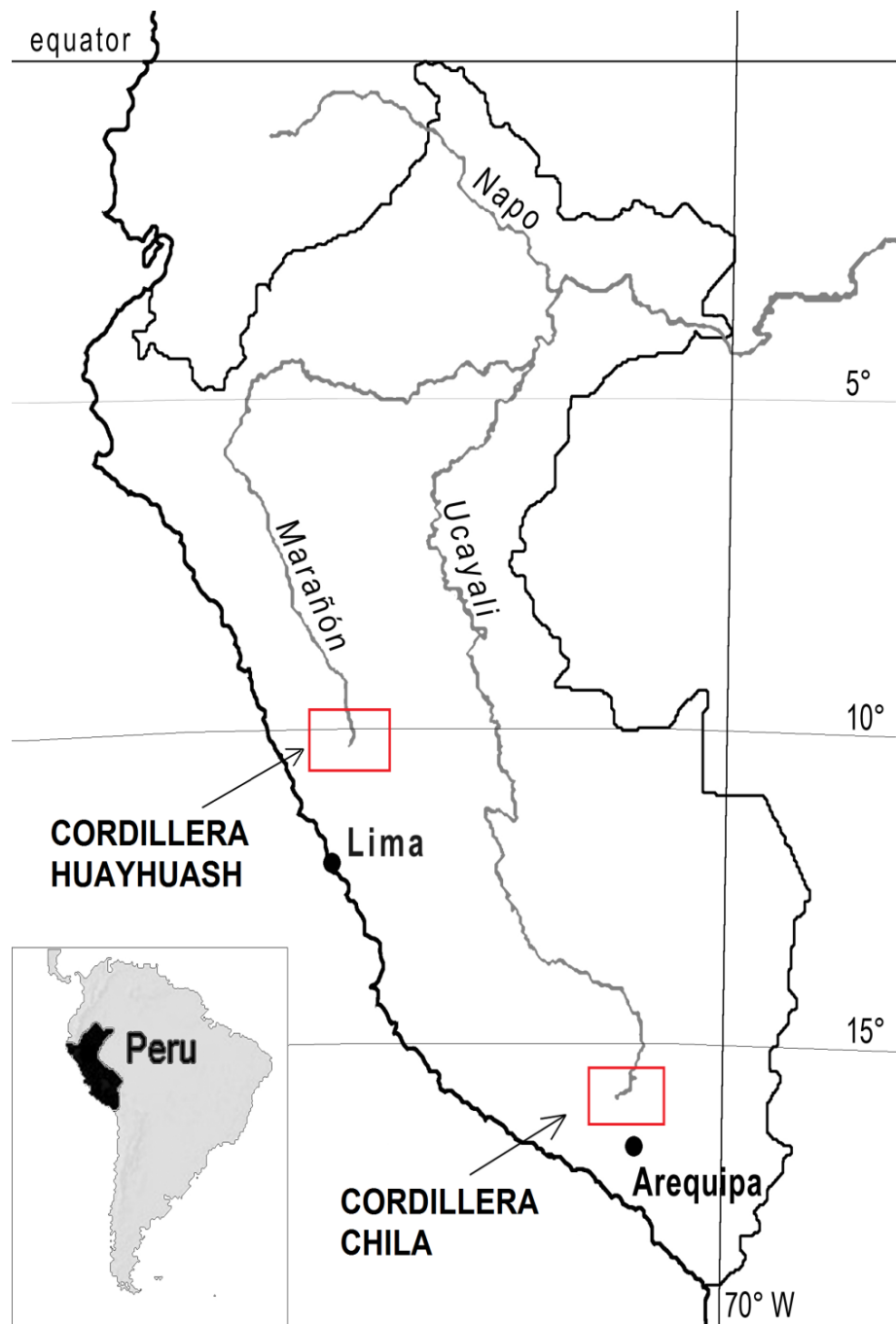


# Climate change impact on the mountain environment in Peruvian Andes and Tien Shan Mountains in Kyrgyzstan



**Prof. Dr. Bohumir Jansky**

Charles University in Prague, Faculty of Science,  
Department of Physical Geography and Geoecology



**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. Marañón 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 Marañón

