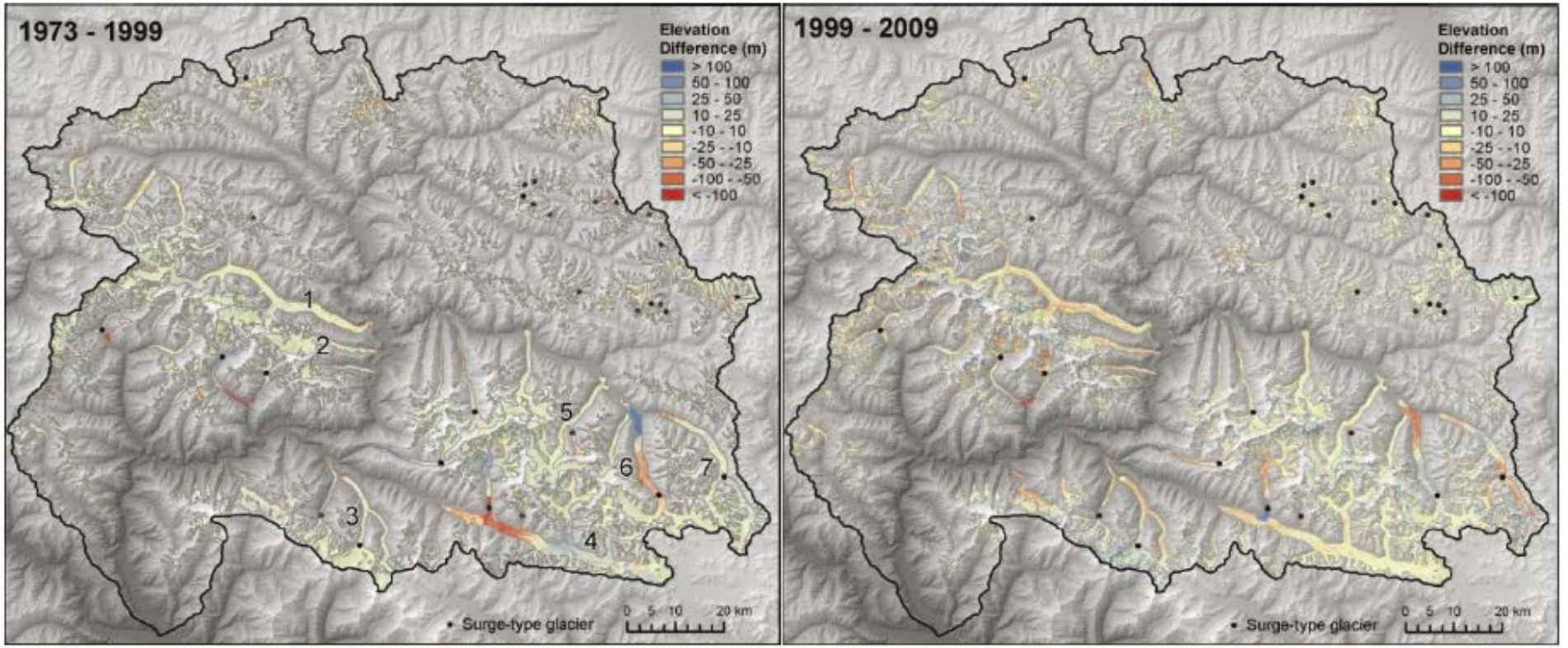
Earth Observation to investigate the characteristics and changes of the cryosphere in High Mountain Asia (EOCRYOHMA), Dragon ID 32437

Mapping of (rock)glaciers and observation of glacier area and volume changes in High Mountain Asia using earth observation data (EOGlacHMA)

Observation of extent and characteristics of snow and permafrost in High Mountain Asia (EOSnoPeHMA)

Observation of surface velocity over ice covered terrain with microwave and multispectral imager

Surface elevation changes in the Hunza basin (Karakoram)



Bolch et al. , 2017, TC

Glacier Mass Changes
Own Studies in High Mountain Asia

Table 1: Glacier mass changes of the investigated regions in High Asia for different periods.

Region	Area covered (km²)	Period 1		Period 2		Reference
		Period	Mass budget	Period	Mass budget	
Khumbu Himalaya	~60	1970 - 2007	−0.32±0.08	2002 - 2007	−0.79±0.52	Bolch et al. (2011b)
Langtang Himal	~86	1974 - 2006	−0.21±0.08	2006 - 2015	−0.38±0.17	Ragettli et al. (2016)
Gangotri Glacier/ Garhwal Himal	~210	1968 - 2006	−0.17±0.12	2006 - 2014	−0.29±0.19	Bhattacharya et al. (2016)
Hunza Basin/ Central Karakoram	2870	1973 - 1999	−0.01±0.09	1999 - 2009	−0.08±0.20	Bolch et al. (2016)
Muztag Ata/ East Pamir	273	1973 - 1999	−0.04±0.42	1999 - 2013	+0.04±0.27	Holzer et al. (2015)
Ala Archa/ Northern Tien Shan	~37	1964 - 1999	−0.45±0.27	1999 - 2012	−0.42±0.66	Bolch (2015)
Tomur Region/ Central Tien Shan	~840	1976 - 1999	−0.42±0.23	1999 - 2009	−0.23±0.19	Pieczonka et al. (2013)
Aksu Catch-ment/ Central Tien Shan	~6600	~1975 - 1999	−0.35±0.34		n.c.	Pieczonka and Bolch (2015)

Bolch et al. , 2016

Inventory and activities of rockglaciers in Northern Tien Shan (Kazakhstan, Krygyzstan, China) using satellite SAR interferometry and optical imagery

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[2] Earth System Science Programme, Faculty of Science, The Chinese University of Hong Kong, Hong Kong, China
[3] Gamma Remote Sensing, Gümligen, Switzerland
[4] Chair of Cartography, Technische Universität München, Munich, Germany
[5] Department of Geosciences, University of Oslo, Oslo, Norway

1 - Introduction

Rational

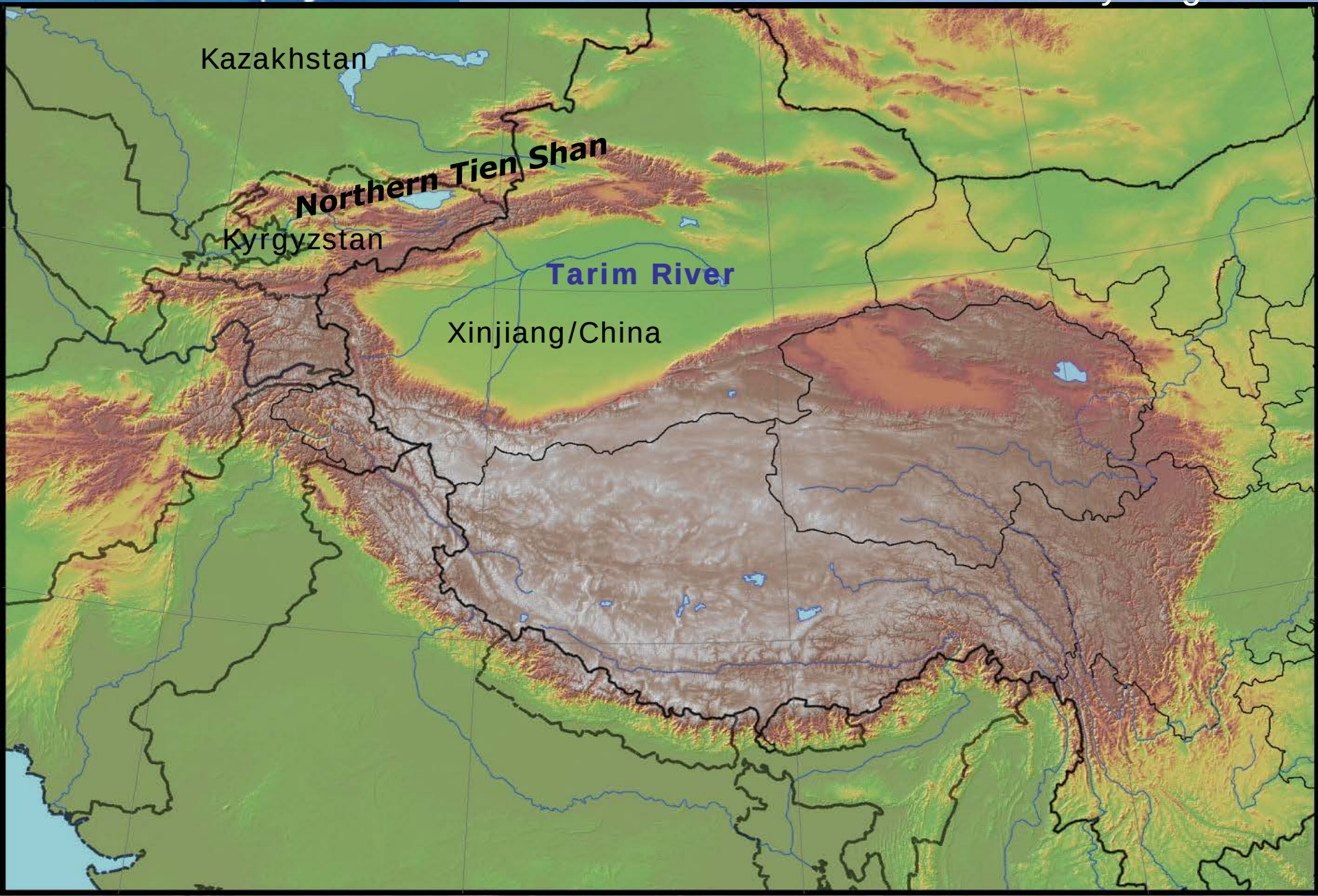
- Rockglaciers are the best visual expression of mountain permafrost and are widespread in the Tien Shan.
- These ice-debris landforms can, in contrast to permafrost itself, be mapped and monitored directly using remotely sensed data.
- Previous studies showed that changes in rockglacier flow can be related to climate conditions.
- However, no consistent rock glacier inventory of the whole Tien Shan exists and information about rockglacier flow is rare.
- Most previous studies concentrated on few valleys in the Ile Range of Northern Tien Shan (Kazakhstan).