Rio Ucayali

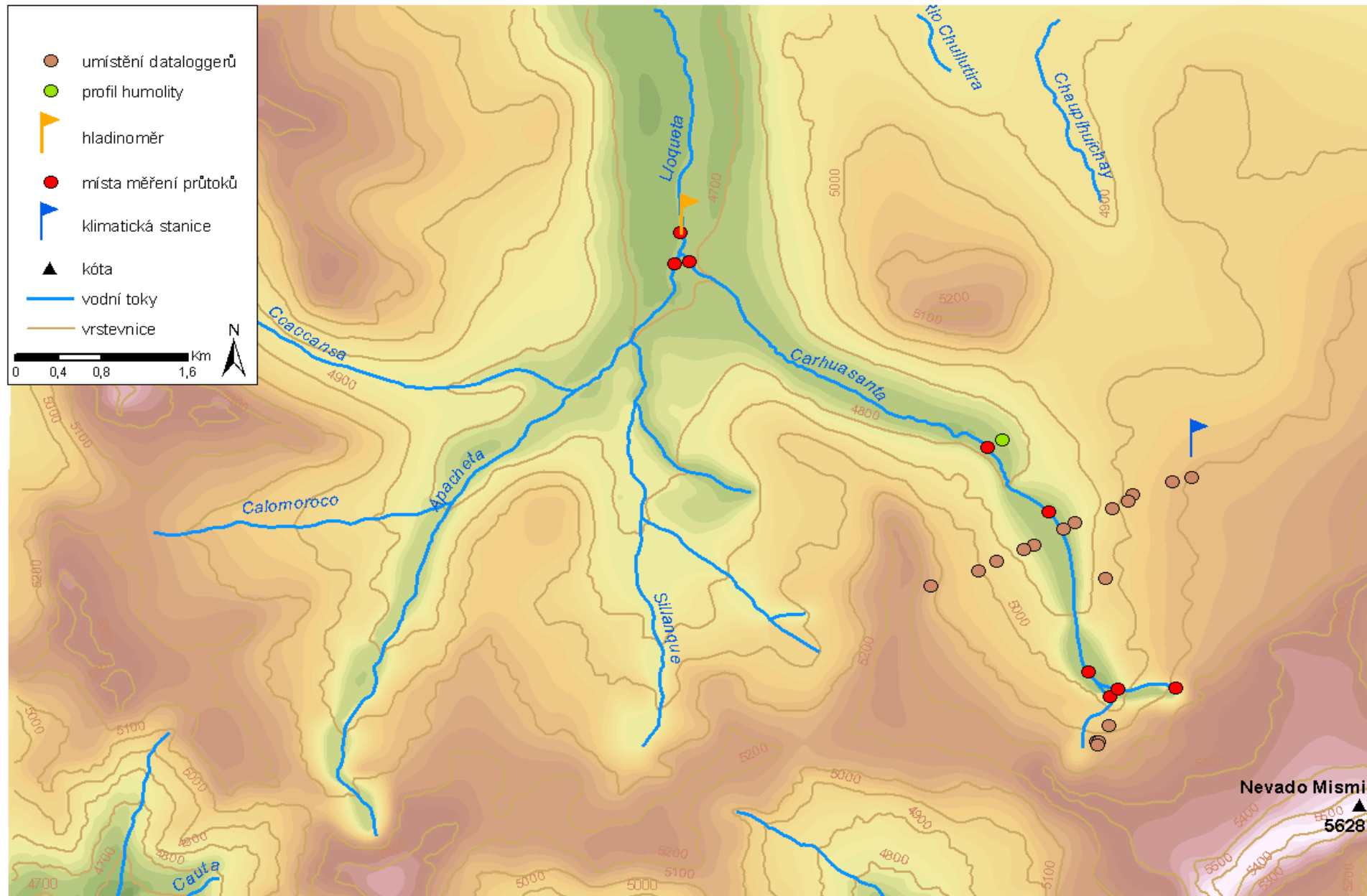
LIMA

BOLIVIA

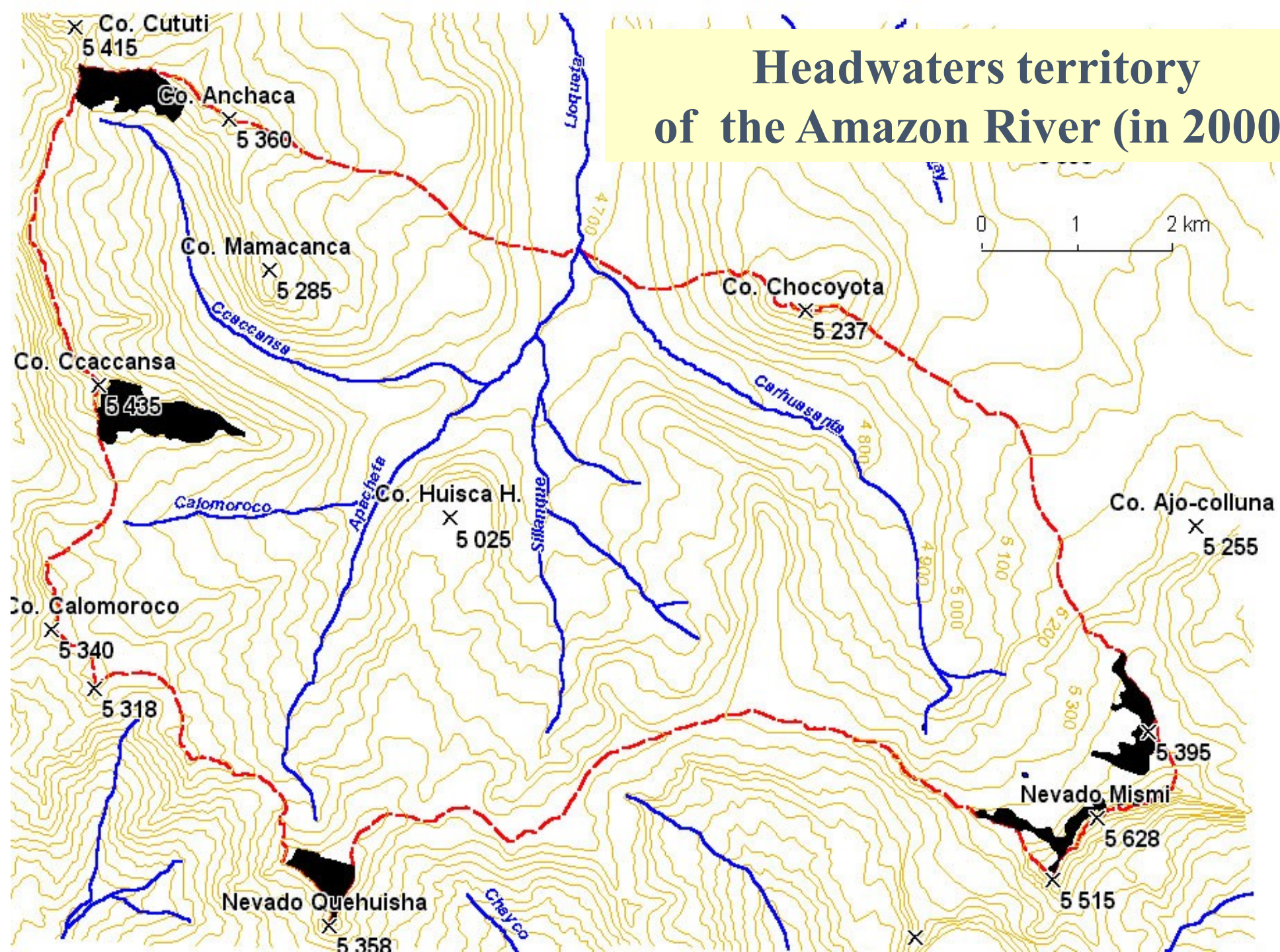
Amazon source area

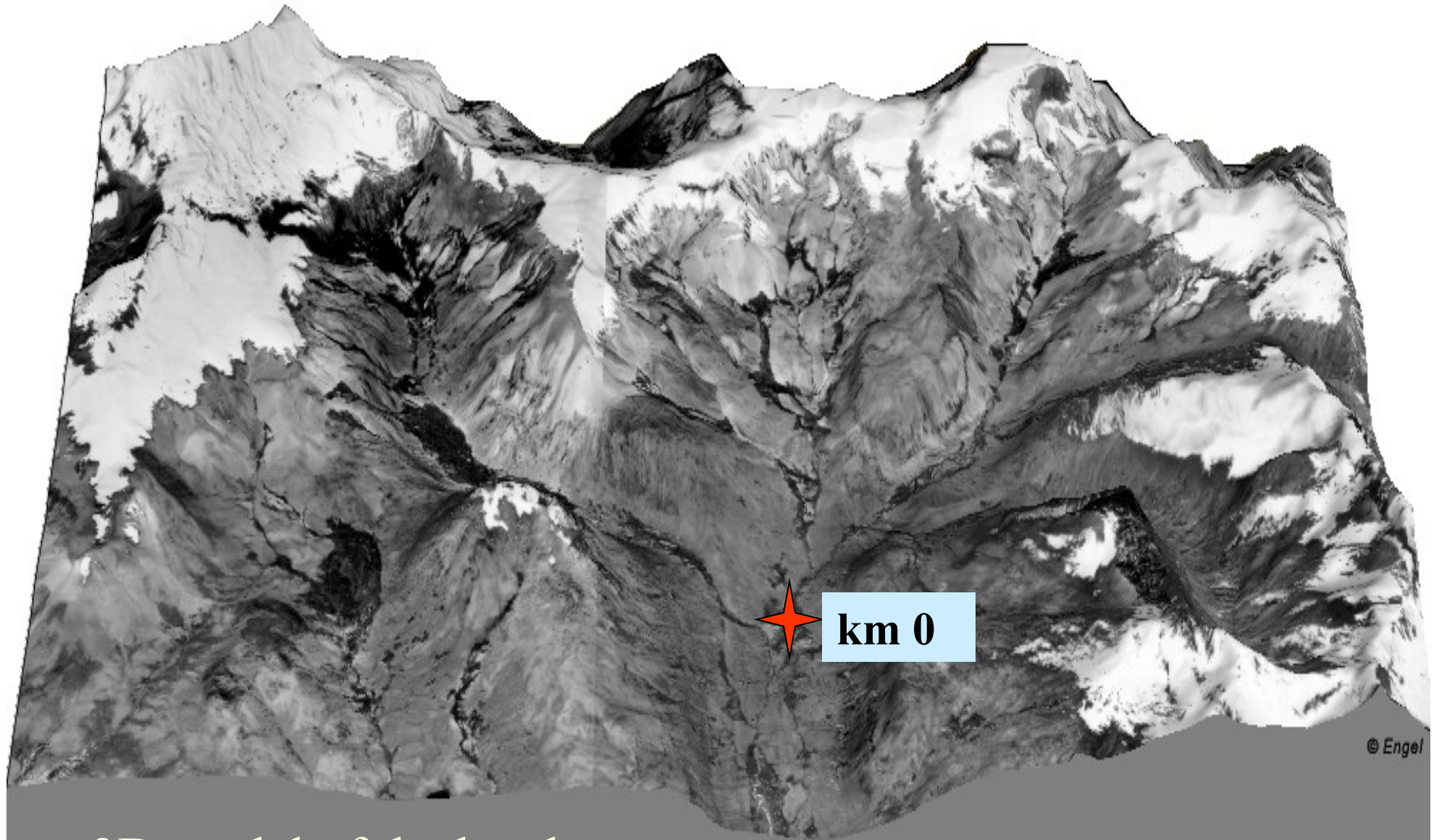
Arequipa

# 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 km<sup>2</sup>*** out of total 57.15 km<sup>2</sup>.

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

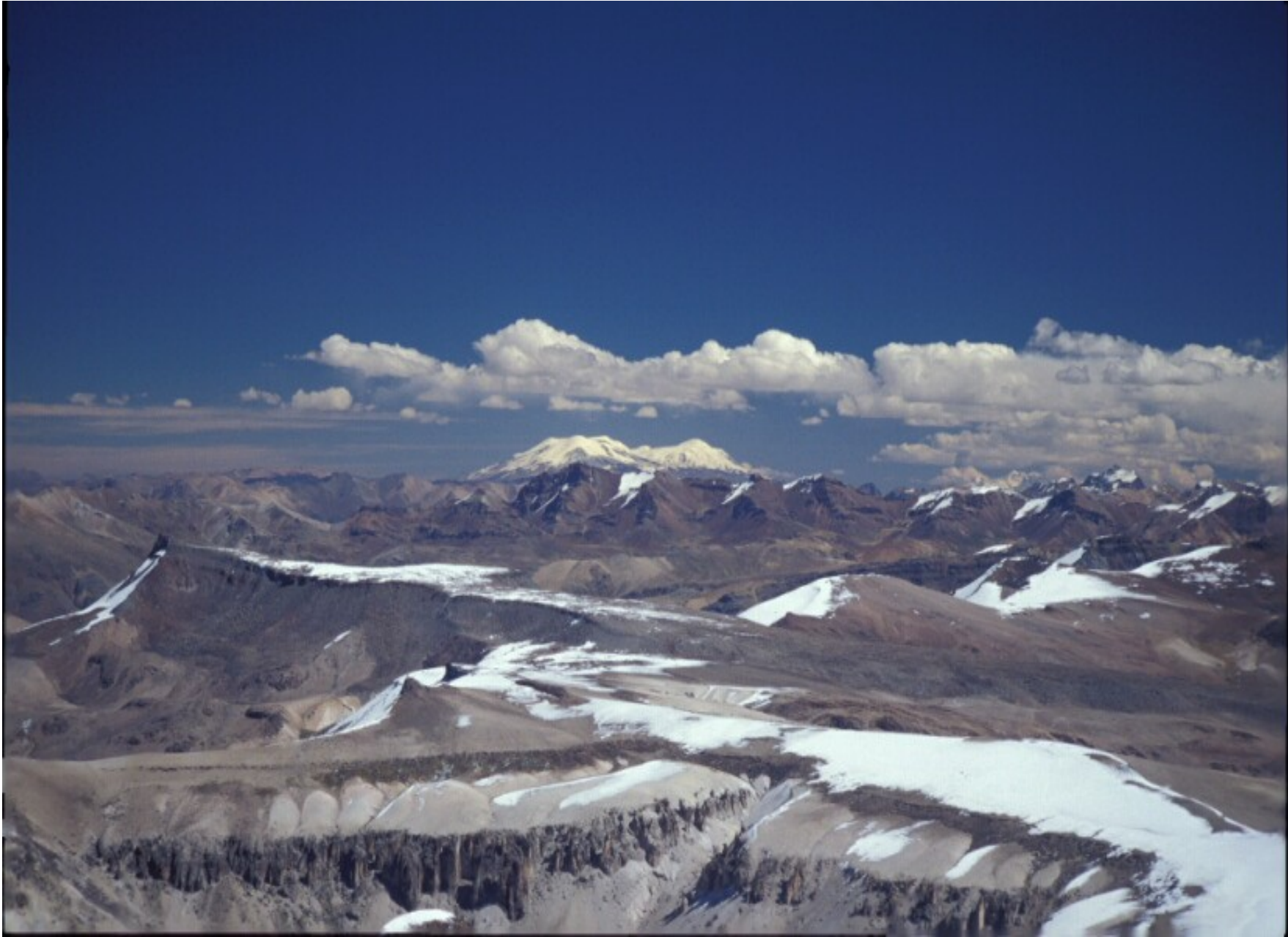
# Glacier retreat since 1955 to 1999

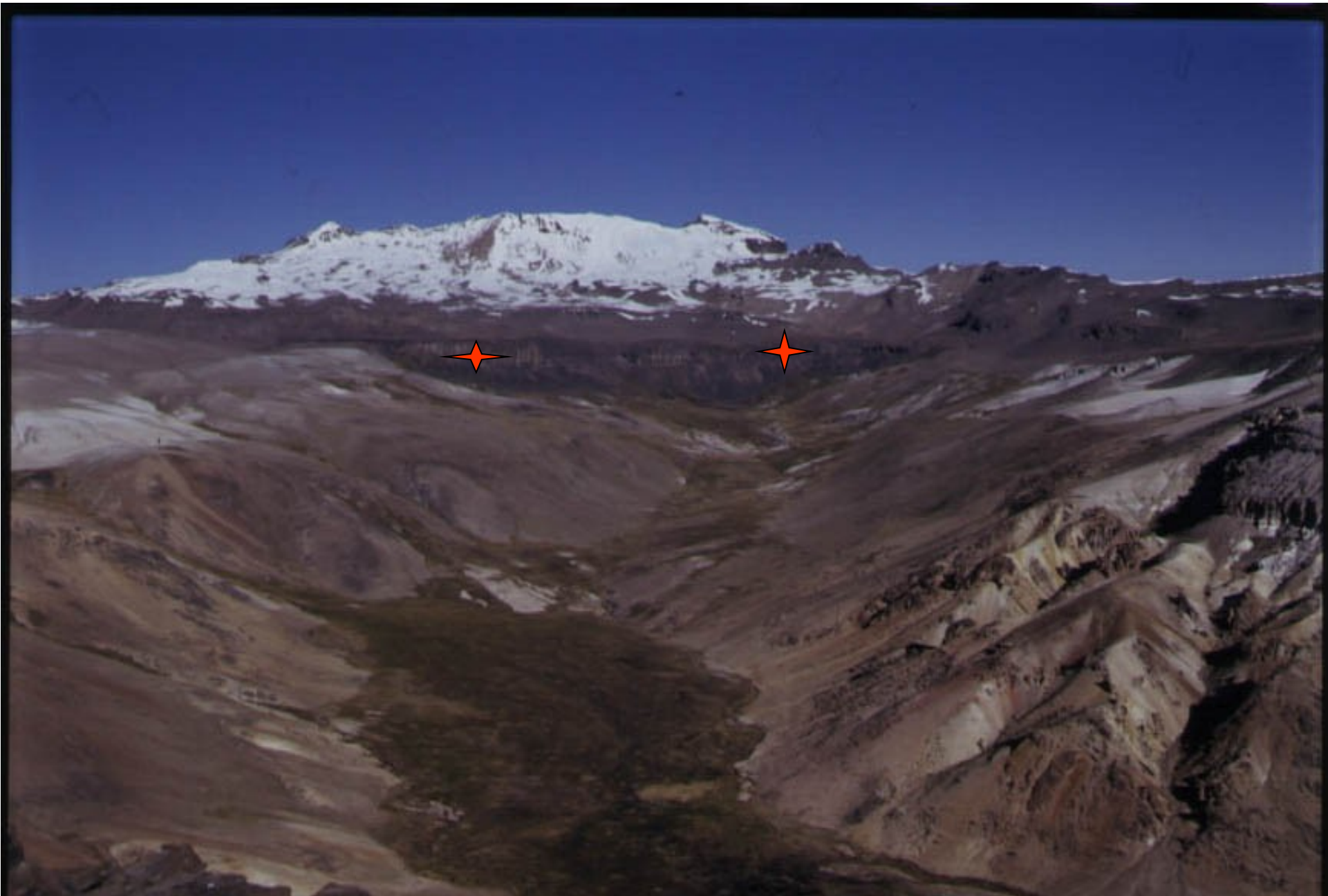


# Glaciers dynamic in the Amazon River headwaters territory since 1955 to 2000

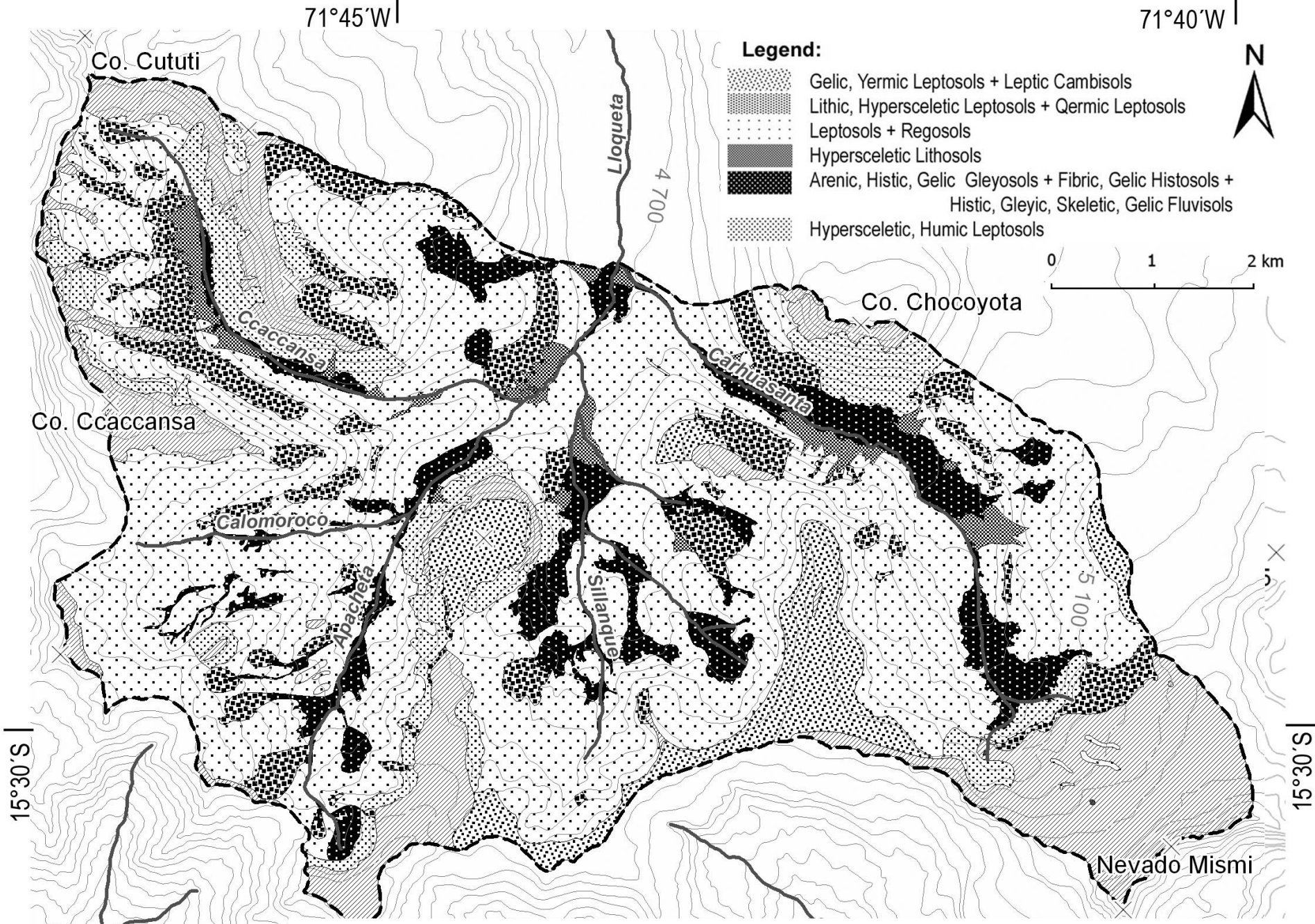
Glacier	Area [km <sup>2</sup> ]		Difference %	Max. alt. [m]	Min. alt. [m]	Orientation
	1955	2000				
Mismi	0.57	0.45	21	5628	5250	NW
Chayco	0.72	-	100	5200	5150	NW
Quehuisha	0.97	0.20	79	5358	5250	N
Calomoroco	0.42	-	100	5340	5200	NE
Ccaccansa	0.66	0.51	23	5435	5250	S
Cututi	0.50*	0.38	24	5360	5200	S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

71°45'W |

| 71°40'W

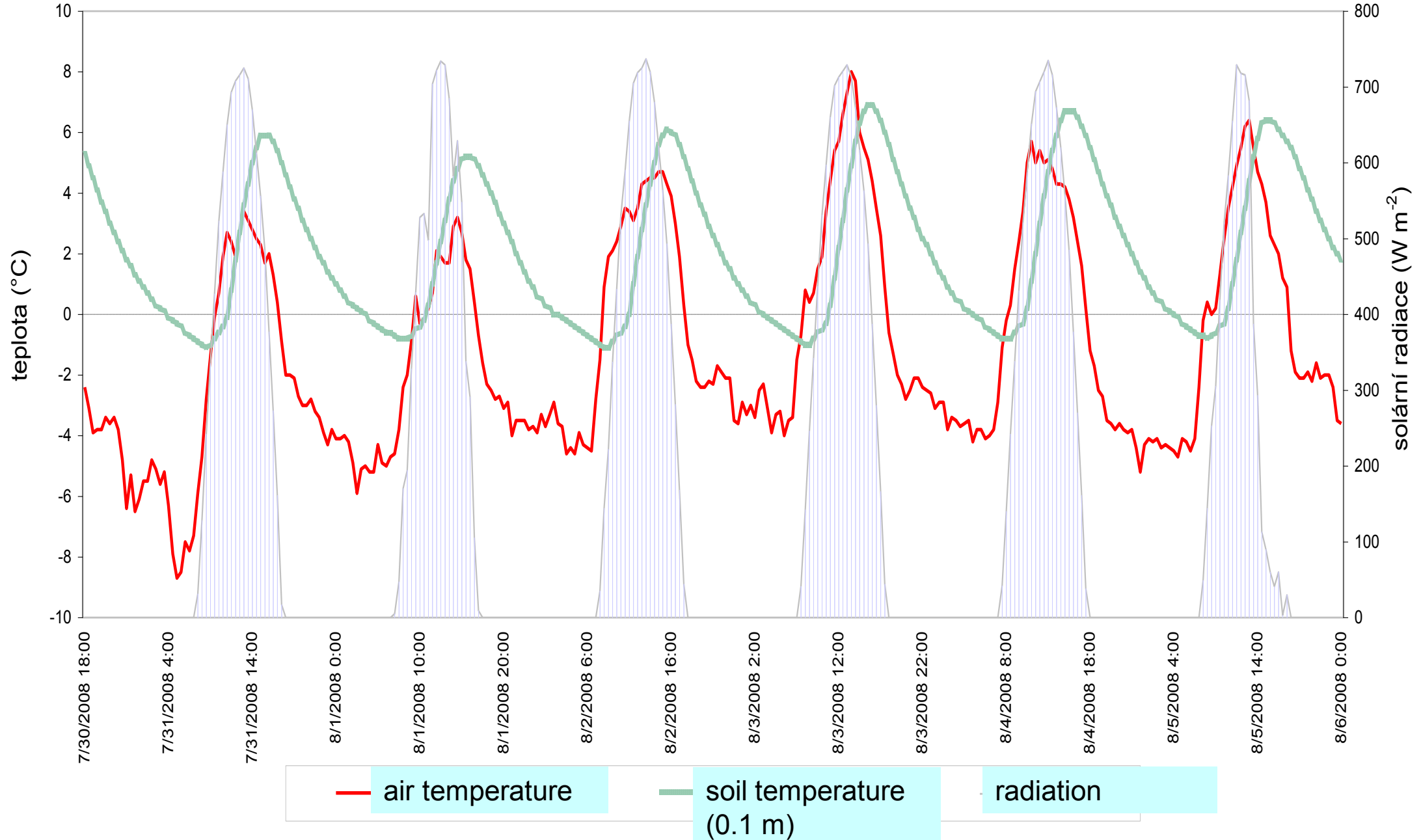


Die Talvegetation „Champa“ (*Distichia muscoides*)



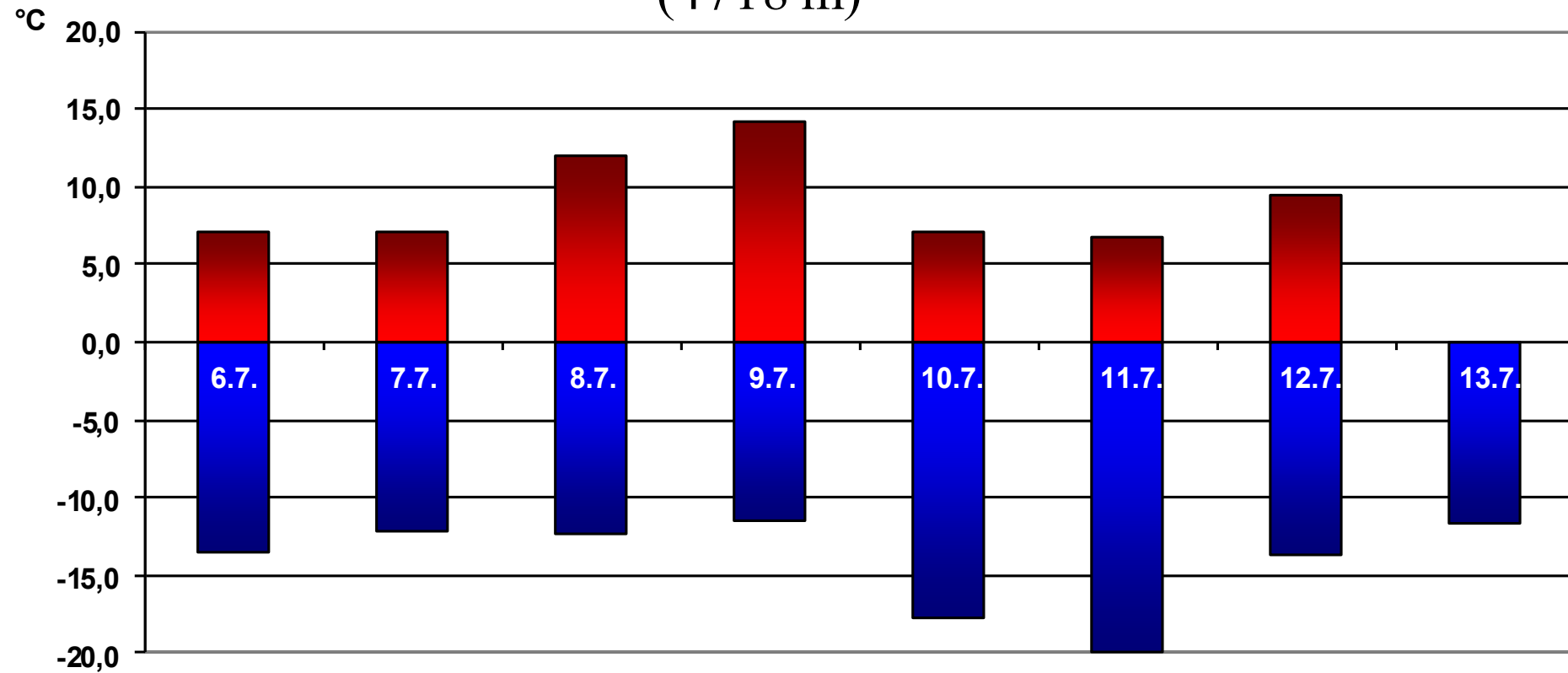


The climatic station at the Amazon's source, located at 5075 m above sea level: it was **the highest located station in Peru**. In background Nevado Mismi (5628 m).



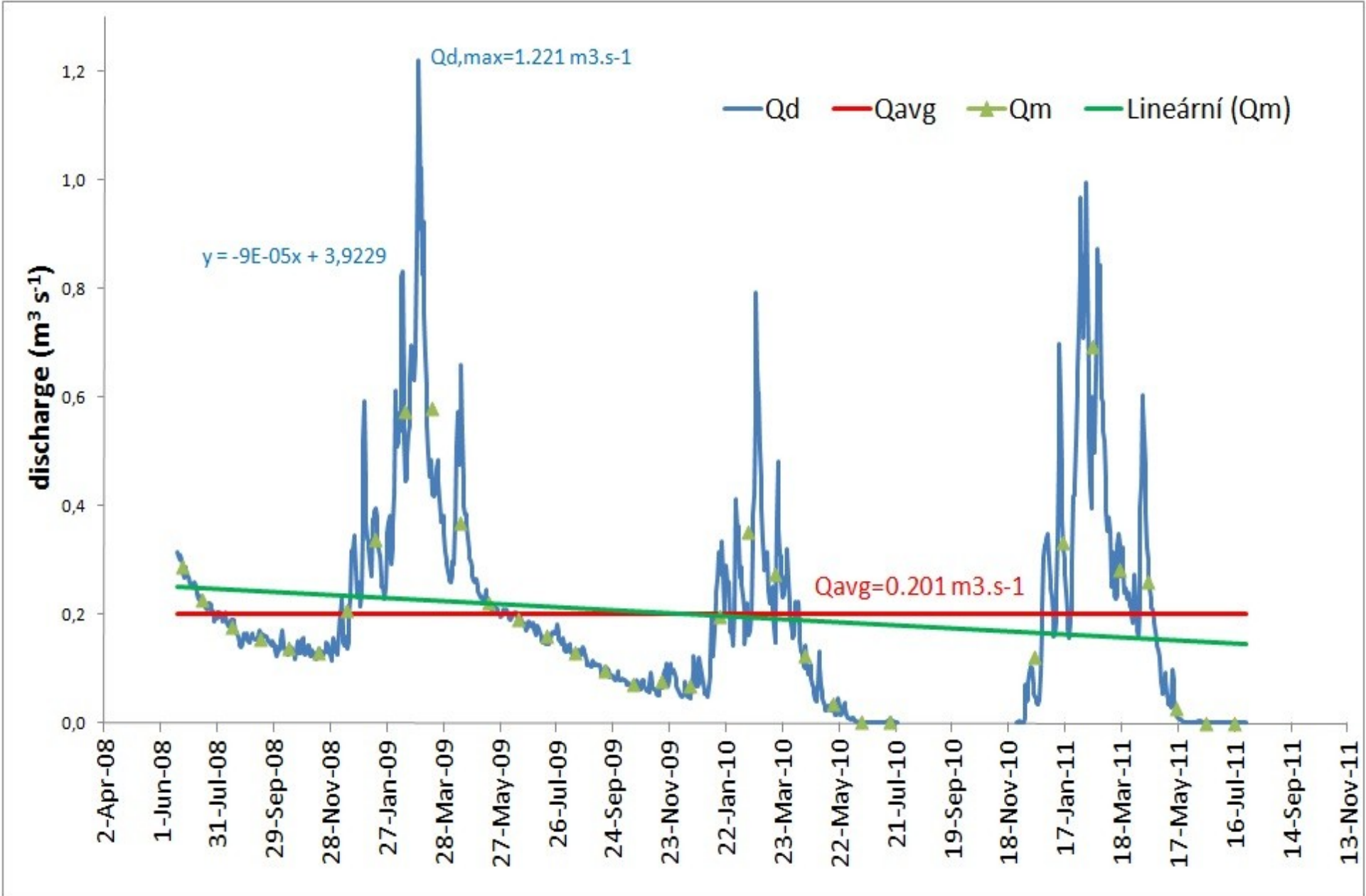
Air temperature, soil temperature and solar radiation at the Amazon's source. The climatic station of the Charles University in Prague (5075 m a.m.s.l., period 30.7. - 6.8. 2008).