1 - Introduction

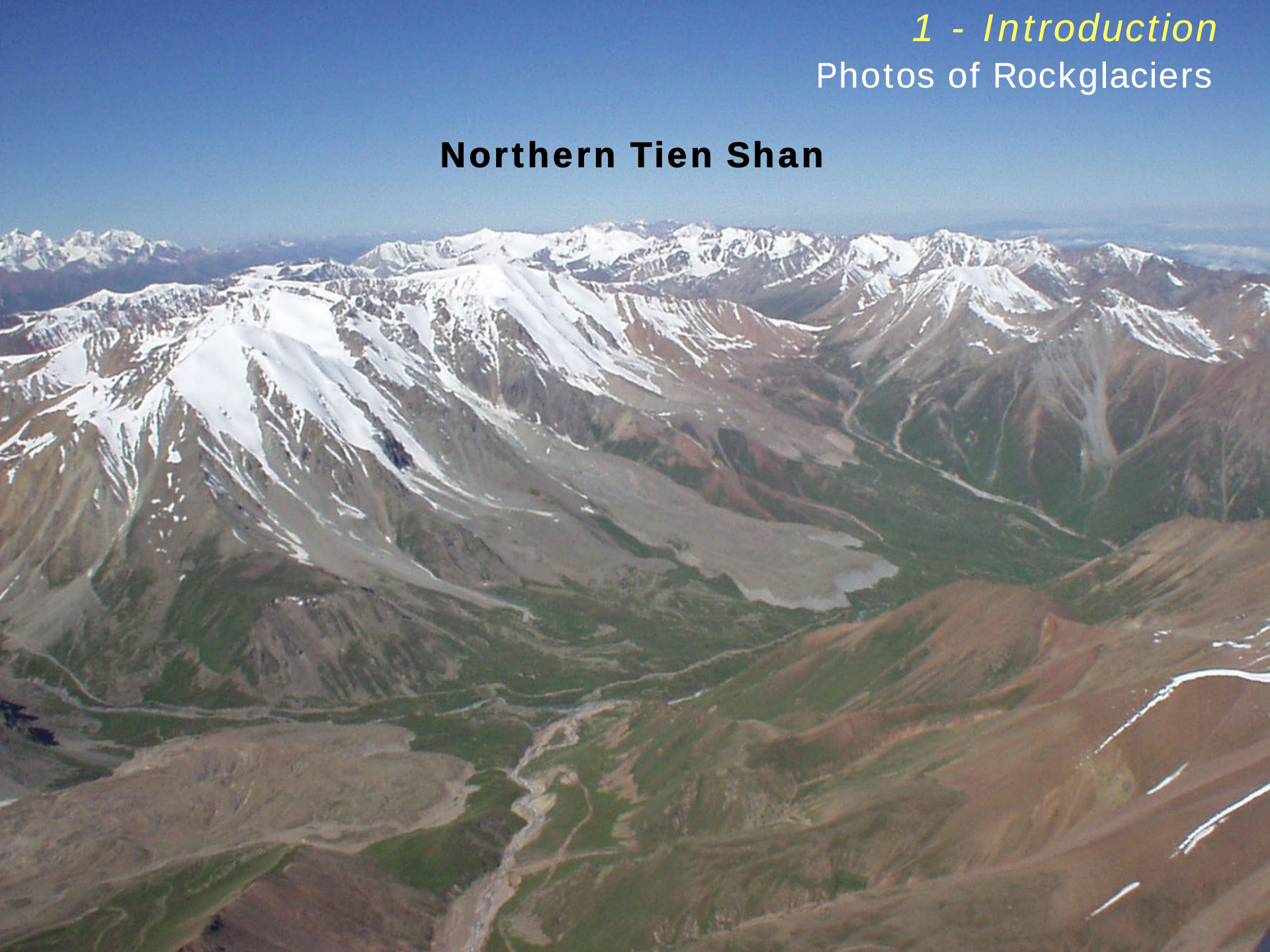
Photos of Rockglaciers

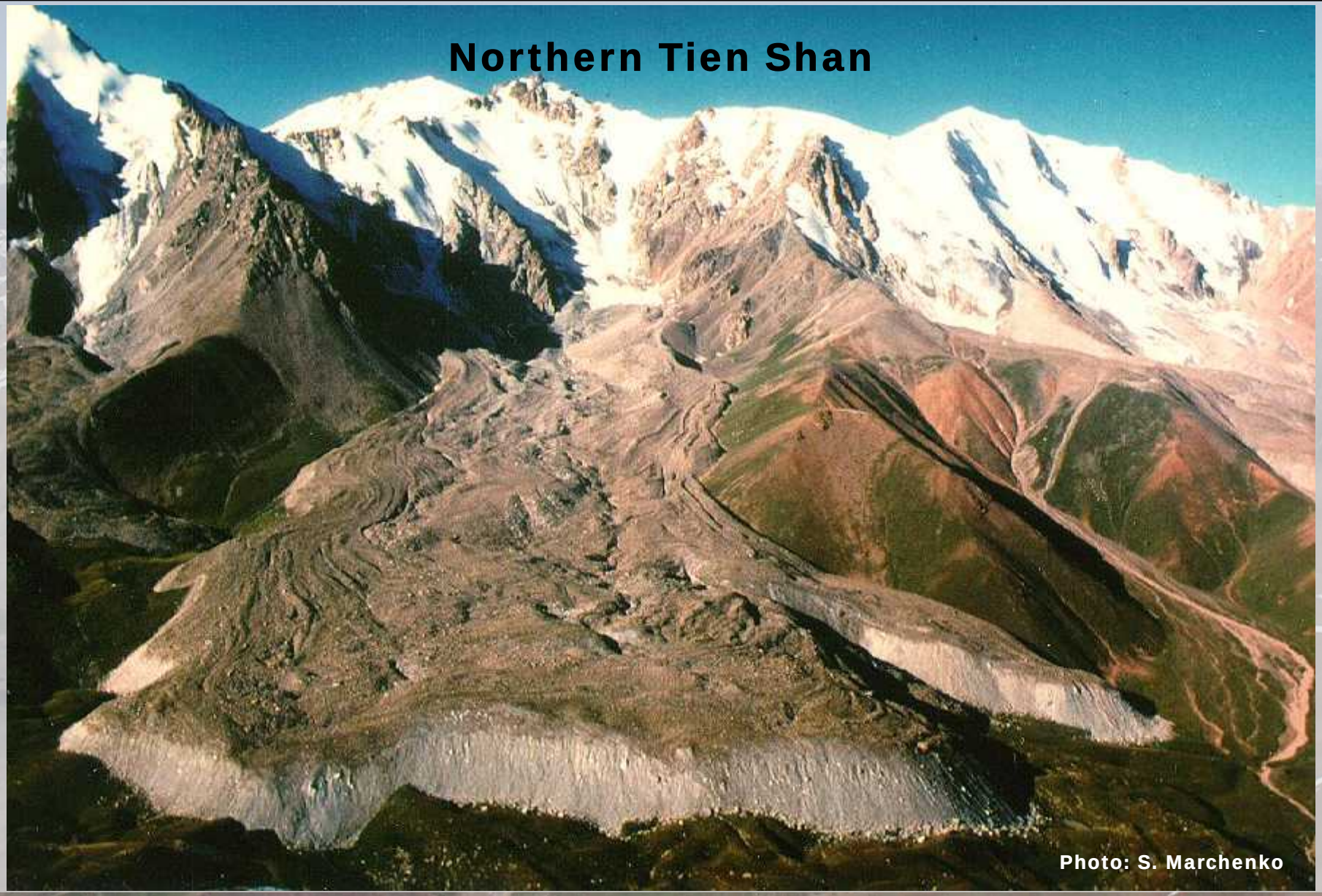
1 - Introduction

Study Region

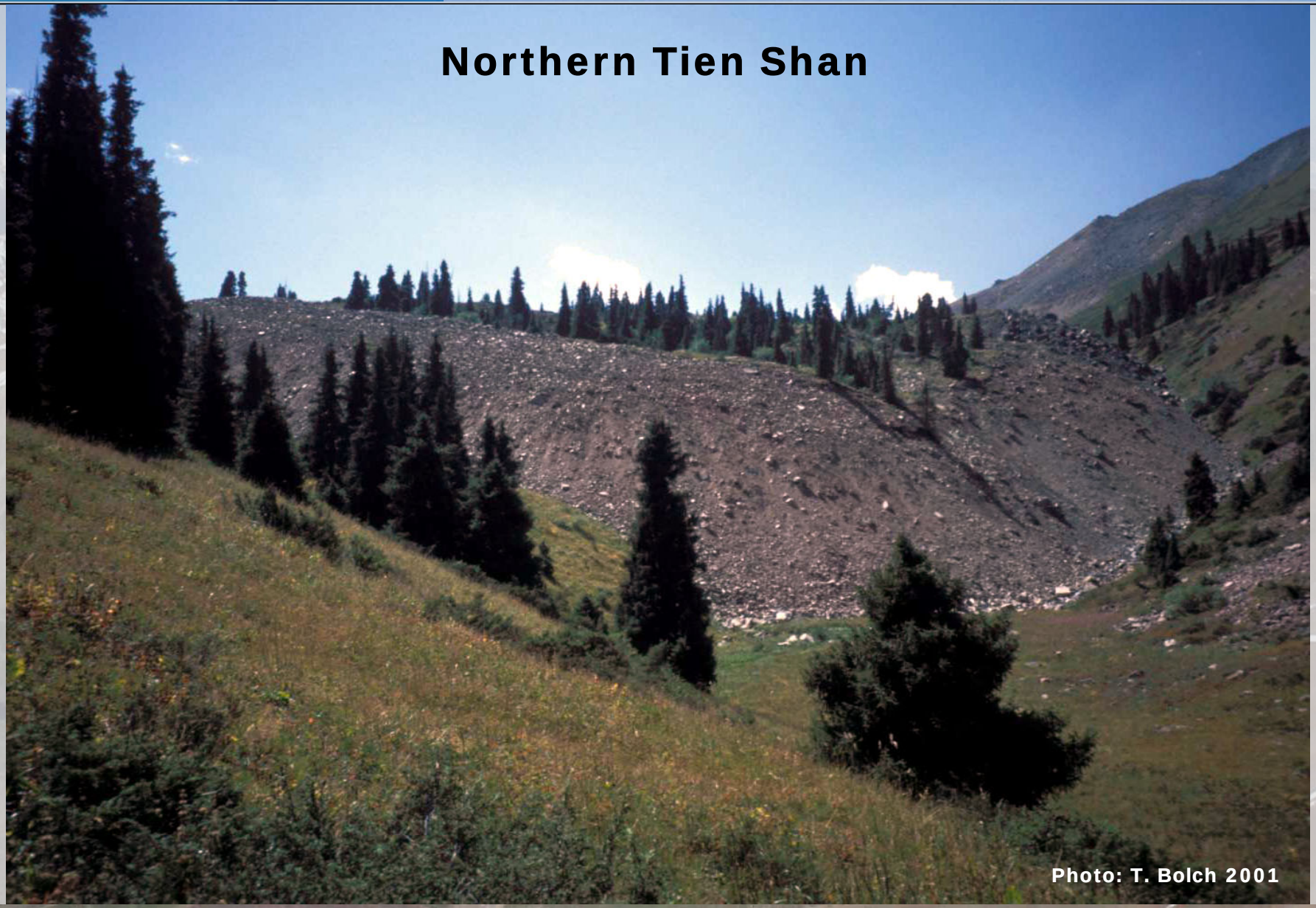


Northern Tien Shan



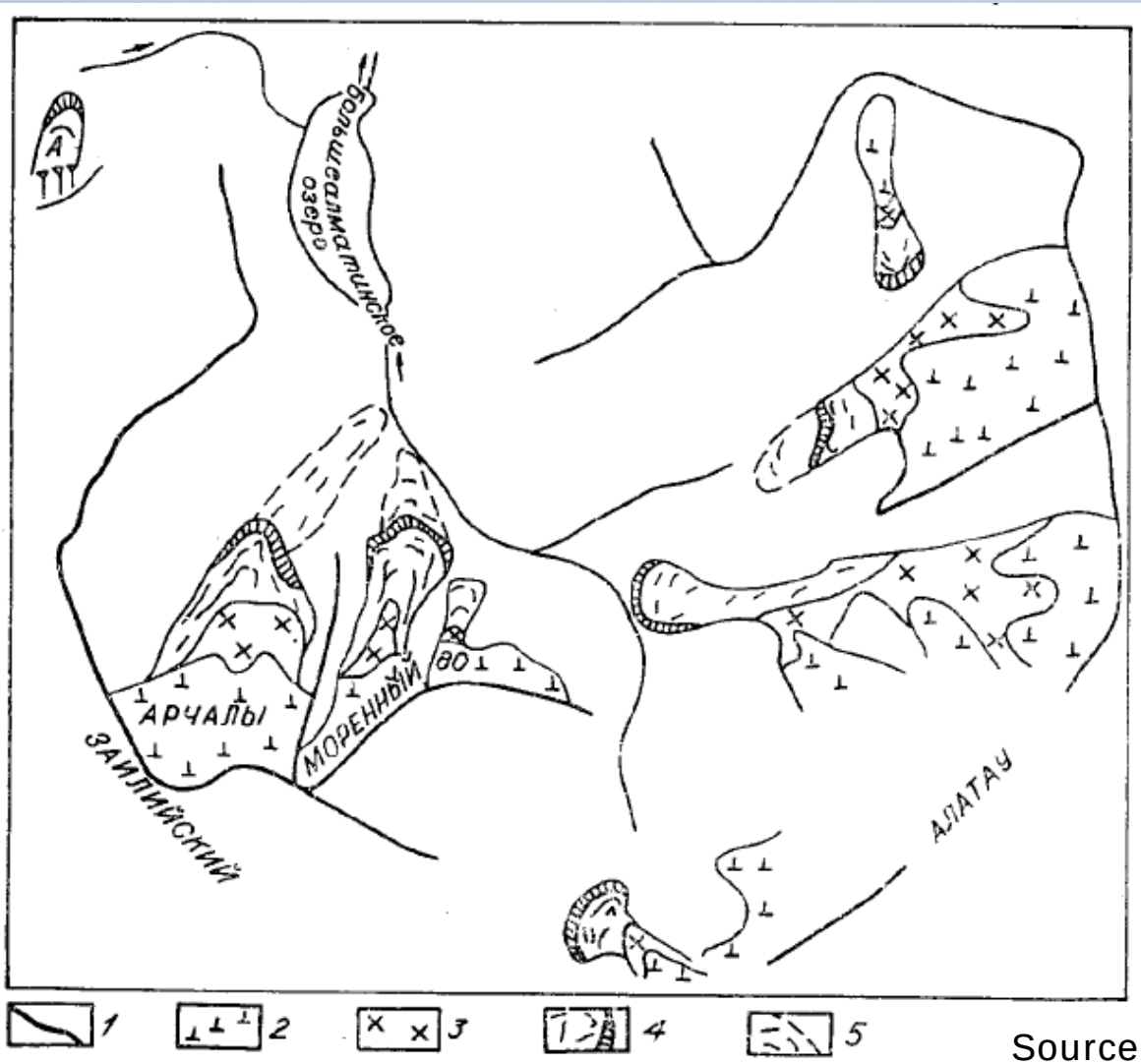

Northern Tien Shan
Photo: S. Marchenko


Northern Tien Shan
Photo: T. Bolch 2002


Northern Tien Shan
Photo: T. Bolch 2001

2 – Previous Studies

Rockglaciers in Big Almatinka Valley (Ile Alatau)