# The confluence of Carhuasanta and Apacheta rivers (4718 m)

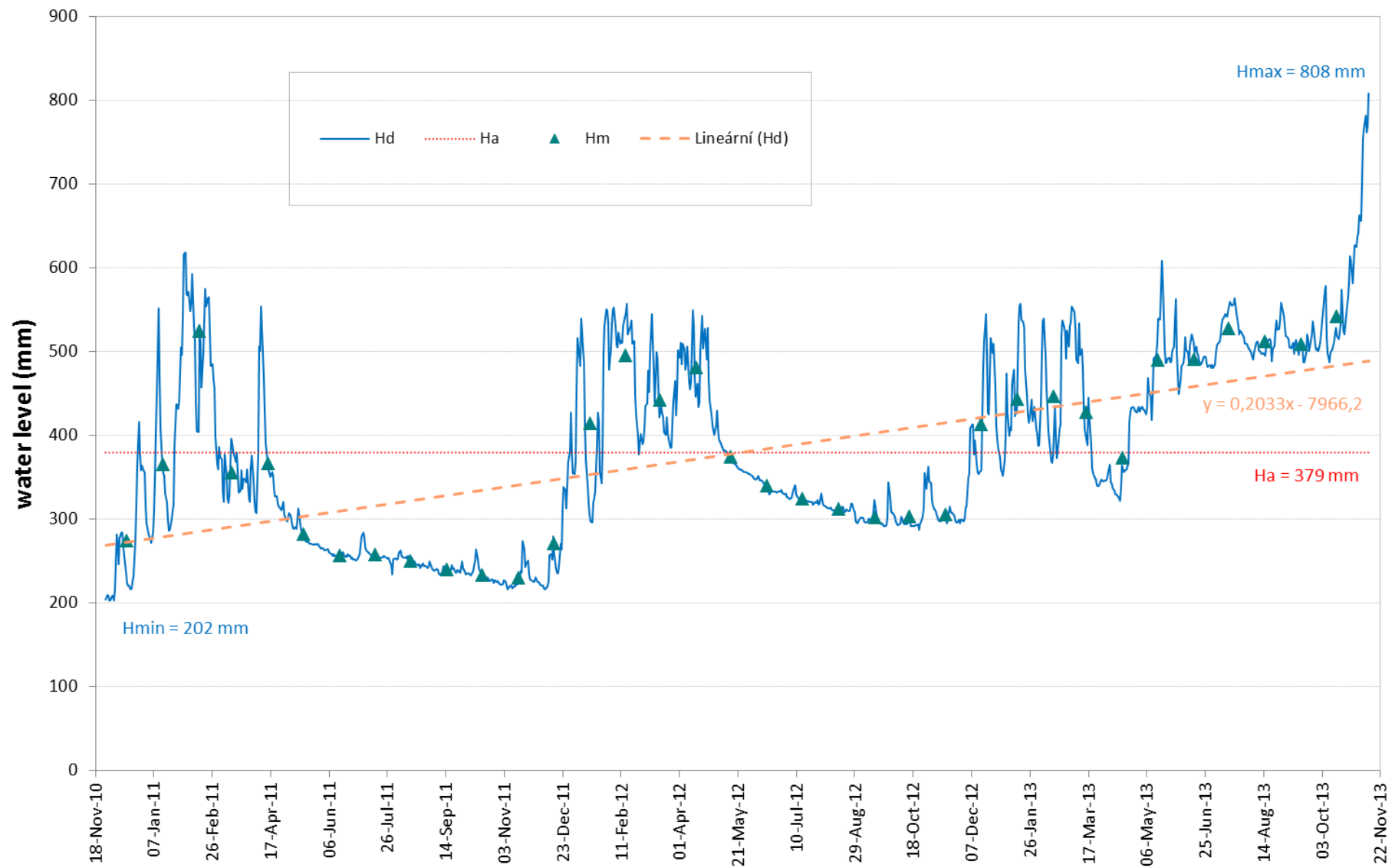


■ denní maximum teploty vzduchu ■ denní minimum teploty vzduchu





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



# Headwaters territory of the Marañón 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

# Proglacial Cangrajanca Lake

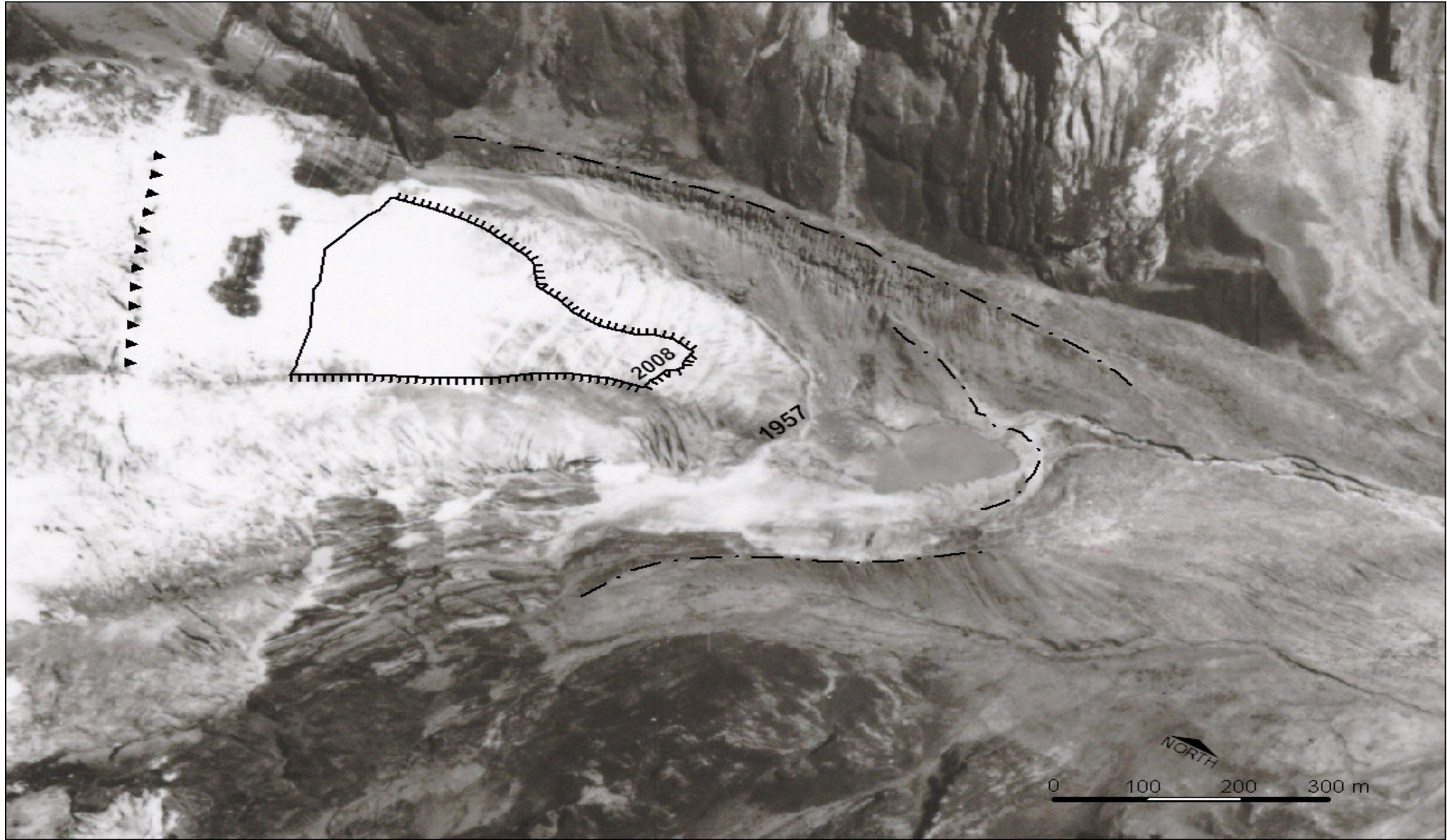




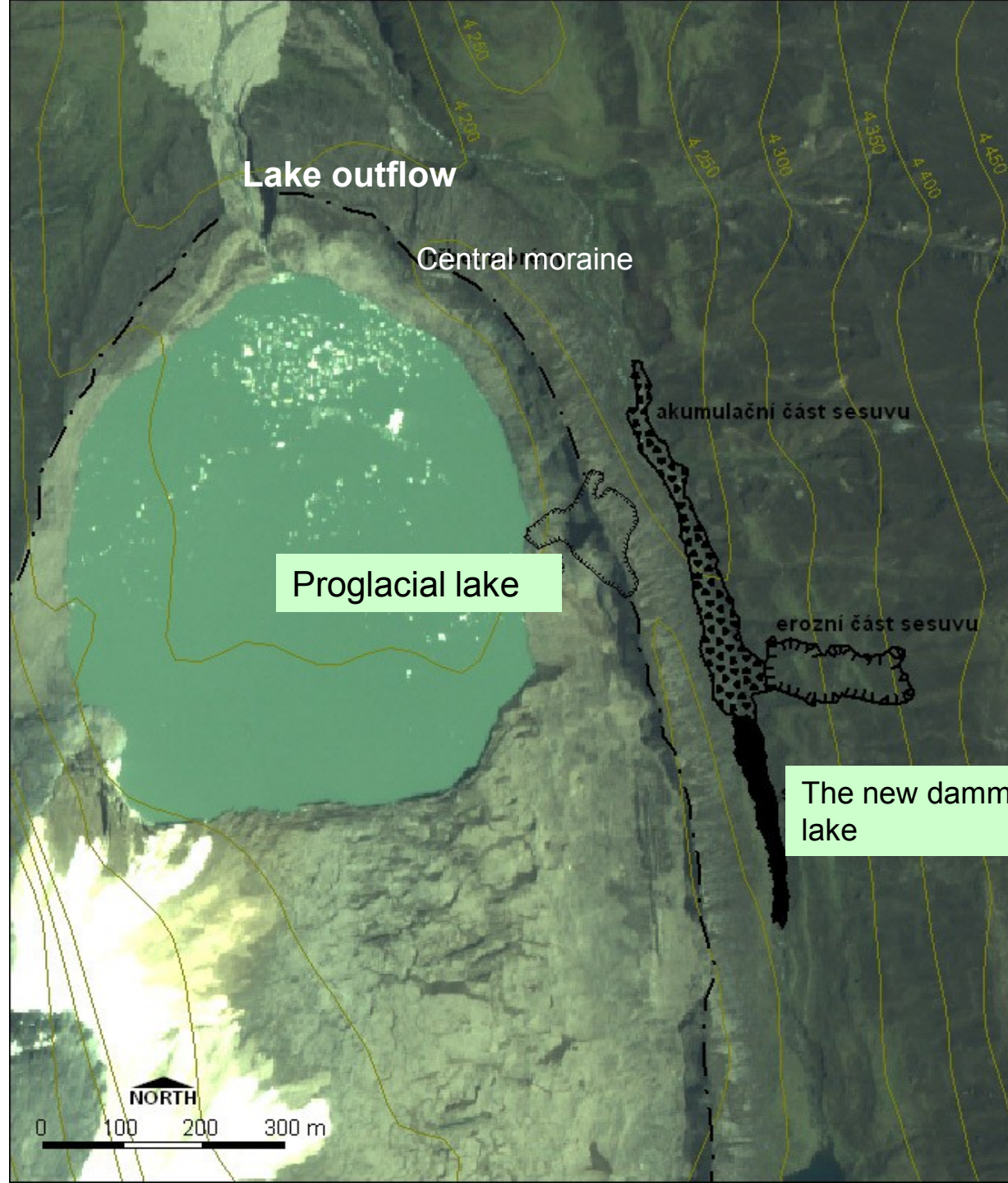
Dangerous Cangrajanca lake with periodical outburst. The lake basin is filled from the Yerupaja glacier.

# 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

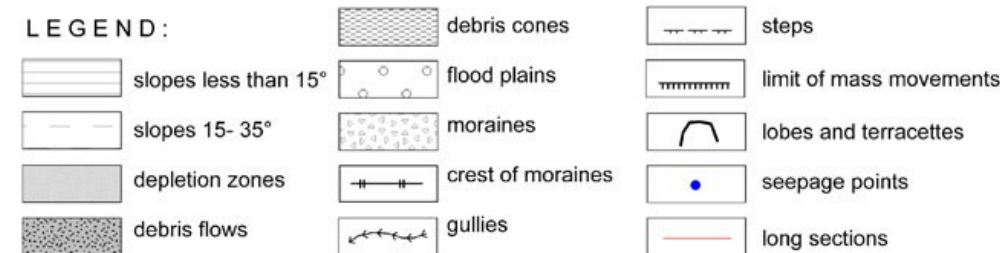
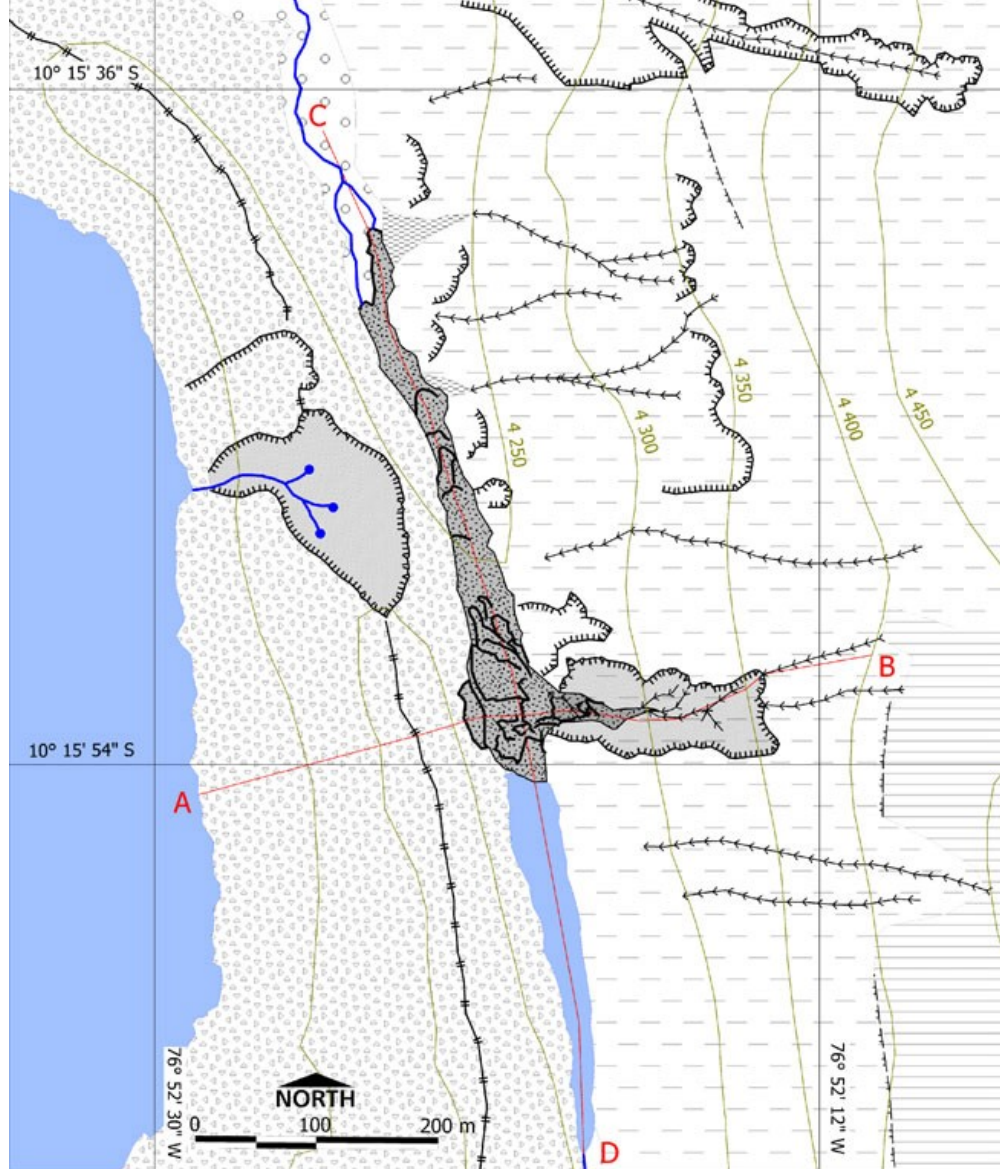
The debris flow was triggered by cumulative rainfall combined with an extreme precipitation event:

- From the end of January to the beginning of March 2009, the Cordillera Huayhuash experienced abnormally high precipitations that 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



The new lake (E) dammed 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 groundwater erosion