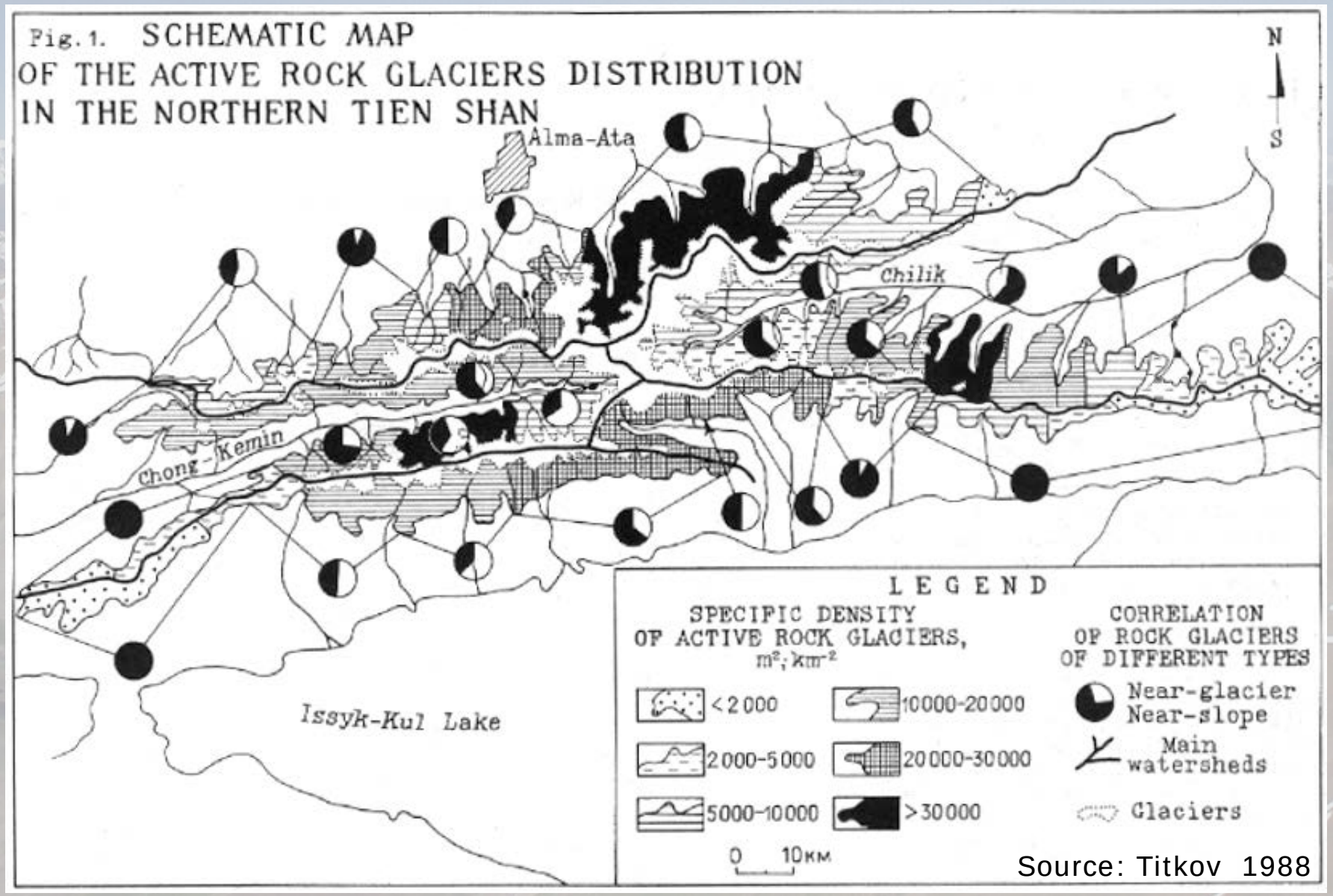


Source: Glazovsky 1978

Рис. 1. Каменные глетчеры в верховьях р. Бол. Алматинки.
1 — гребни; *2* — ледники; *3* — морены; *4* — активные каменные глетчеры; *5* — древние каменные глетчеры.

2 – Previous Studies

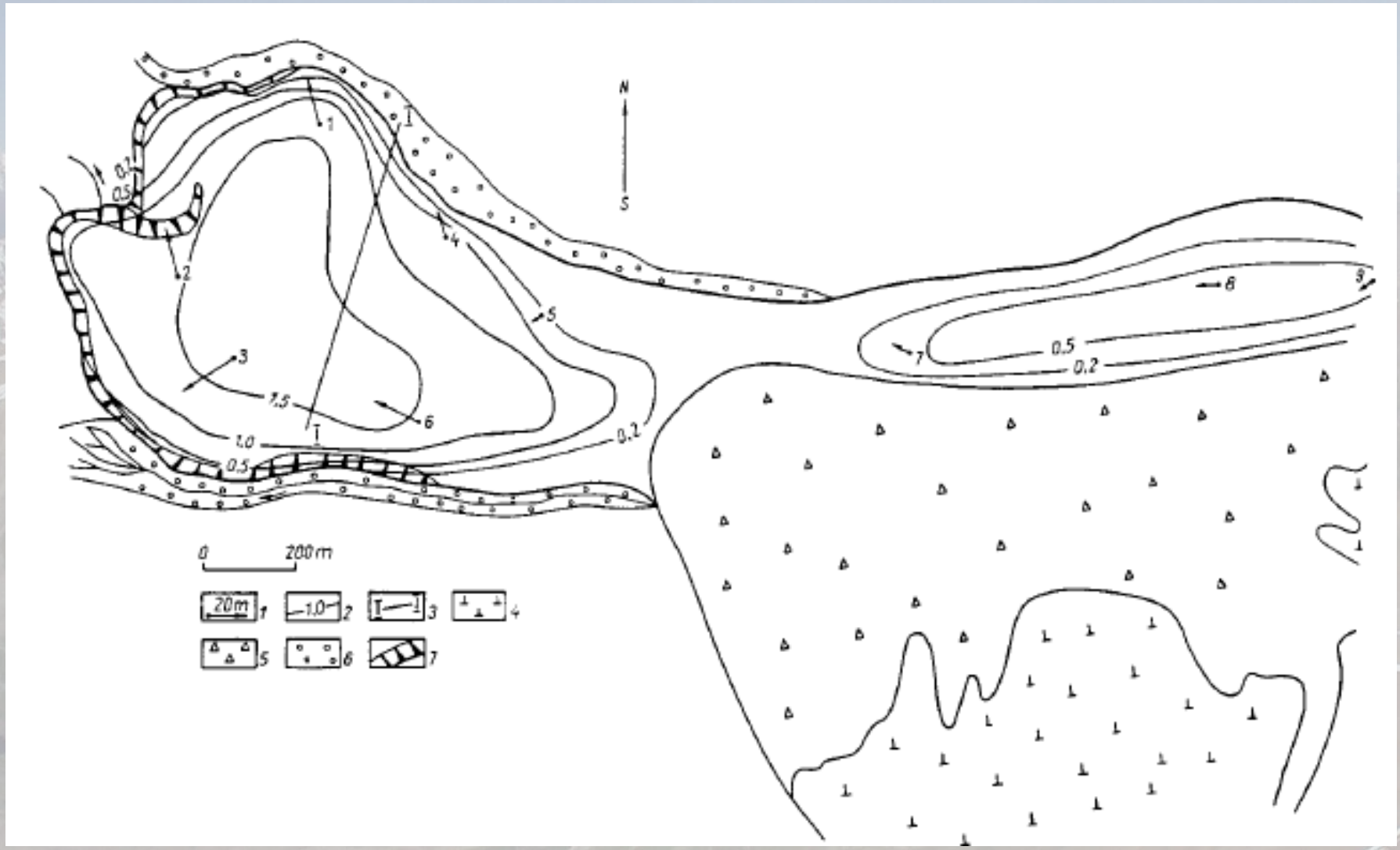
Rockglacier Density in Northern Tien Shan



Source: Titkov 1988

2 – Previous Studies

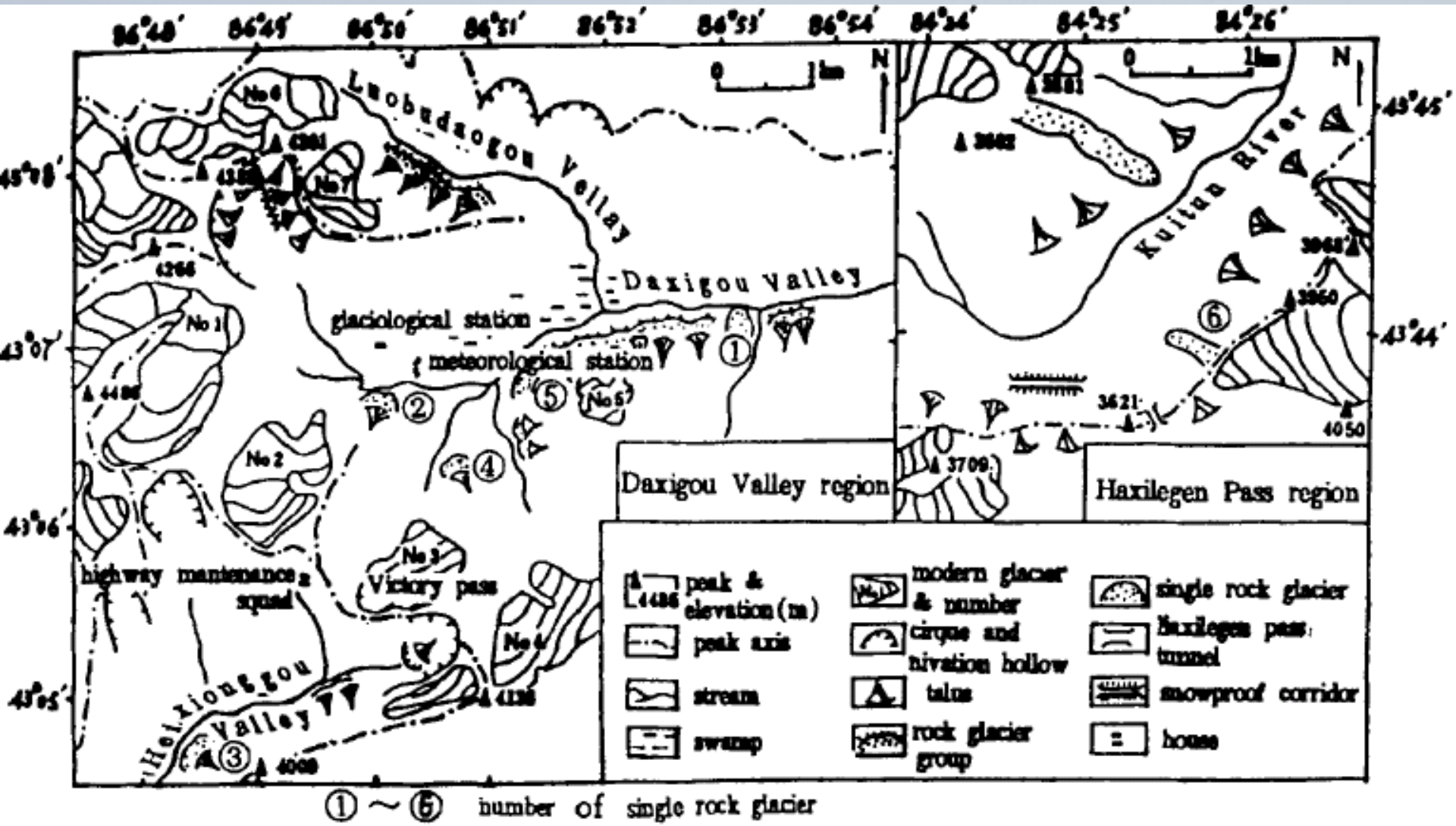
Rockglacier movement



Gorbunov et al. (1992)

2 – Previous Studies

Rockglaciers Chinese Tien Shan



Zhu et al. (1996)