# Conclusions

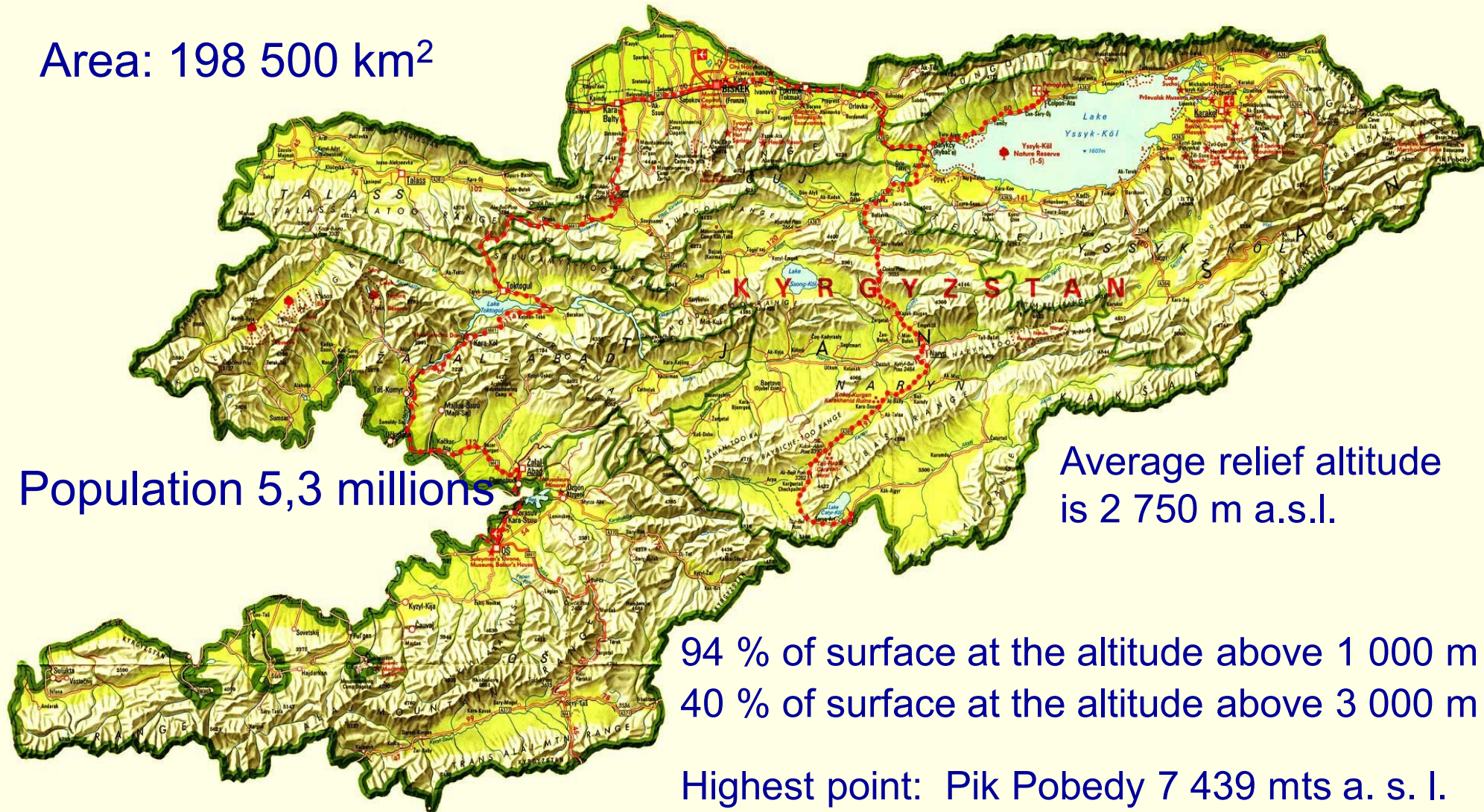
- The monitoring has confirmed **a falling trend in the flow rate**, following the retreat of area glaciers.
- At present, the **Cordillera Chila** mountain range no longer has any glaciers. The last of them melted between 2000 and 2007.
- The **Cordillera Huayhuash** mountains show a relatively slow 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<sup>2</sup>