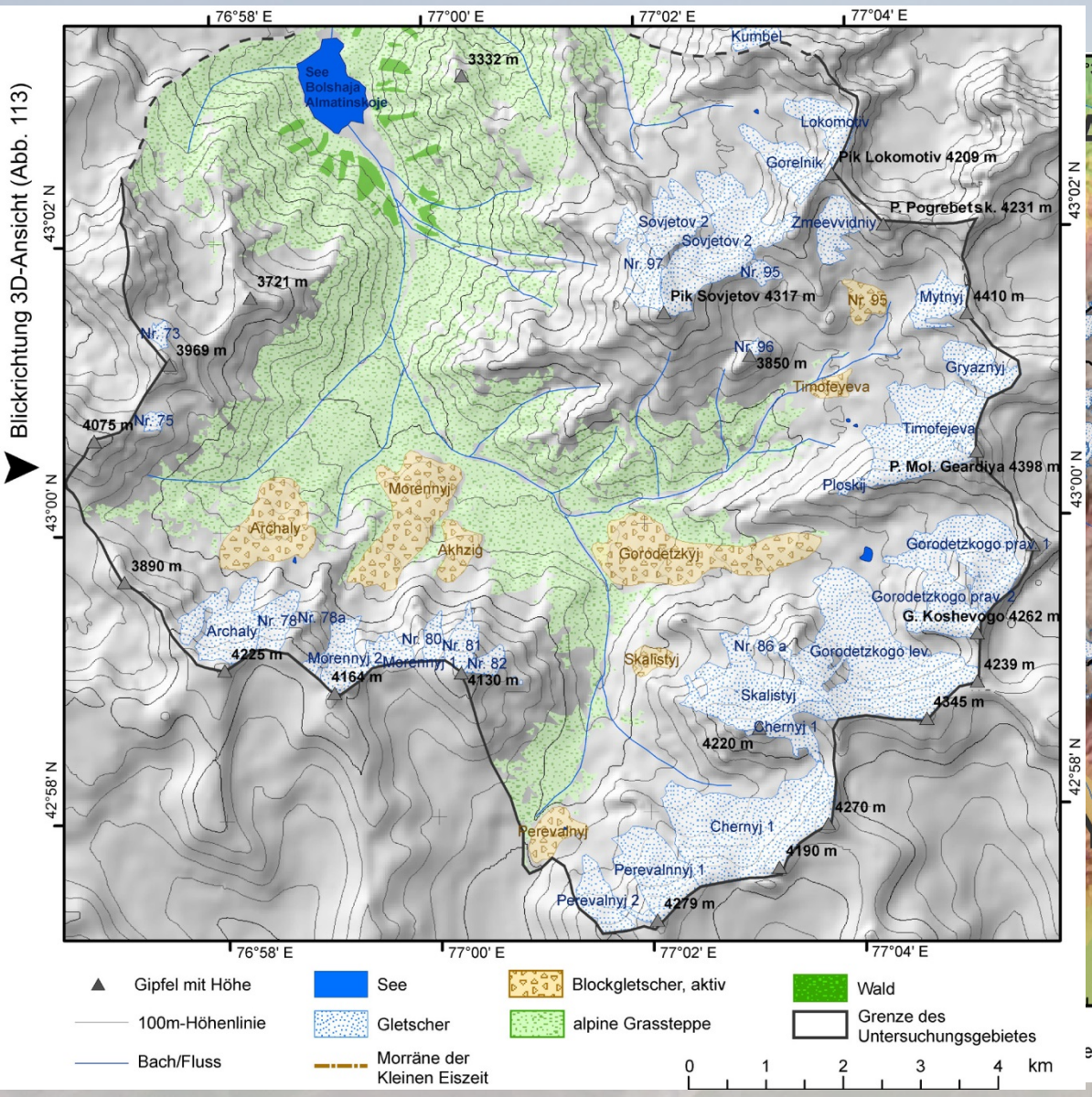
Mapping of Rockglaciers (traditional):

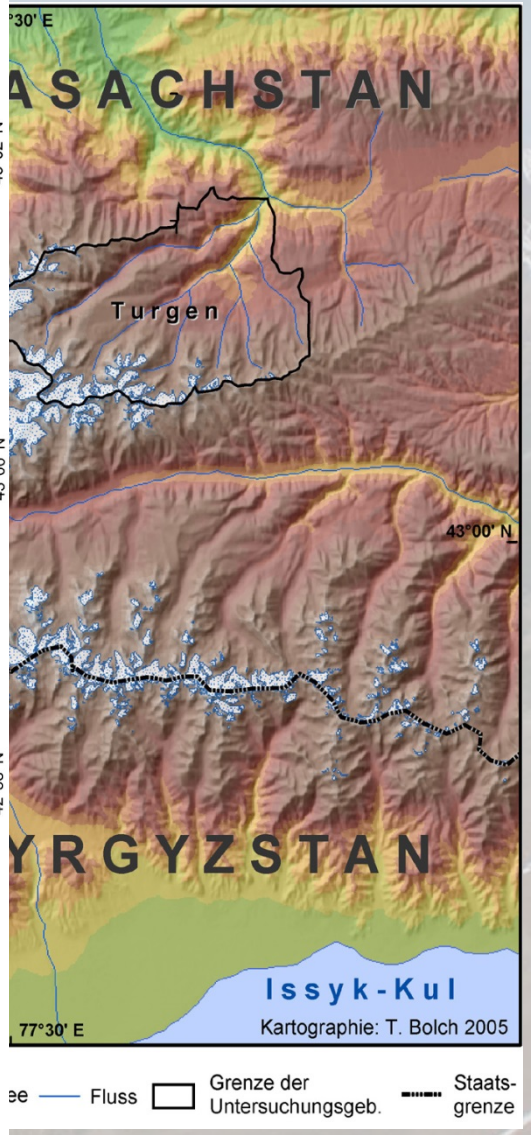
- Field investigations

- Identification and manual delineation using satellite images (e.g. Landsat ETM resolution merge, ASTER) aided by aerial images and Google Earth

2 – Previous Studies

Rockglaciers in Big Almatinka Valley

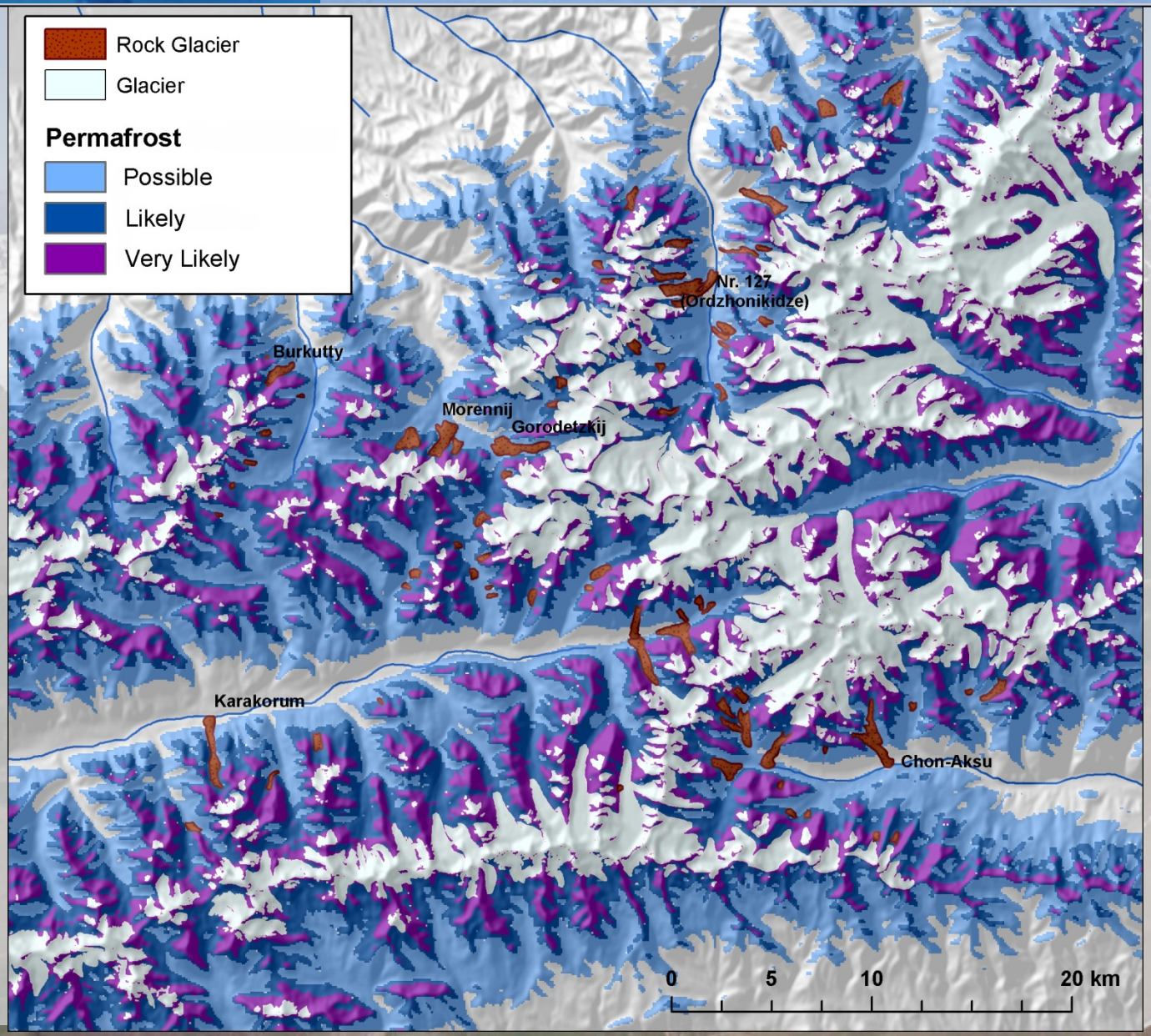




Bolch (2006)

2 – Previous Studies

Rockglaciers and Permafrost in Northern Tien Shan



Bolch & Gorbunov (2014), PPP

Ice volume of glaciers and rockglaciers

Valley	Ice Volume Glacier	Ice Volume Rockglaciers	Ratio Rockglacier/ Glacier
Bolshaja Almatinka	0,51 km²	0,048 km3	9,4 %
Malaja Almatinka	0,18 km²	0,005 km²	2,6 %
Levij Talgar	2,23 km²	0,056 km²	2,5 %
Turgen	0,88 km²	0,012 km²	1,3 %
Chon-Aksu	1,48 km²	0,062 km²	4,2 %
Chon-Kemin	1,39 km²	0,032 km²	2,3 %
Sum/Average	6,67 km²	0,214 km²	3,2 %

Assumptions for the thickness and ice content of the (rock)glaciers:

Estimation of Glacier Thickness[1] [m]: $28.5 \cdot (a\ [km^2])^{0.357}$

Estimation of Rockglacier Ice Content[2]: 40 – 60% by Volume

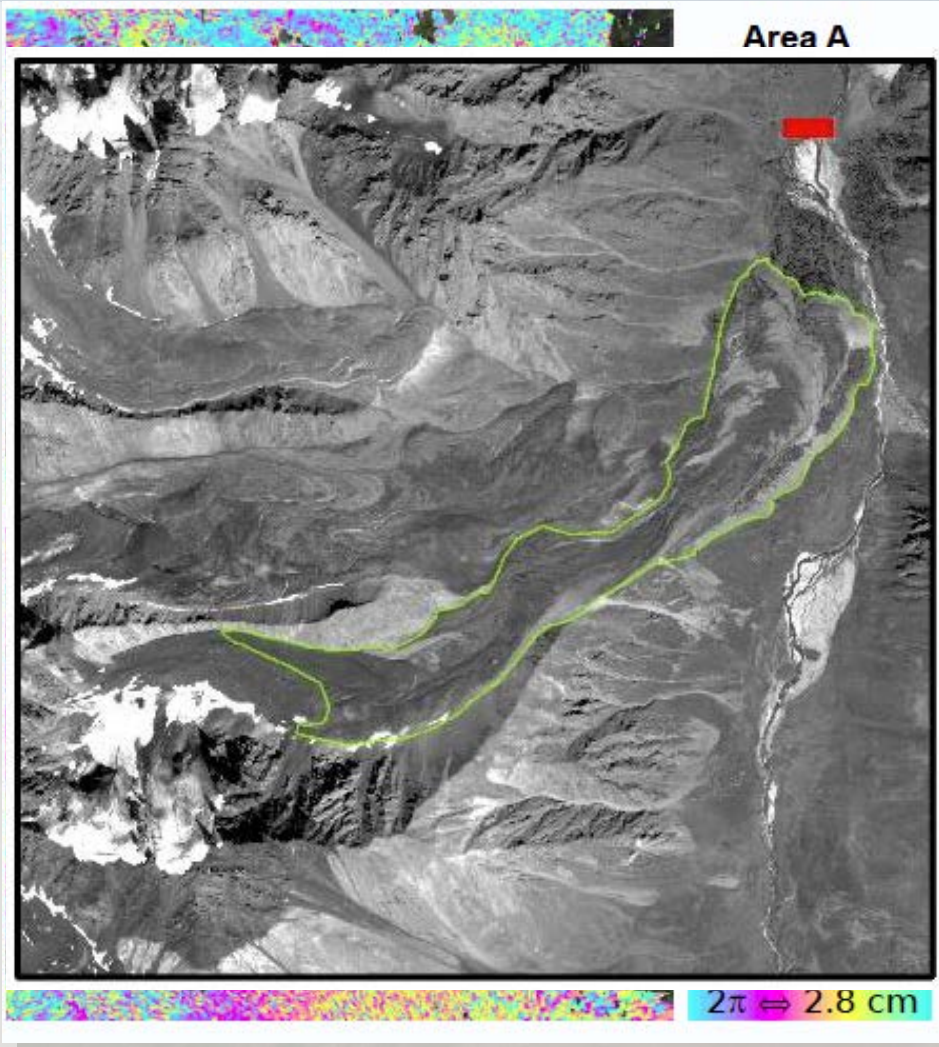
Estimation of Permafrost Thickness in Rockgl.[3]: 20 m

Bolch & Marchenko (2009)

Based upon: [1] Chen & Ohmura (1990), [2] Arenson et al. (2002), Barsch (1996), [3] Gorbunov & Titkov (1989), Croce & Milana (2002), own investigations

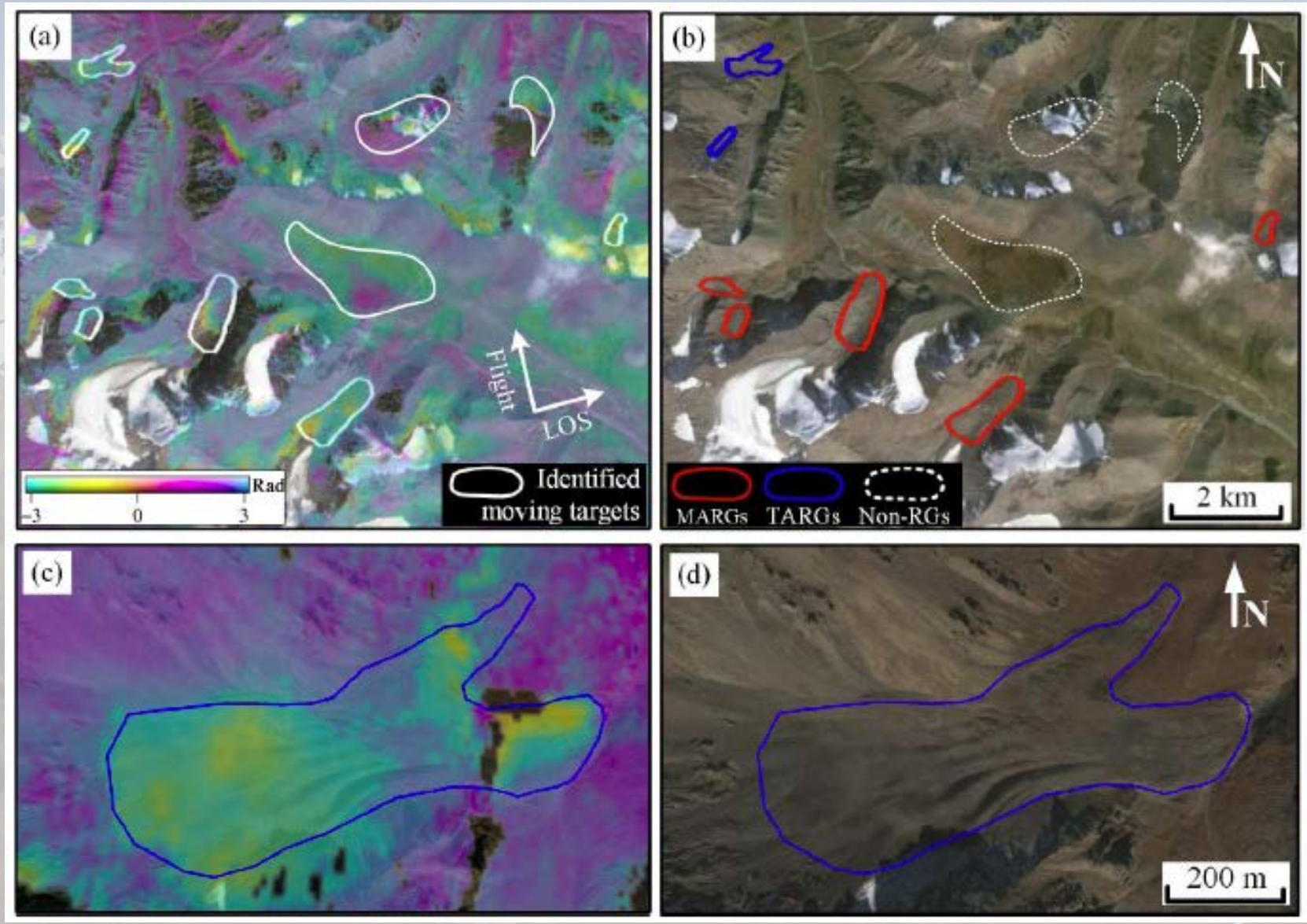
Mapping of Rockglaciers aided by SAR iterferogramms:

- SAR interferograms with short baselines and time intervals between 1 day and 1 year from the ERS-1/2 (1998-1999), ALOS-1 PALSAR-1 (2006-2010), ALOS-2 PALSAR-2 (2014-2016) and Sentinel-1 (2015-2016)
- Final identification and classification aided by Google Earth and high resolution satellite imagery (e.g. Pleiades)
- Deformation rates are expressed using different classes (cm/day, dm/month, cm/month and cm/yr).



3 – Methodology

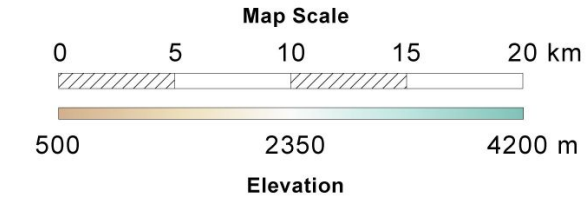
Mapping and Analysis of Rockglaciers

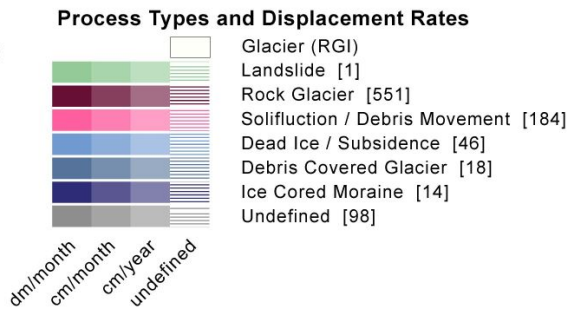


Wang et al., 2017, TC

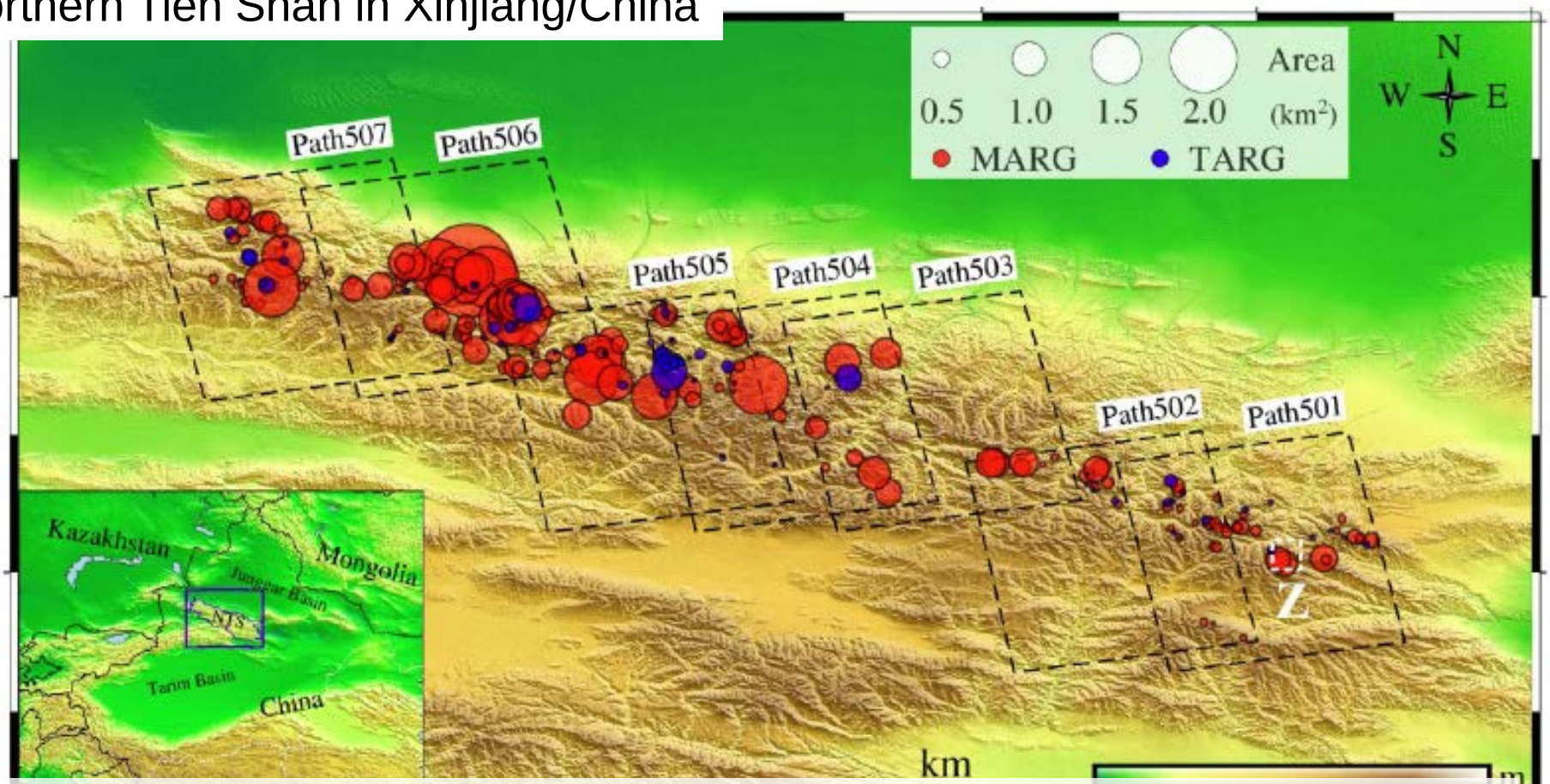
Northern Tien Shan in Kazakhstan and Kygyzstan

Overall, more then 550 rockglaciers were identified, several of them moved more than 1 cm/day.