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



landslides



floods

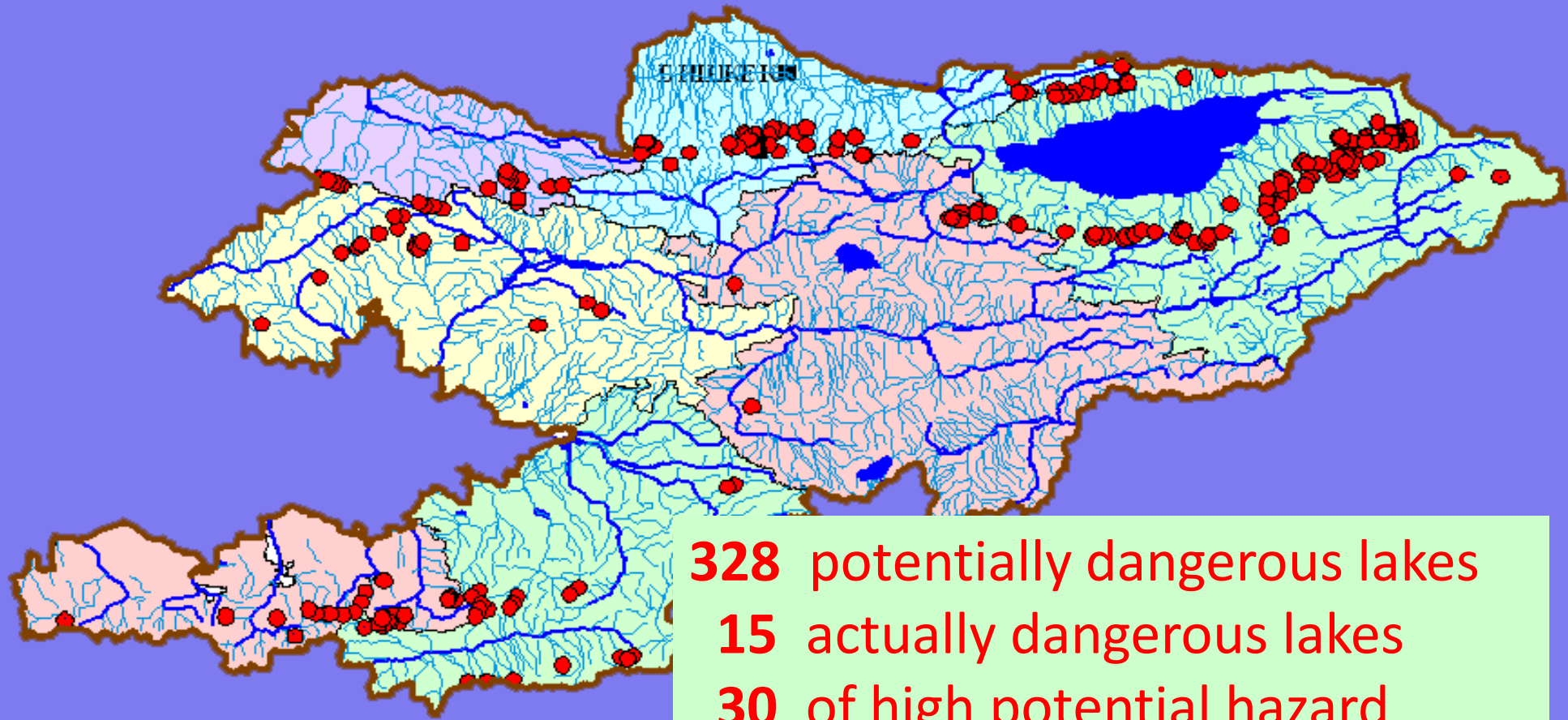


debris-flows

# The hazardous alpine lakes in Kyrgyzstan

1923 lakes covering more than 0.1 km<sup>2</sup>

100 lakes more than 1 km<sup>2</sup>



**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



More than 100  
victims

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

Dammed  
by glacier

Interglacial

Intermoraine

Thermokarst

By landslide

By debris-  
flow

**Glacial**

**Moraine-  
glacial**

**Moraine**

**Moraine-  
riegel**

**Dammed**

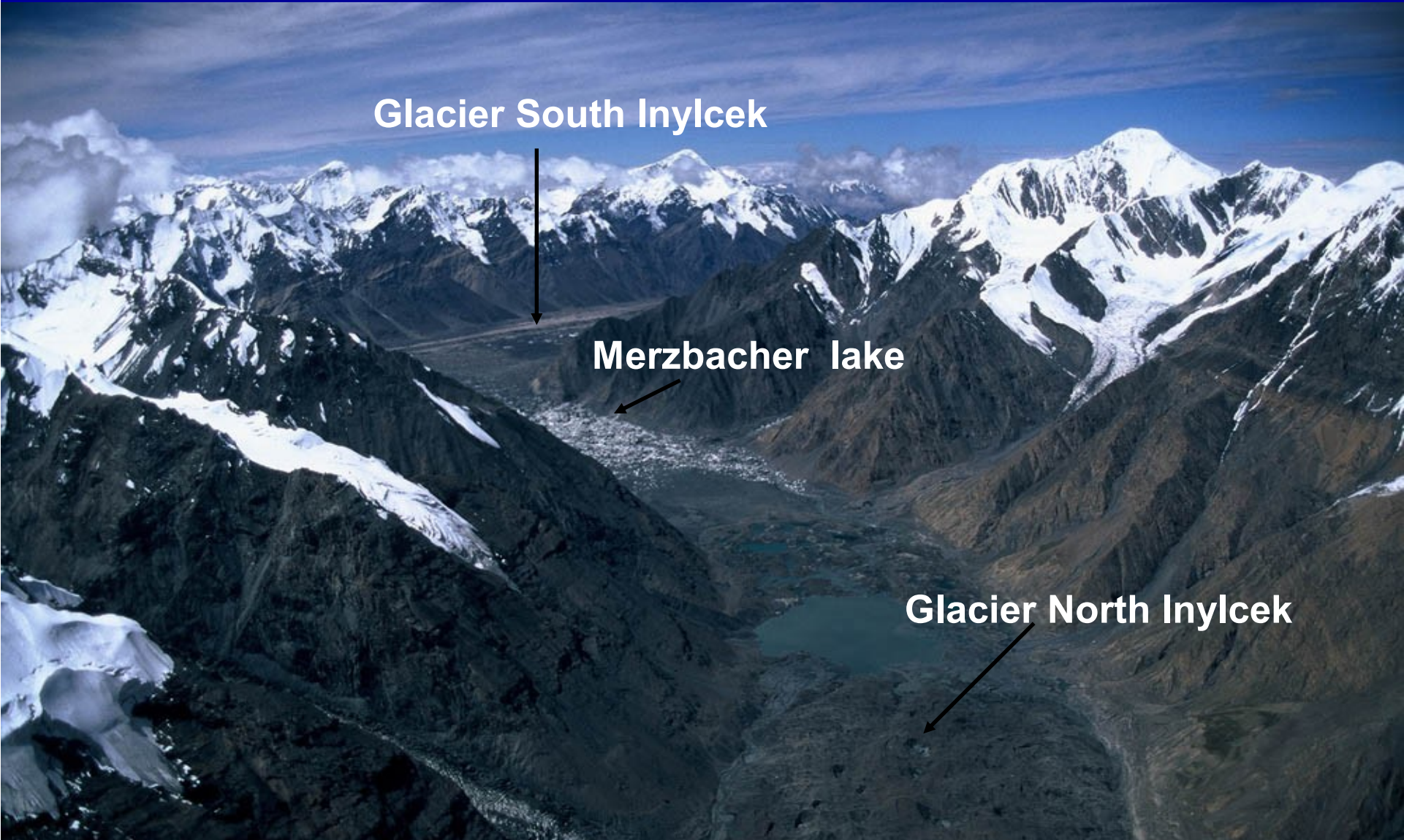
# Tectonic lakes



**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

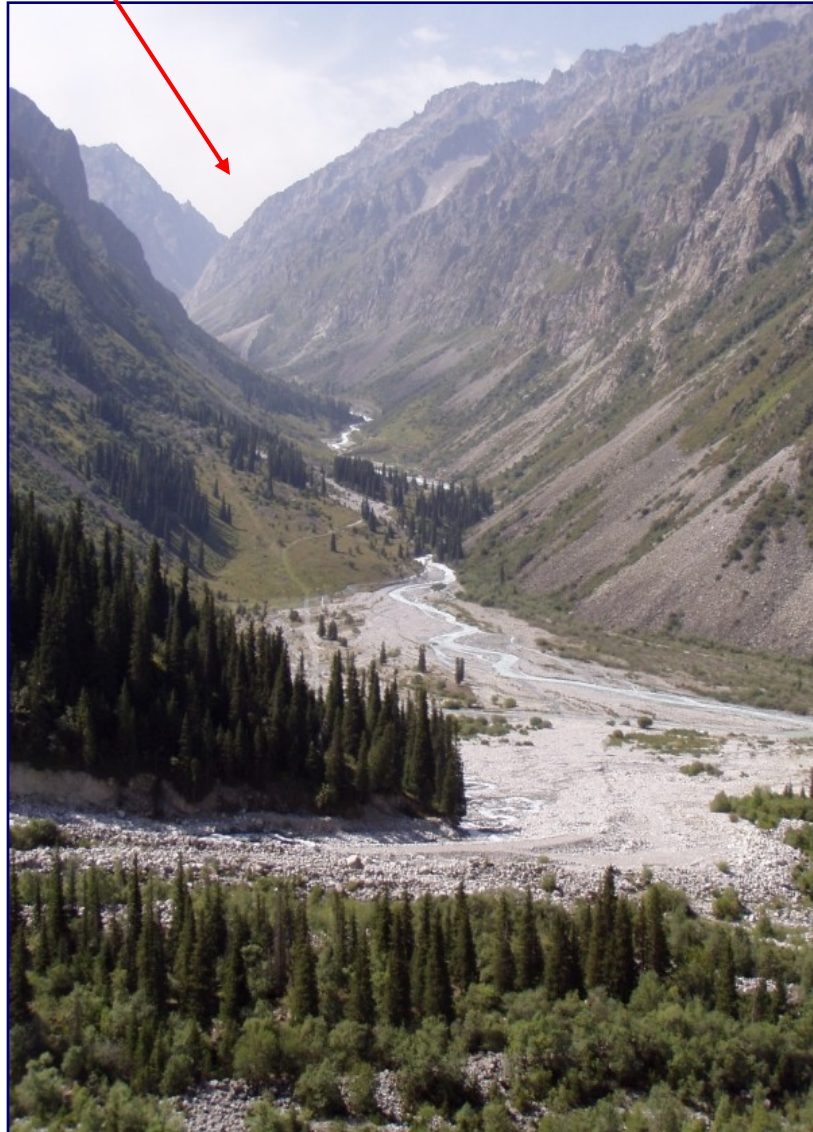


Glacier Ak - Sai



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



landslide

periodical outflow

Koltor lake

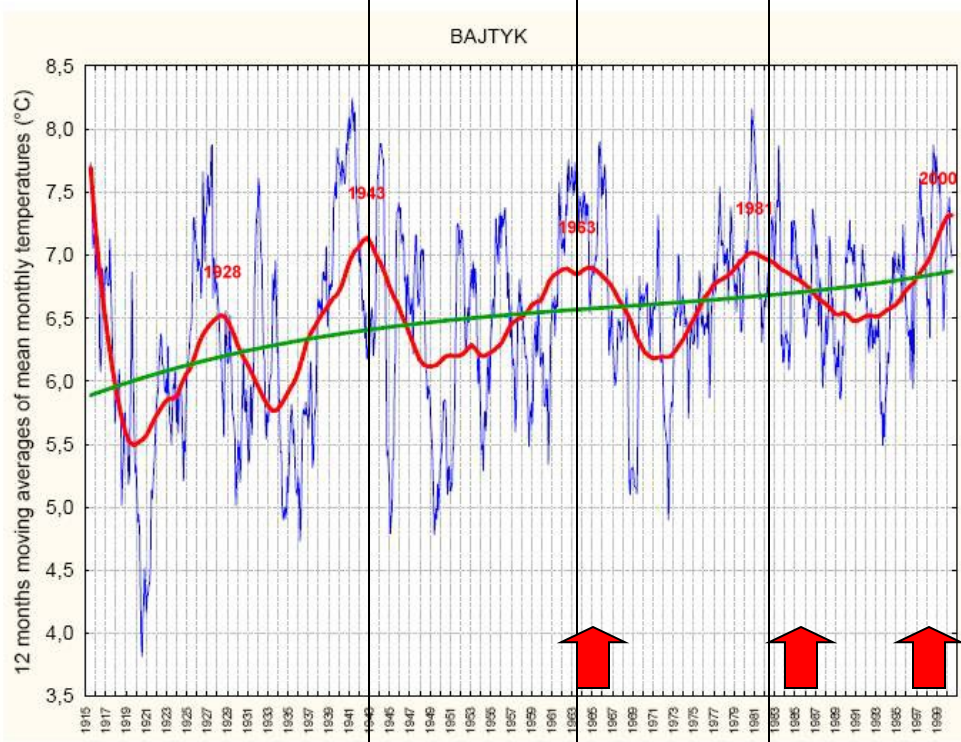
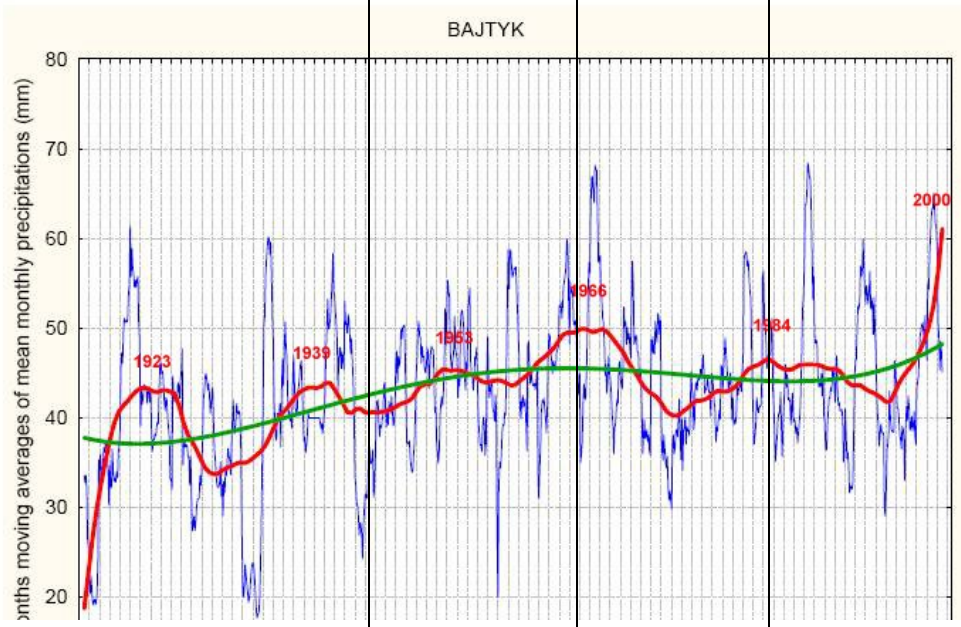
# Koltor lake: Superficial outflow after intensive precipitation



# 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.  
Step 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**

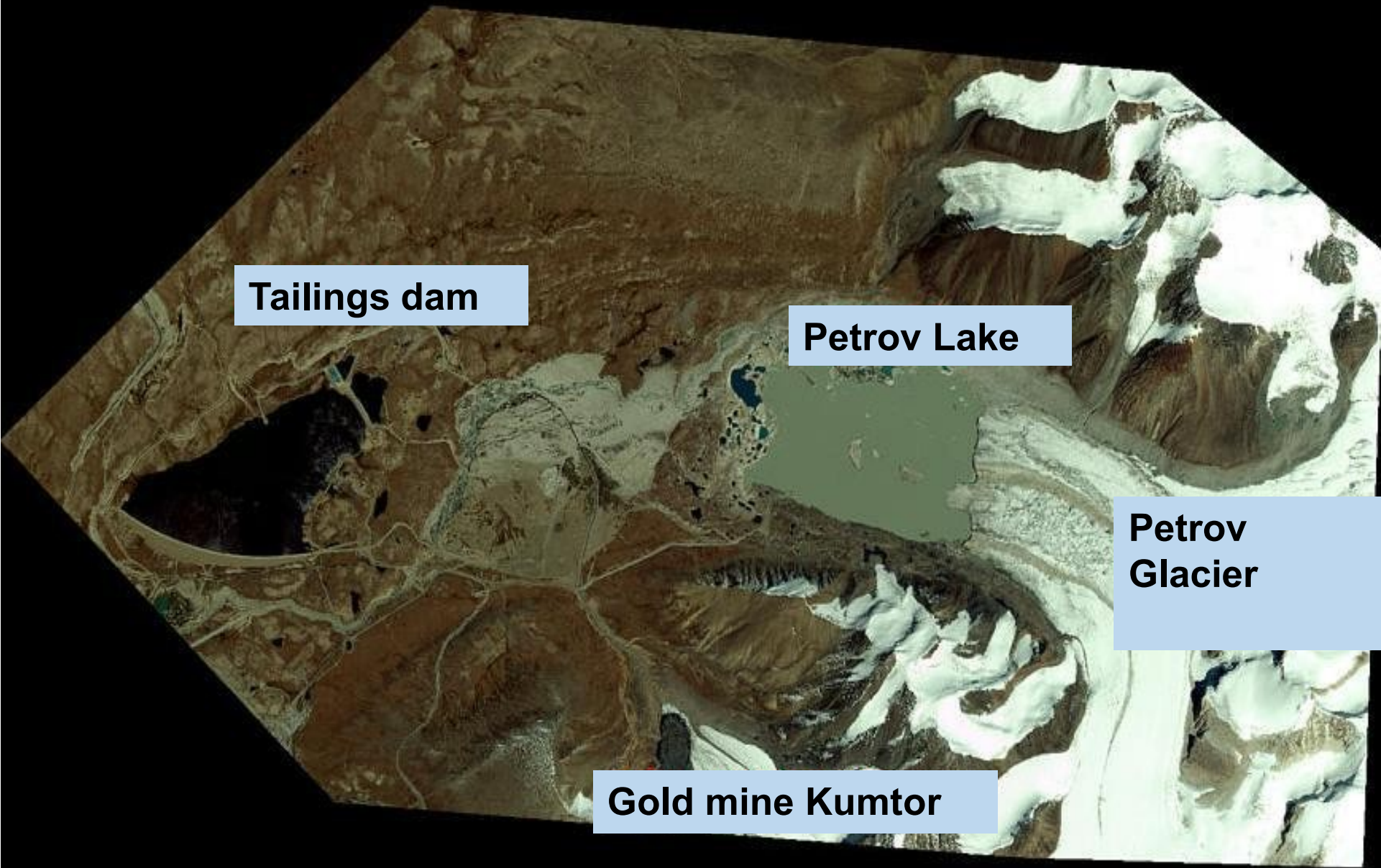
# Petrov lake: an extremely dangerous evolution



# 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<sup>2</sup> large and 23 km long.





**Tailings dam**

**Petrov Lake**

**Petrov  
Glacier**

**Gold mine Kumtor**

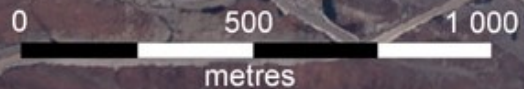
**Satellite image of the Petrov Lake area (QuickBird 2003)**

# Bathymetry of the Petrov Lake

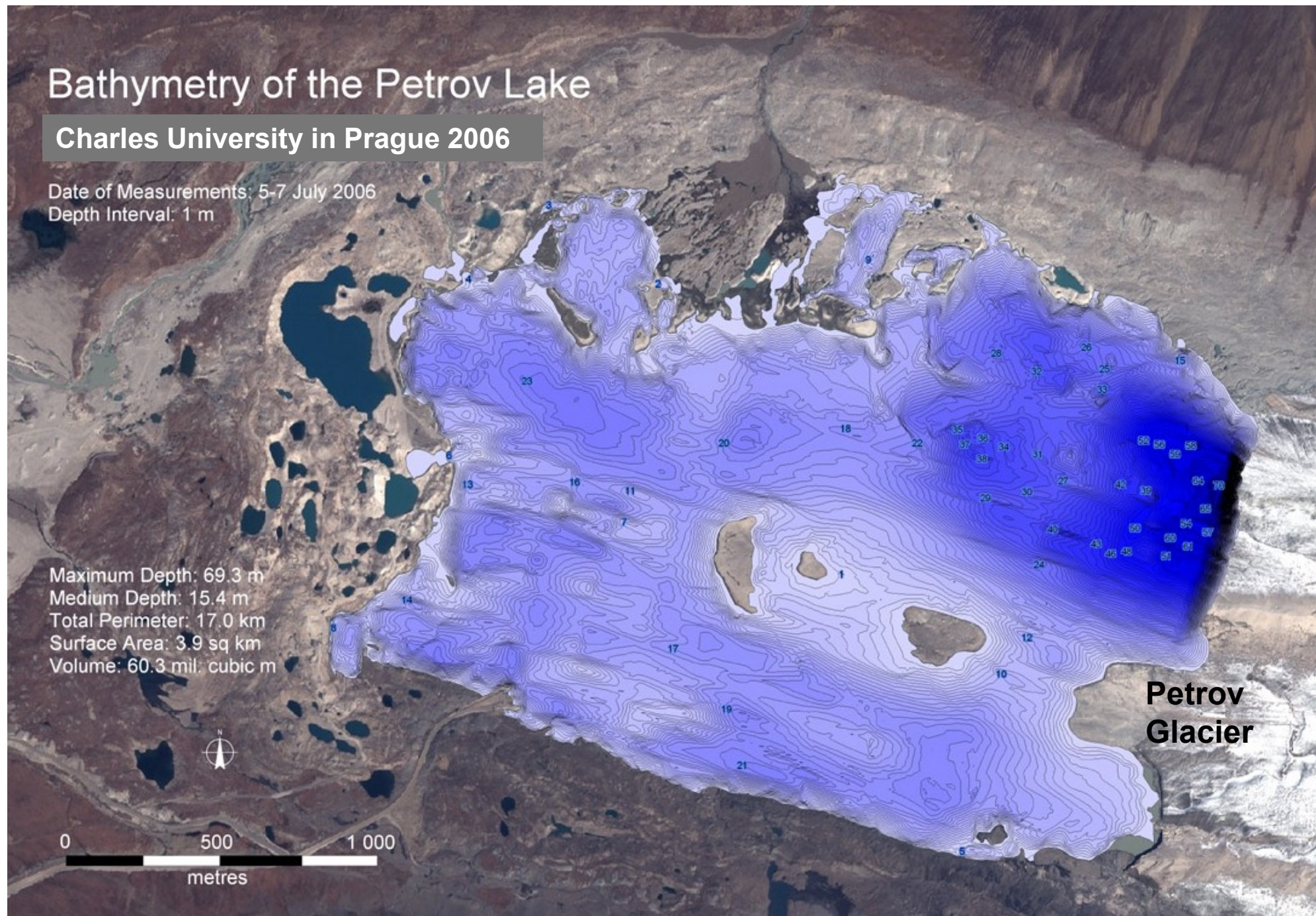
Charles University in Prague 2006

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



**Petrov  
Glacier**

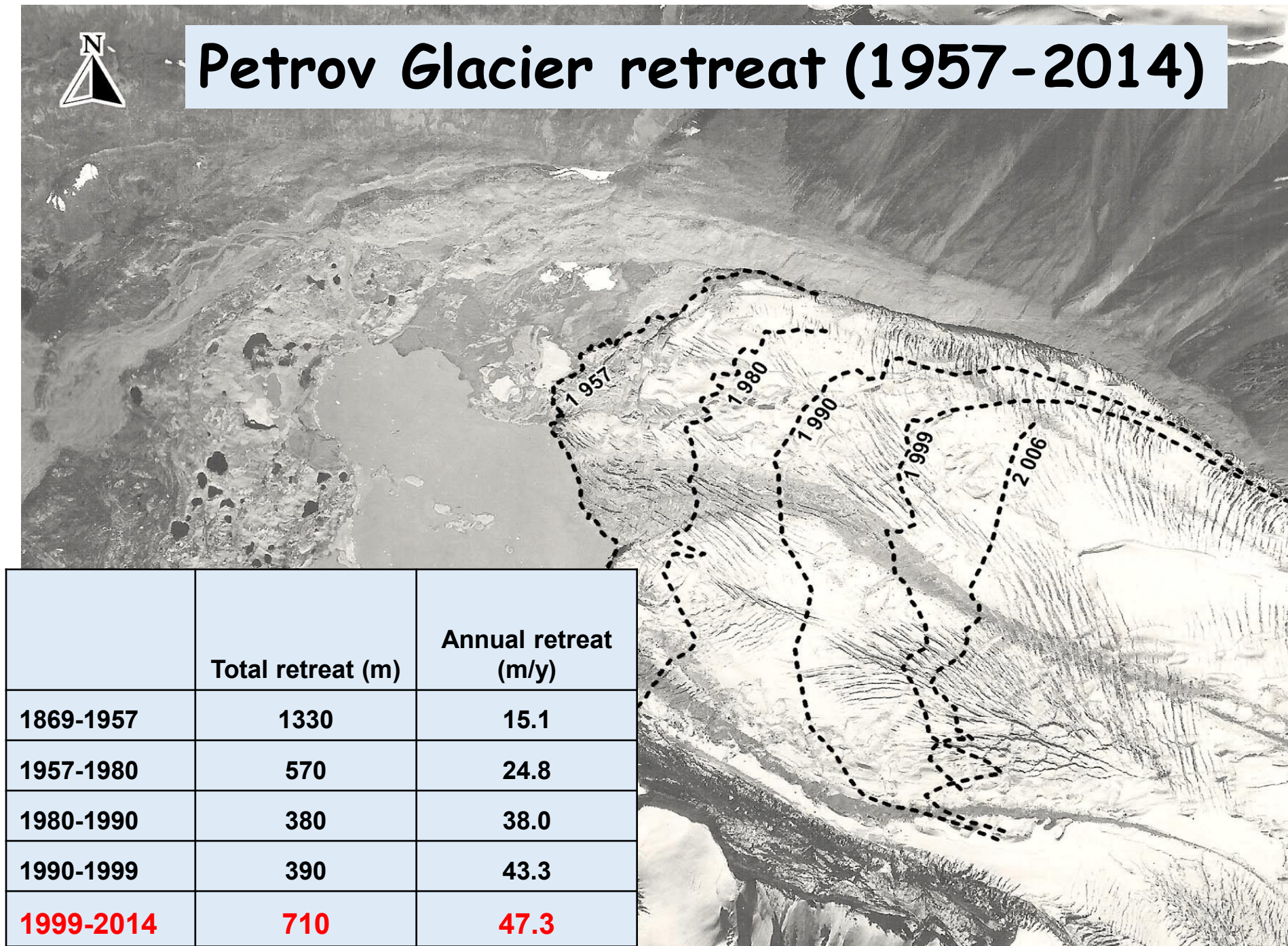




bathymetry

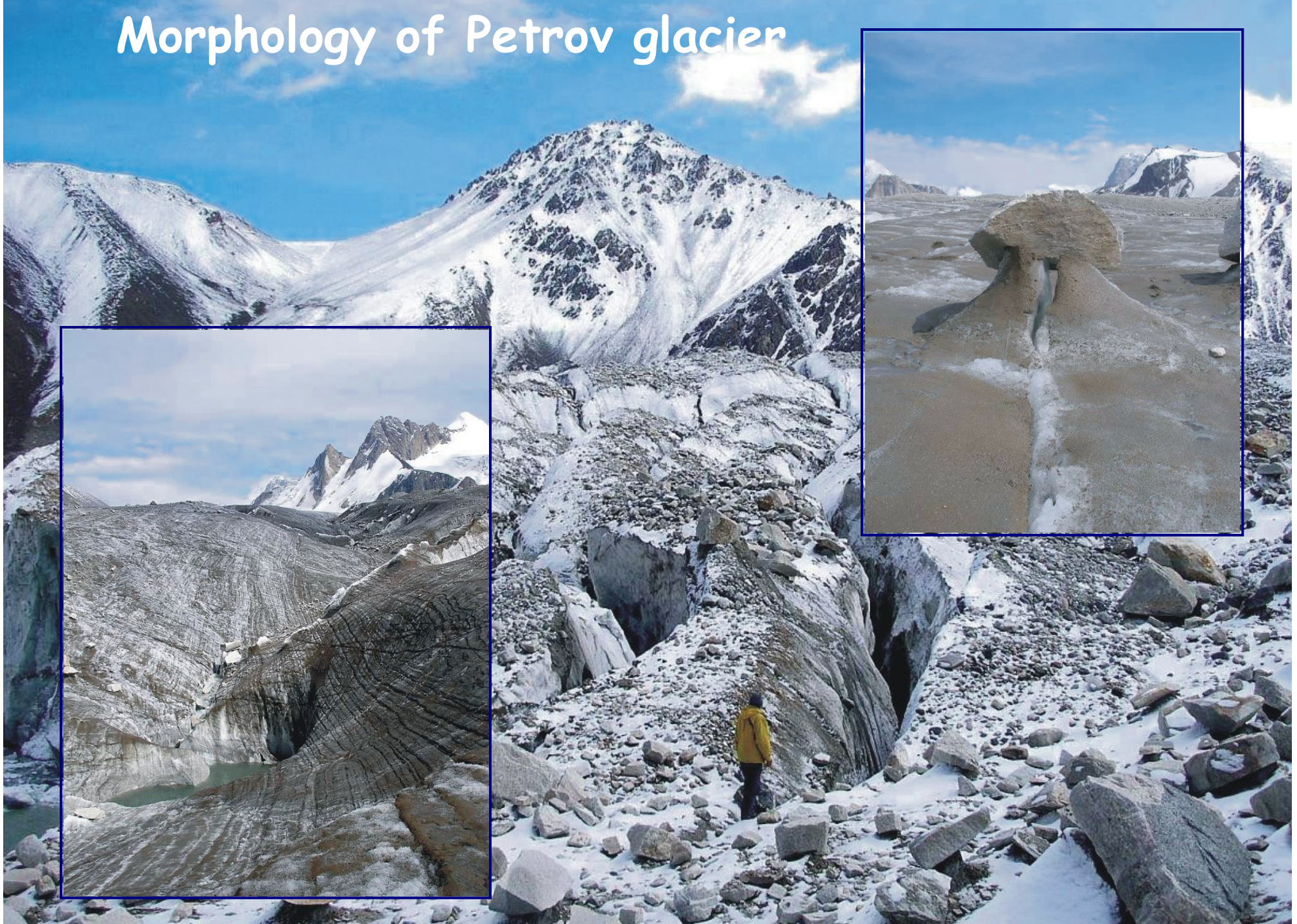


# Petrov Glacier retreat (1957-2014)

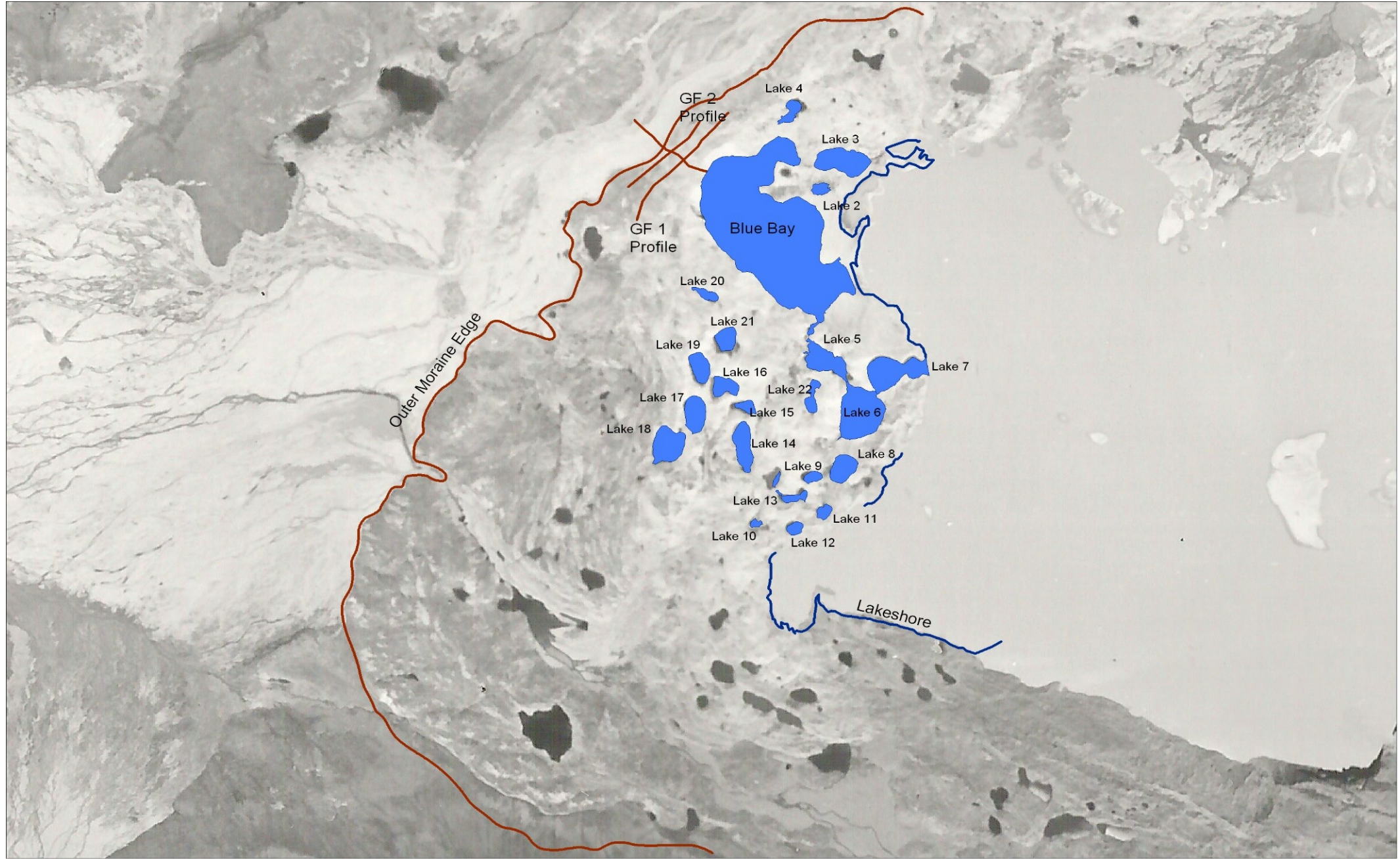


	Total retreat (m)	Annual retreat (m/y)
1869-1957	1330	15.1
1957-1980	570	24.8
1980-1990	380	38.0
1990-1999	390	43.3
<b>1999-2014</b>	<b>710</b>	<b>47.3</b>