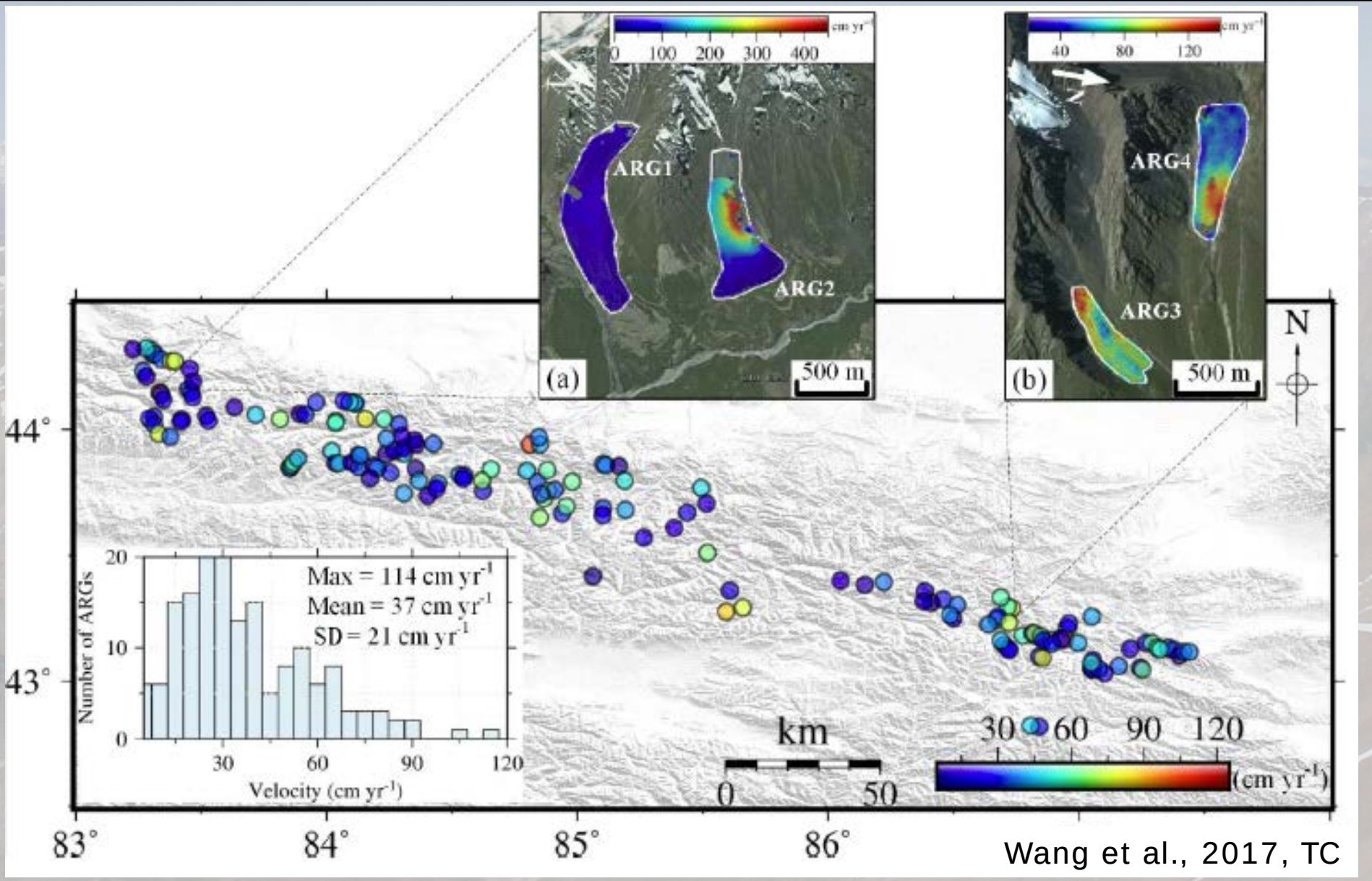
Northern Tien Shan in Xinjiang/China



Overall, more then 250 rockglaciers were identified, most of them are moraine-derived.