# Morphology of Petrov glacier



# The lakes of thermokarstic depressions

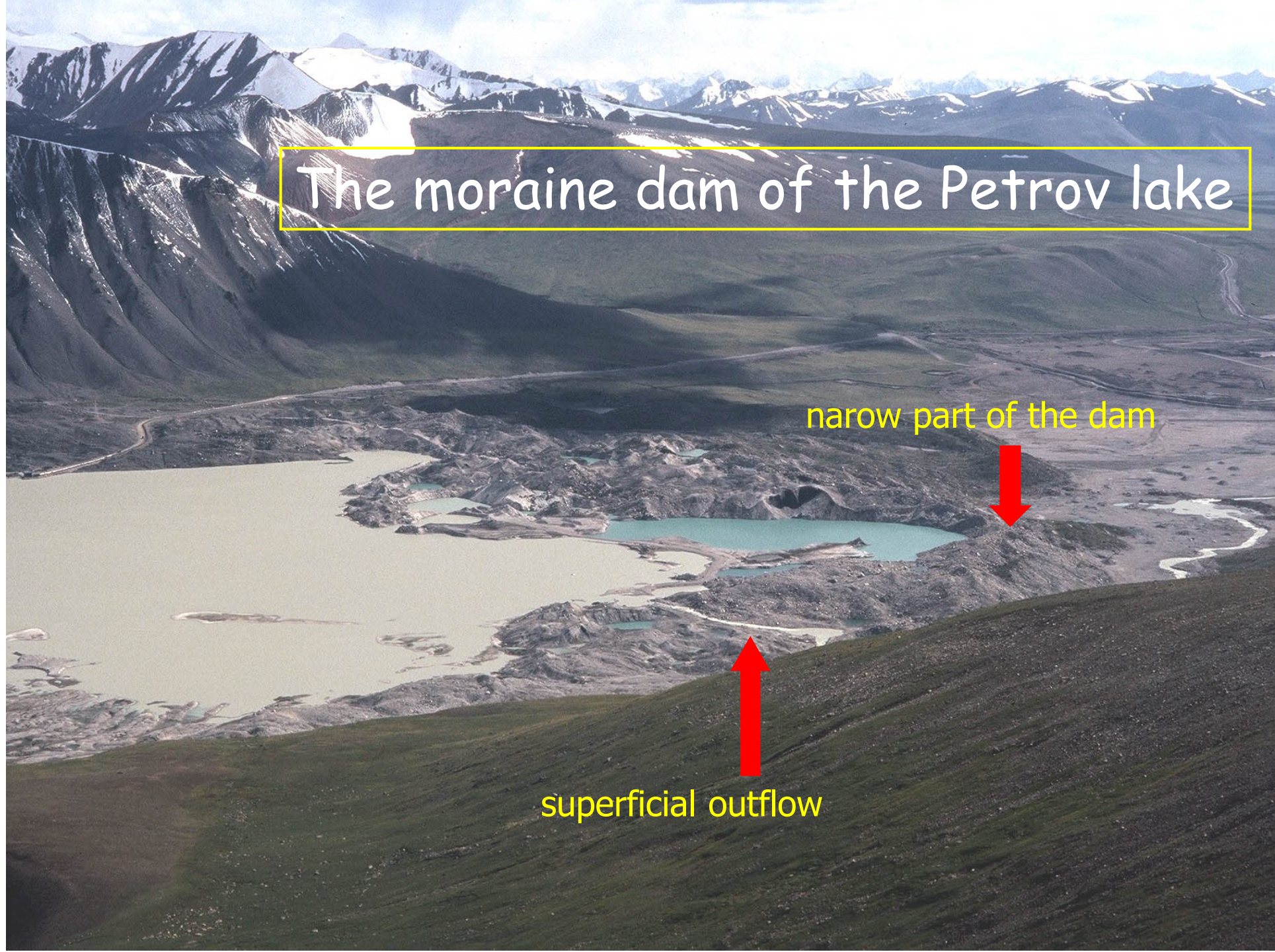


# The moraine dam of the Petrov lake

narrow part of the dam

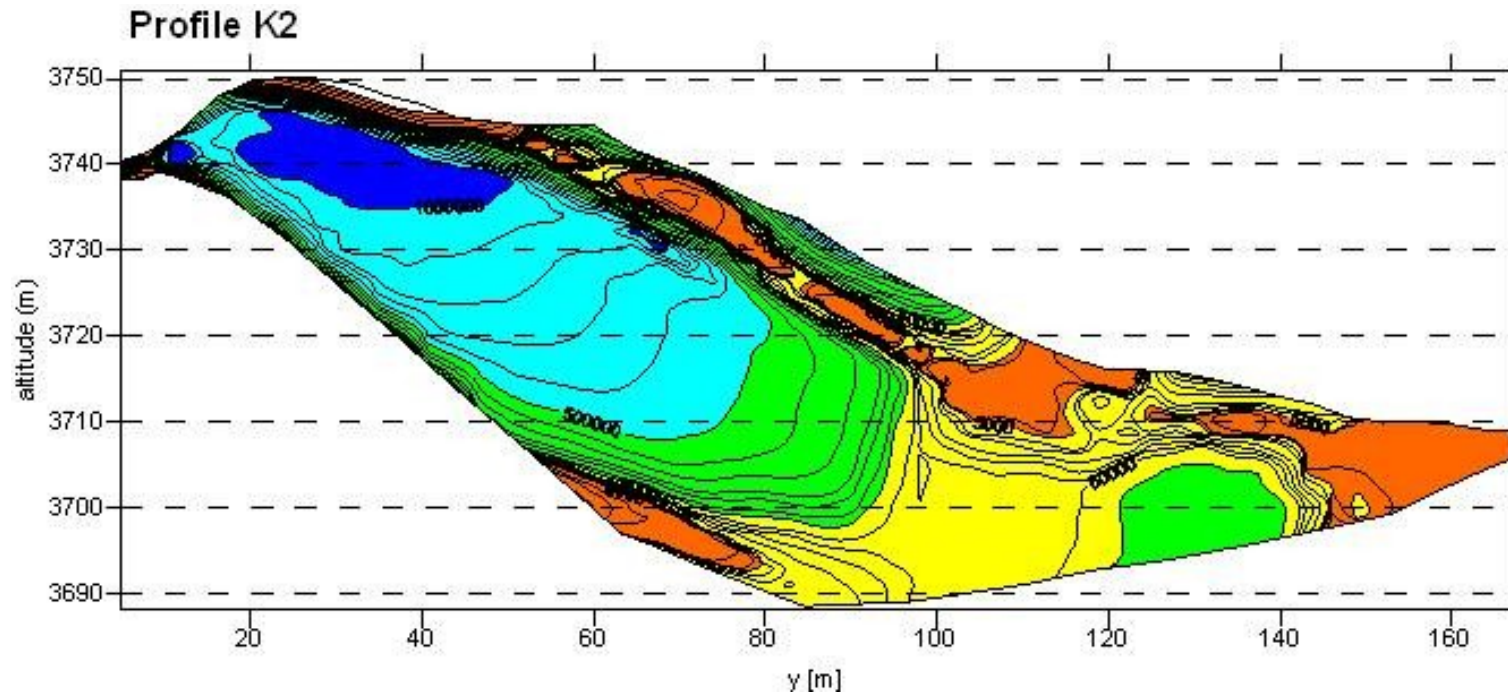
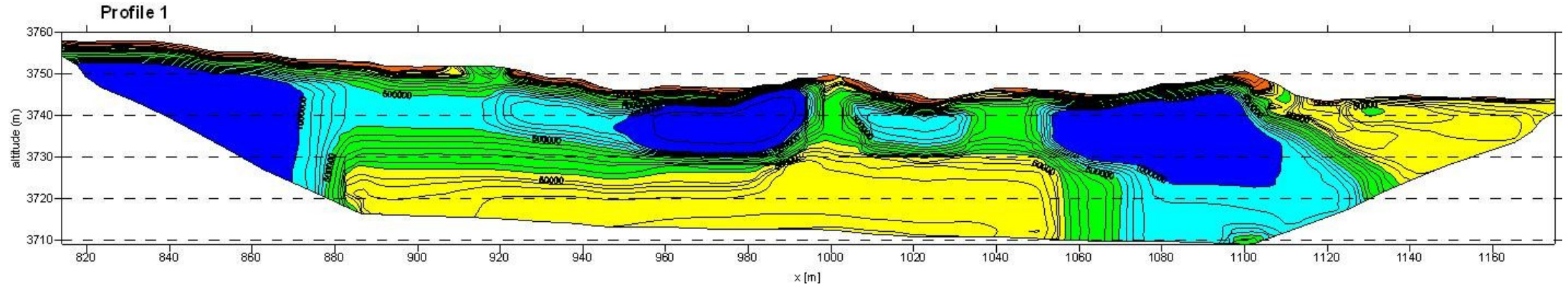


superficial outflow



# Geophysical survey of Petrov lake dam

## Resistivity tomography



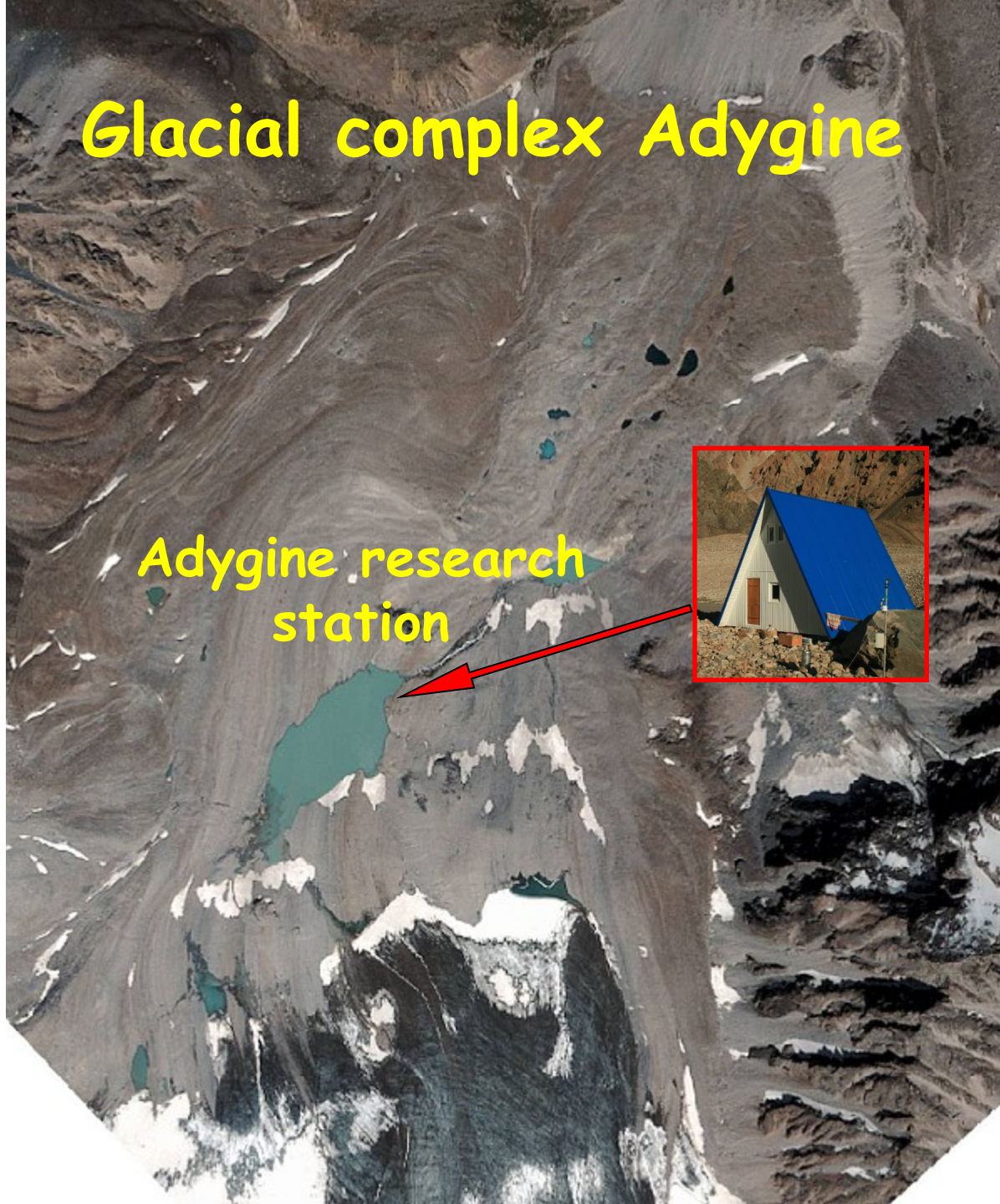


# Conclusions I

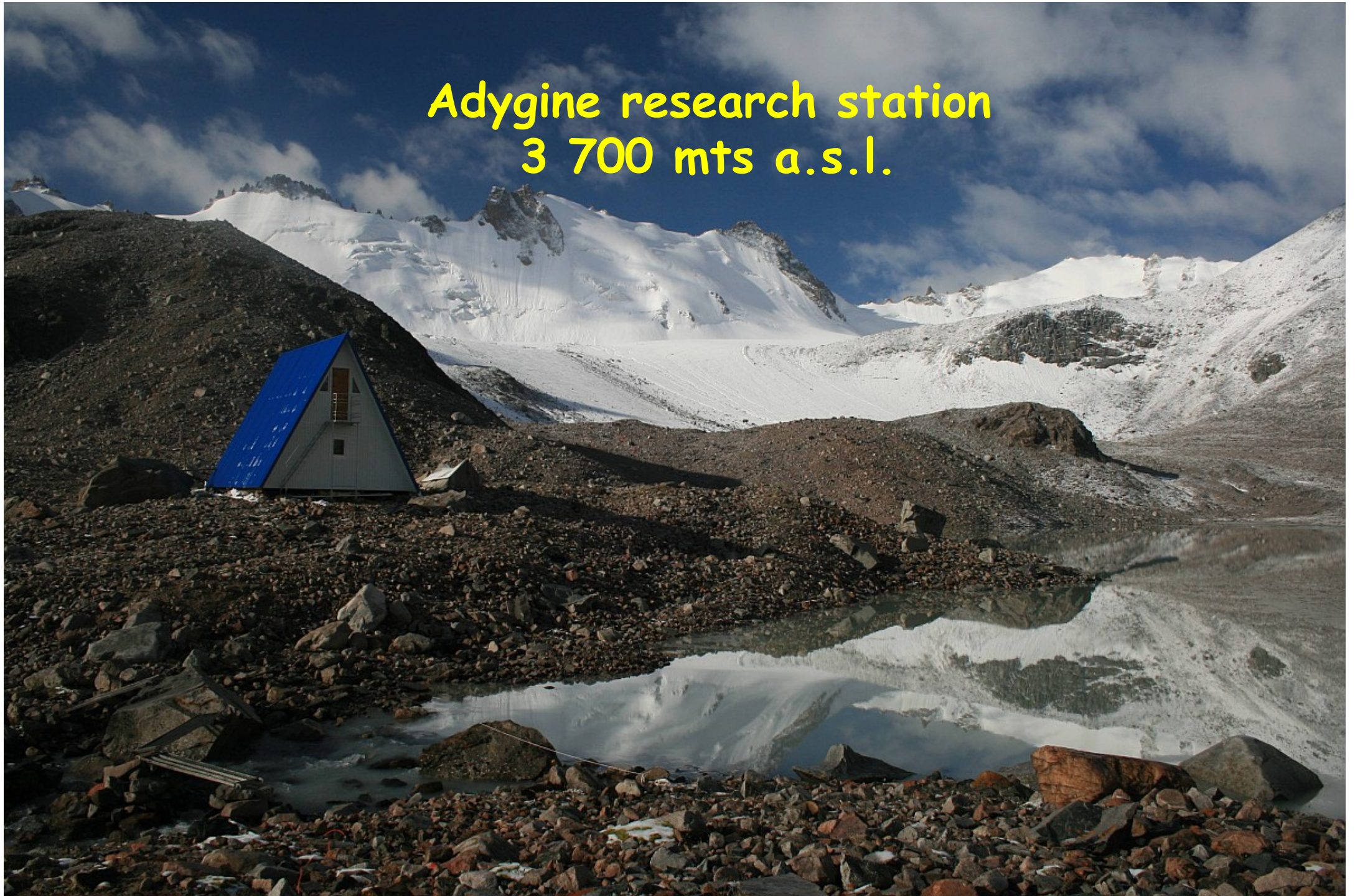
- The thermokarst processes caused by melting of the buried ice in the moraine dam of the Petrov lake most danger and very dynamic development.
- The surface area and volume of the retained water in the Petrov lake increase considerably.
- *Enlarging of the lake size and volume* together with *weakening 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 measurements**
- ➡ 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.
- Higher 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...**





**THANK YOU FOR YOUR ATTENTION !**