Wang et al., 2017, TC

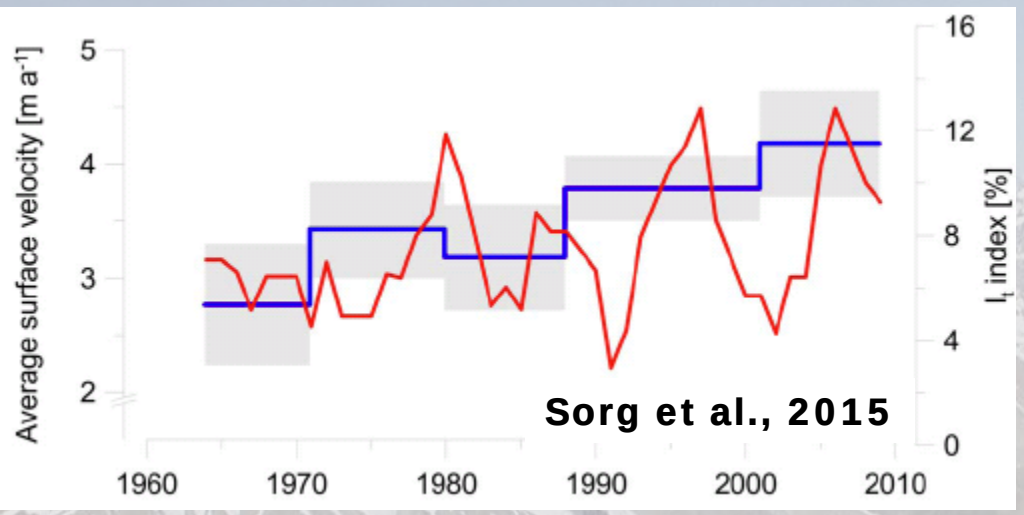
4 – Results
Rockglacier Activity

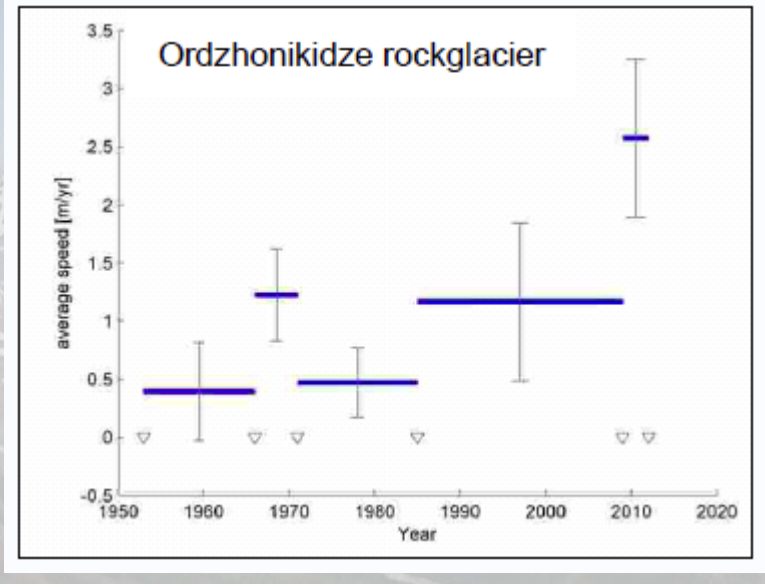


Wang et al., 2017, TC

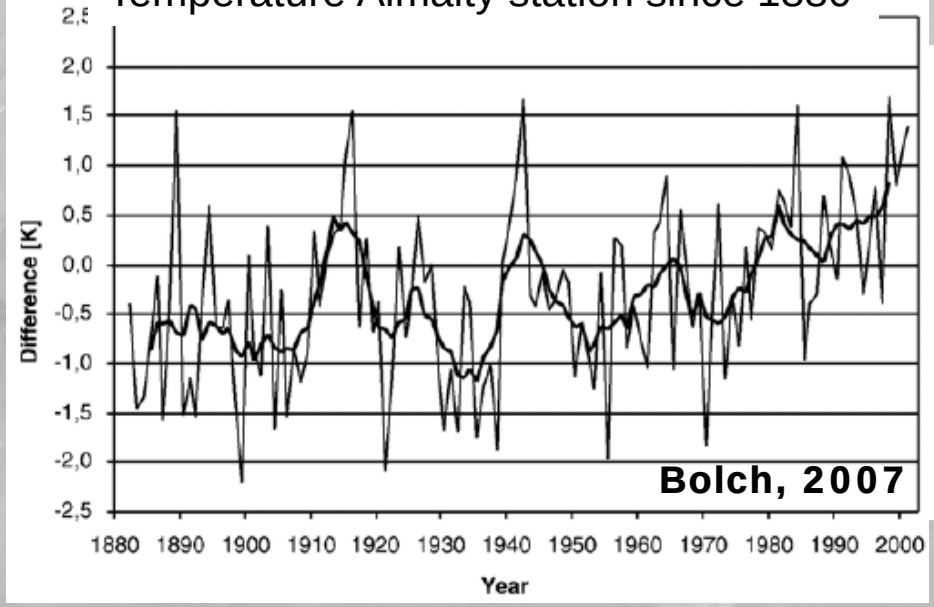
5 – Further Studies

Rockglacier Movement and Climate

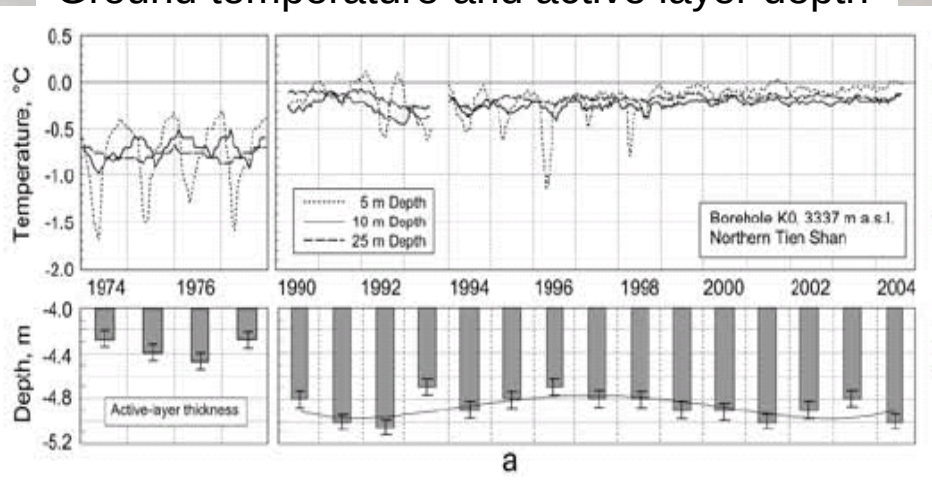




Temperature Almaity station since 1880

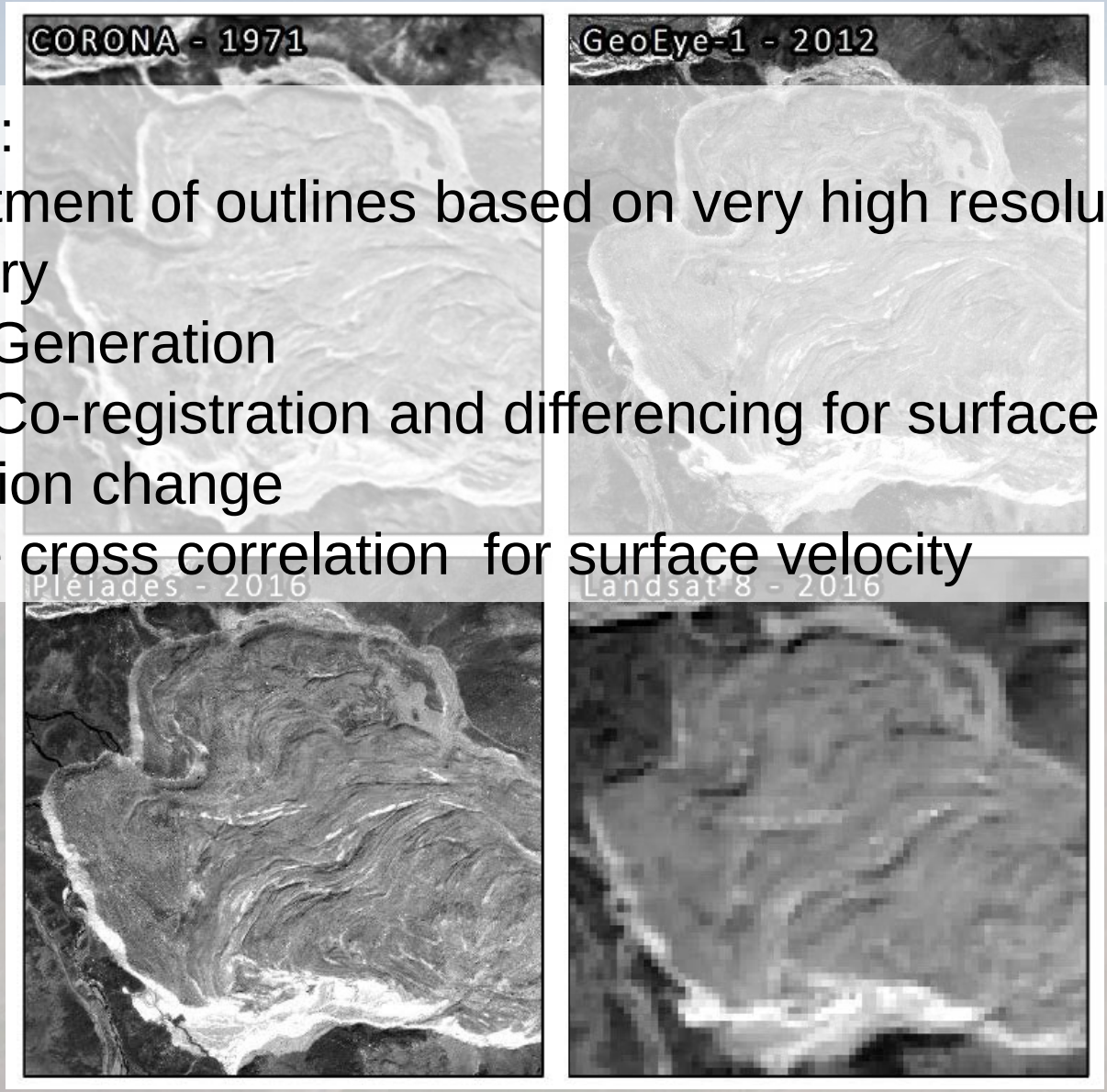


Ground temperature and active layer depth



Bolch & Marchenko, 2009

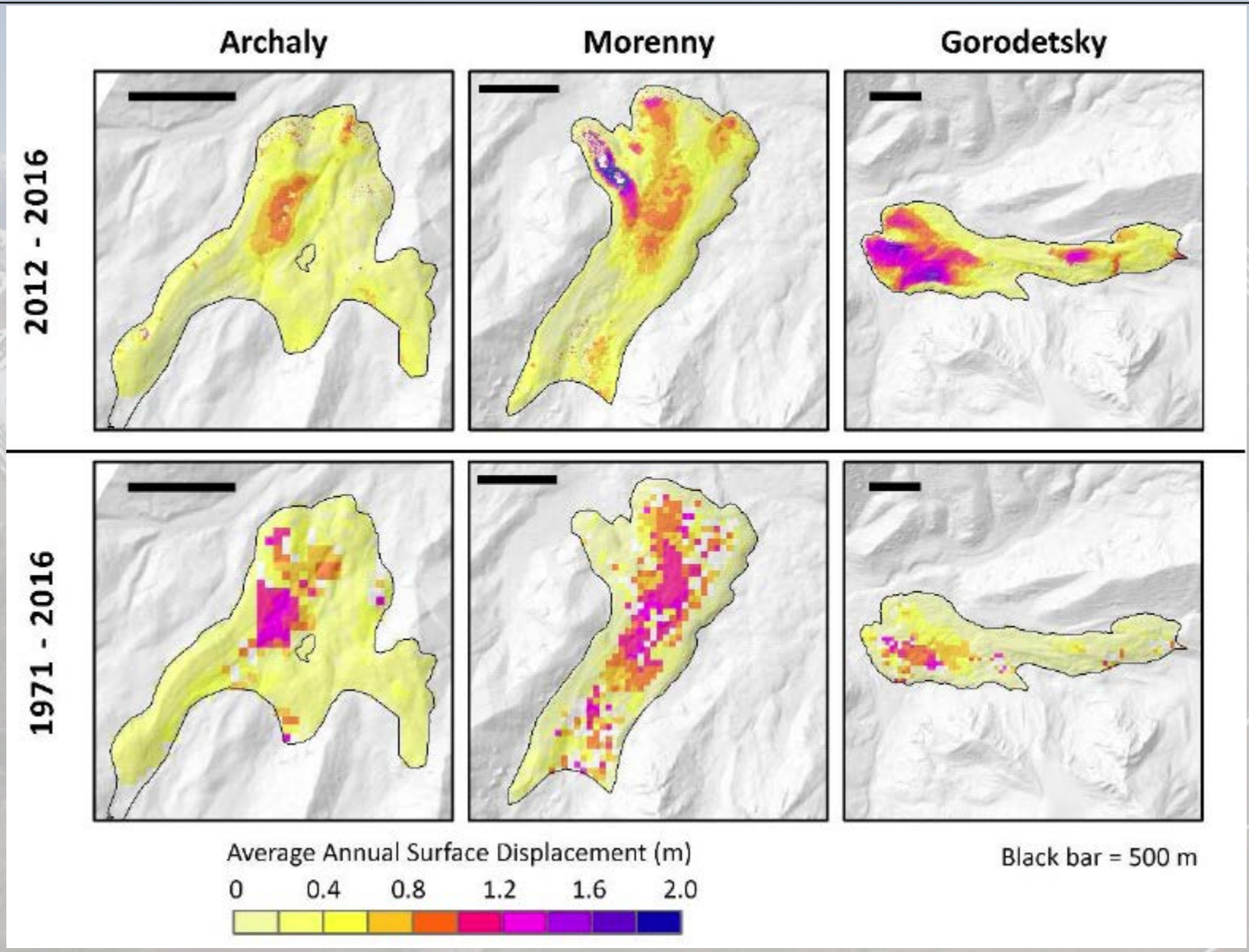
Rockglacier Movement and Elevation Changes



Methods:

- Adjustment of outlines based on very high resolution imagery
- DEM Generation
- DEM Co-registration and differencing for surface elevation change
- Image cross correlation for surface velocity

6 – Detailed Studies
Rockglacier Movement

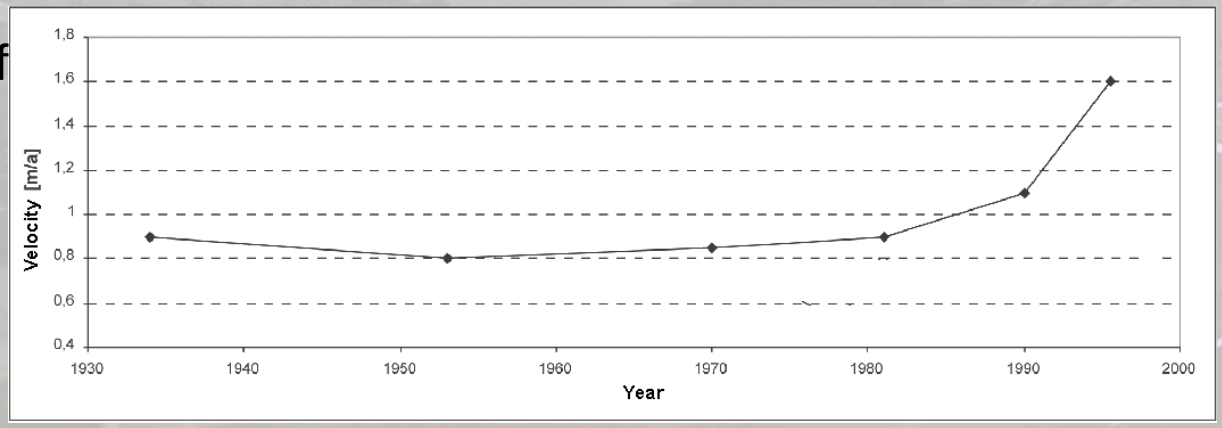


Average Rate of Frontal Advance

Name	Time Period	Frontal Advance
Gorodetzkij:	1923-2003	1.1 m/a
Morennij	1973-1982	0.35 m/a
Burkutty	1984-2004	4.0 m/a

Source of advance rates: Gorbunov & Titkov (1989), Fest (2007), Bolch & Marchenko 2008

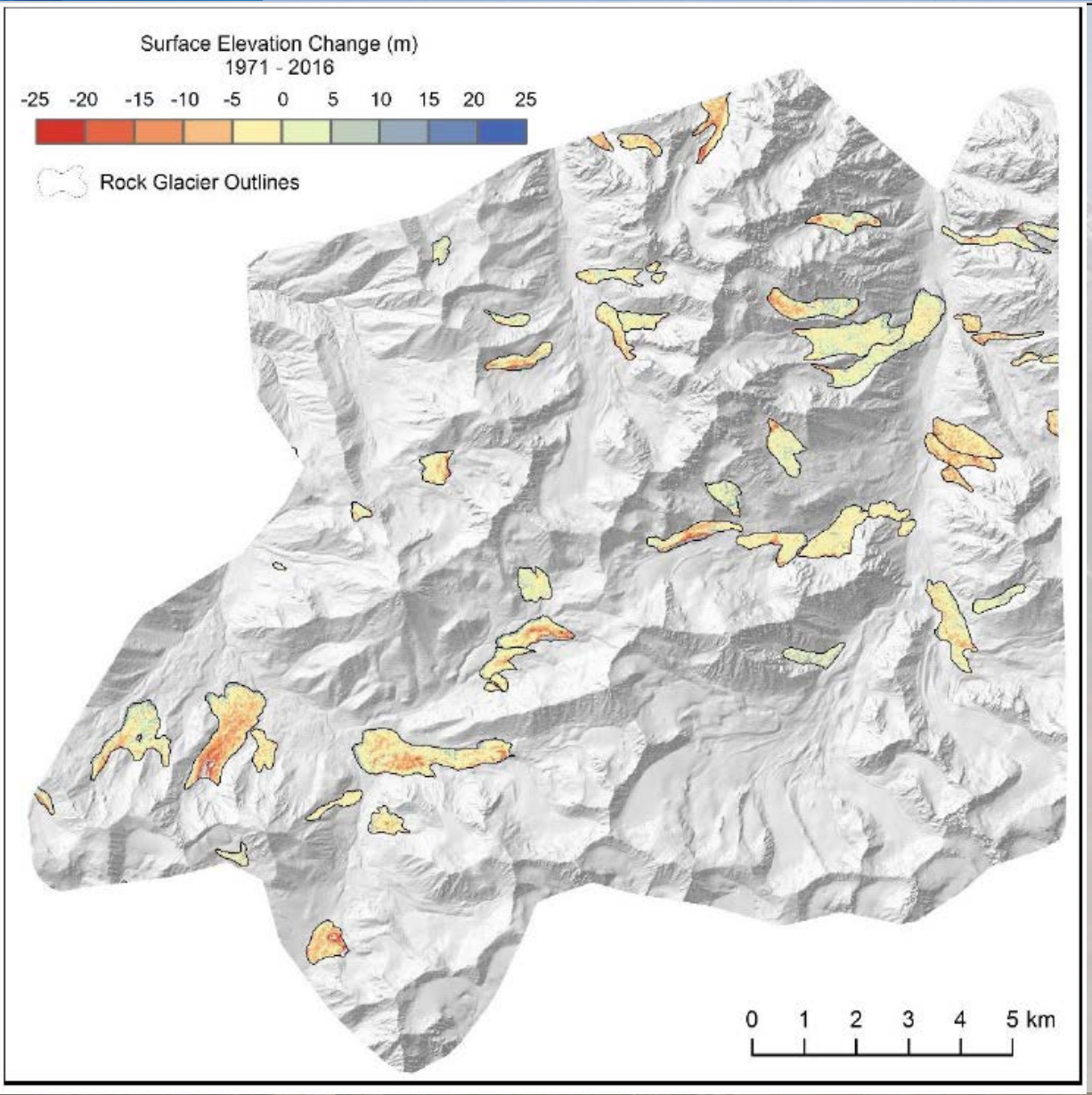
Rate of Frontal Advance of Gorodetzkij Rockglacier



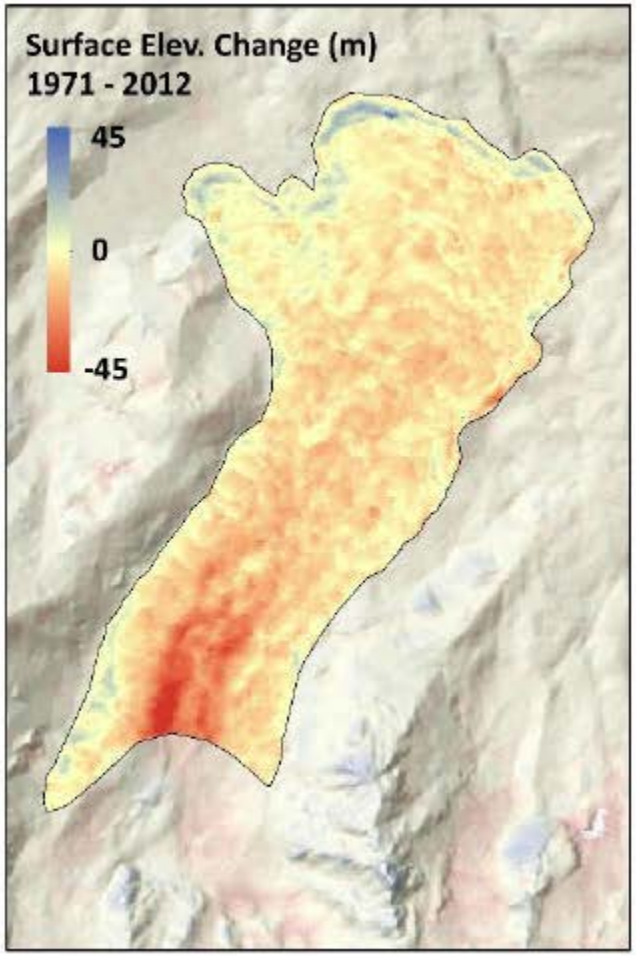
Source: Bolch & Marchenko 2008

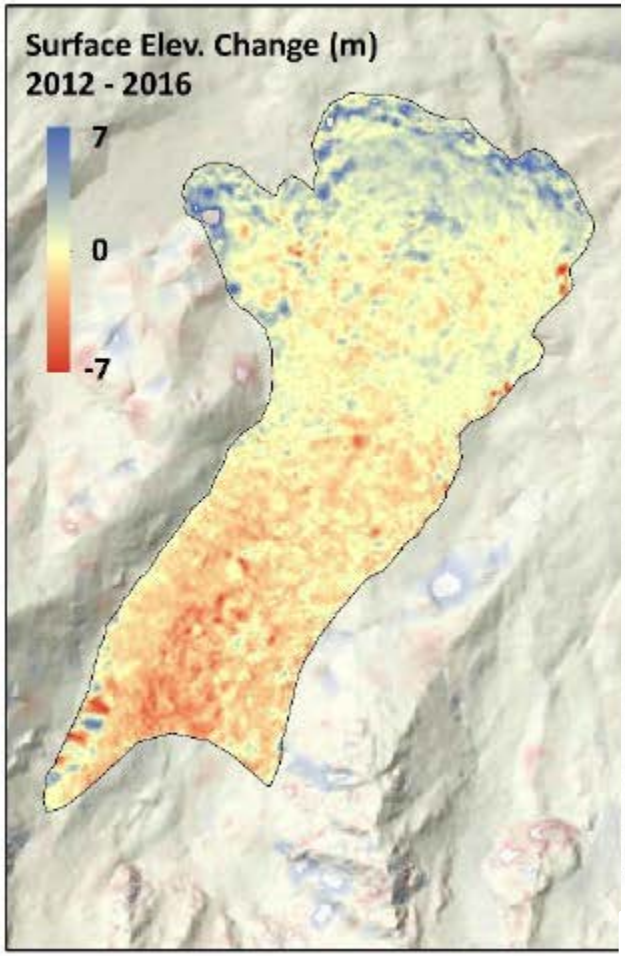
6 – Detailed Studies

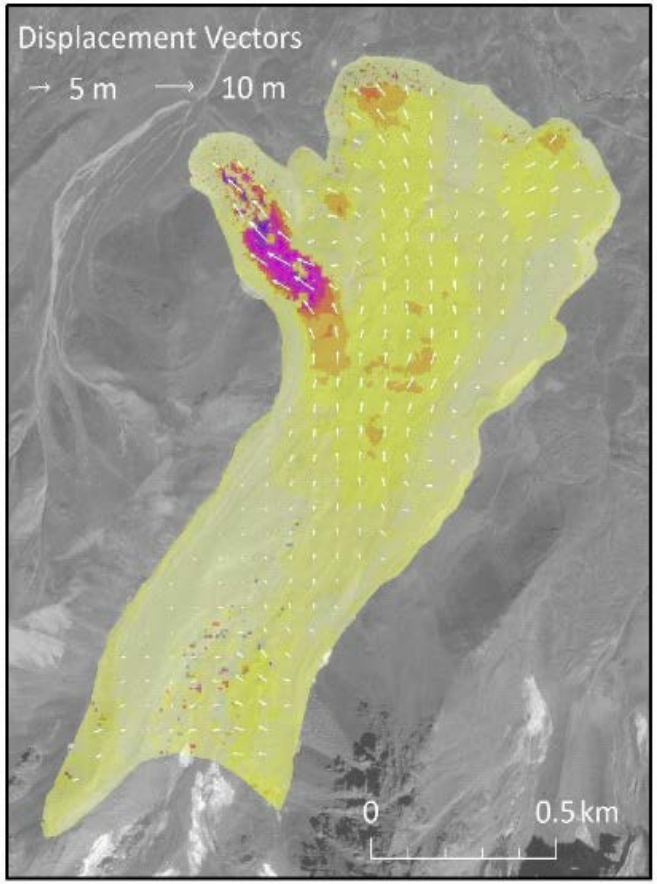
Surface elevation change



Morennij rockglacier



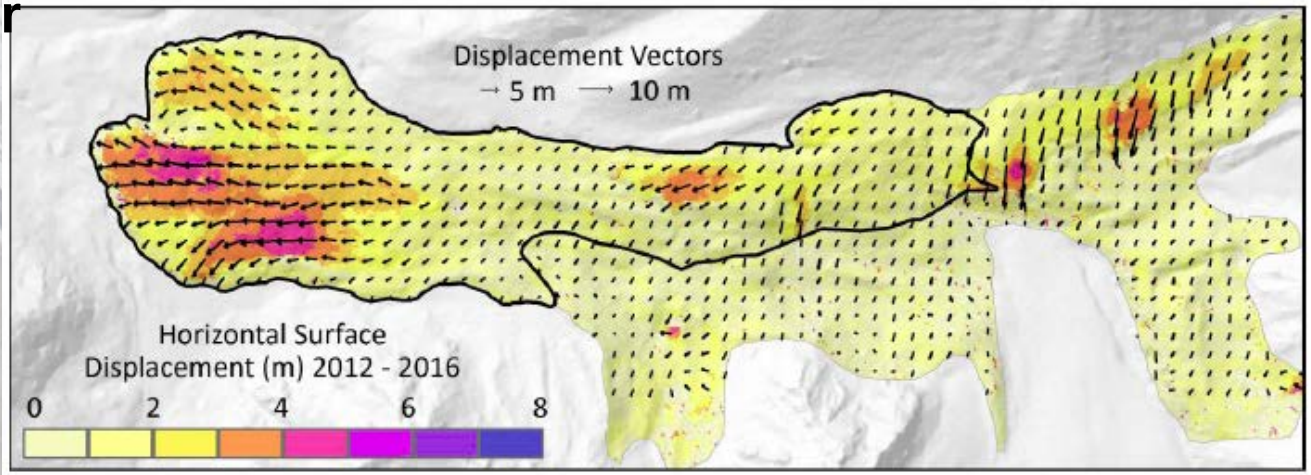


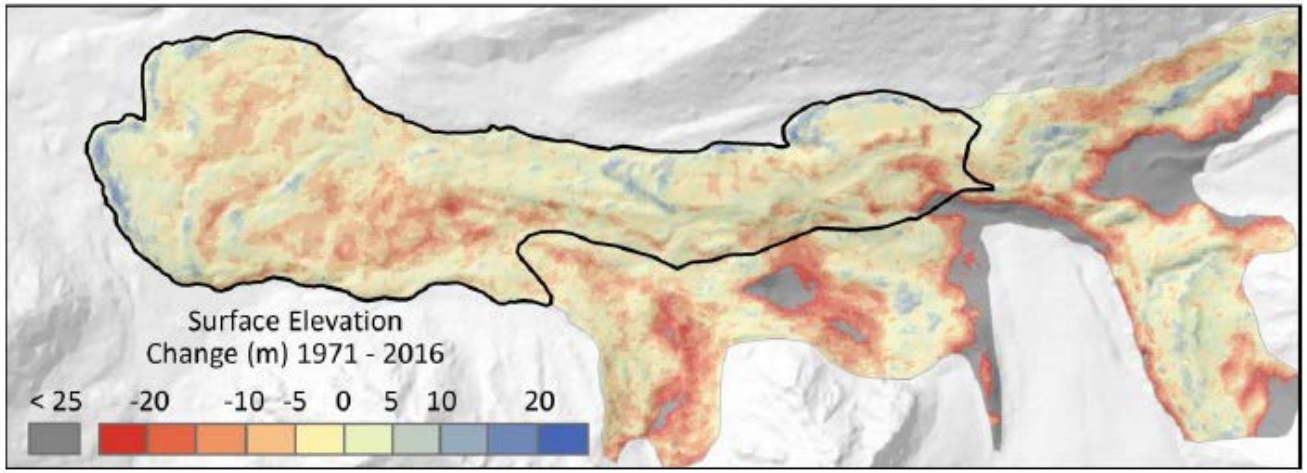


6 – Detailed Studies

Rockglacier Movement and Elevation Changes

Gorodetzkij rockglacier

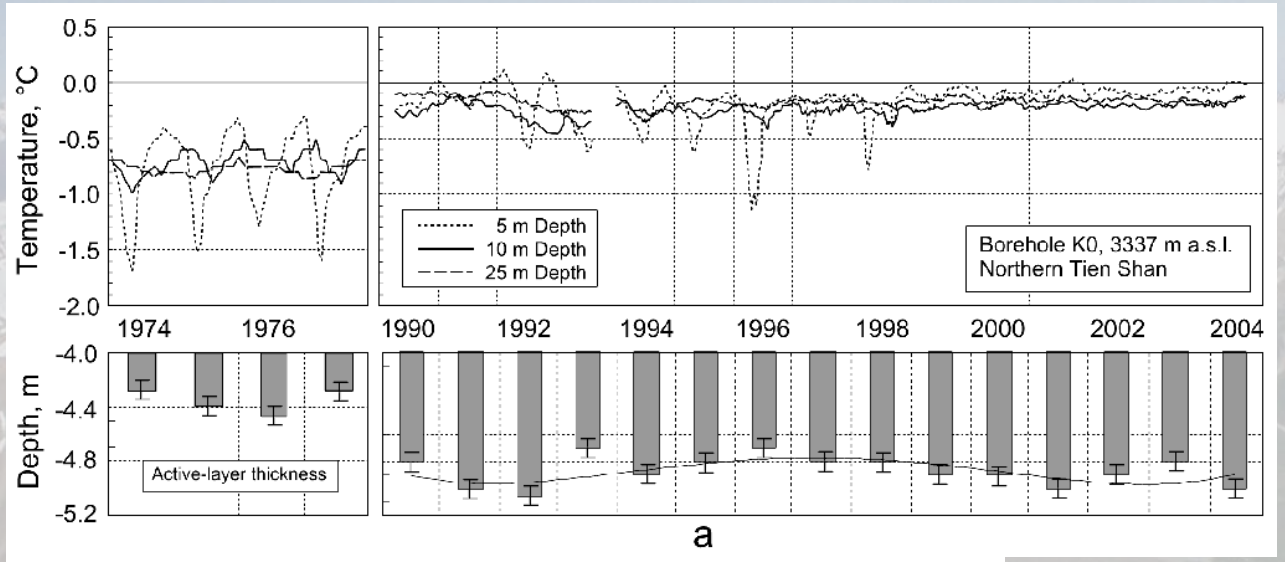


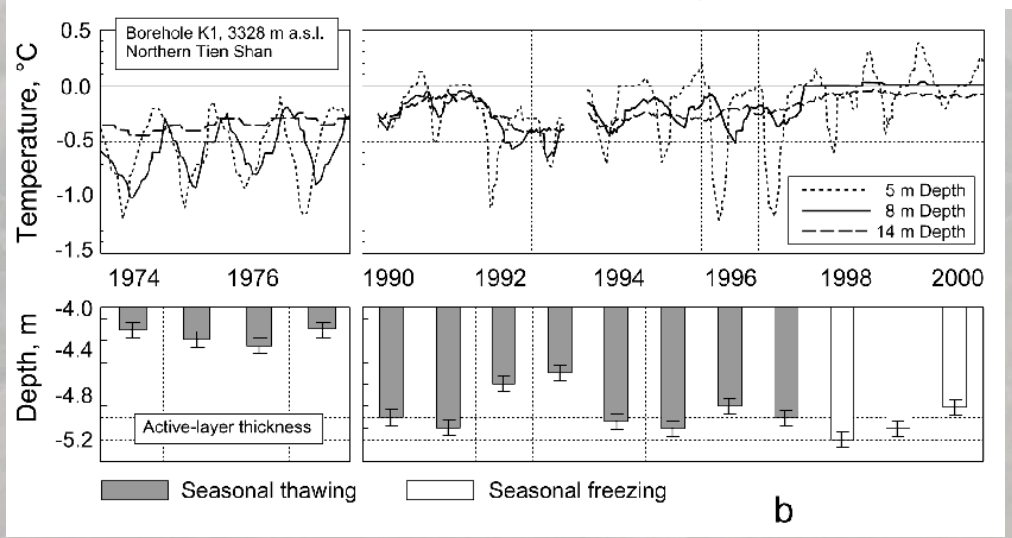


Conclusions and Outlook

- Differential SAR interferograms are suitable to analyse surface deformations and to support rockglacier mapping.
- High resolution optical imagery as e.g. available at Google Earth or Bing, were applied for final classification. If no high resolution images are available Landsat 8 and especially Sentinel-2 data allow also mapping of rockglaciers with the aid of the SAR interferograms.
- We identified so far more than 700 rockglaciers objects with an extent of about 250 km^2 within an area of 4000 km^2.
- Investigations of selected rockglaciers show on average an increase in surface velocity along with increasing temperatures.
- In contrast to glaciers rockglaciers showed mostly elevation gain at their fronts and lowering at their heads.
- We aim to extend the investigations to several target regions in High Asia within the framework of the Dragon program.

Measurements at Permafrost Monitoring Station





⇒ **Increase of Permafrost-temperatur 1975 – 2005 varries between 0.3 and 0.6 K**

⇒ **Increase of the active Layer thickness 1975 – 2005 from ~3.2 m to ~5 m**

(Marchenko et al. 2006. GPC)

1 - Introduction

Study Region