

On the results of the study of the glaciers of Chukchi and Kolyma highlands by satellite images and field investigation

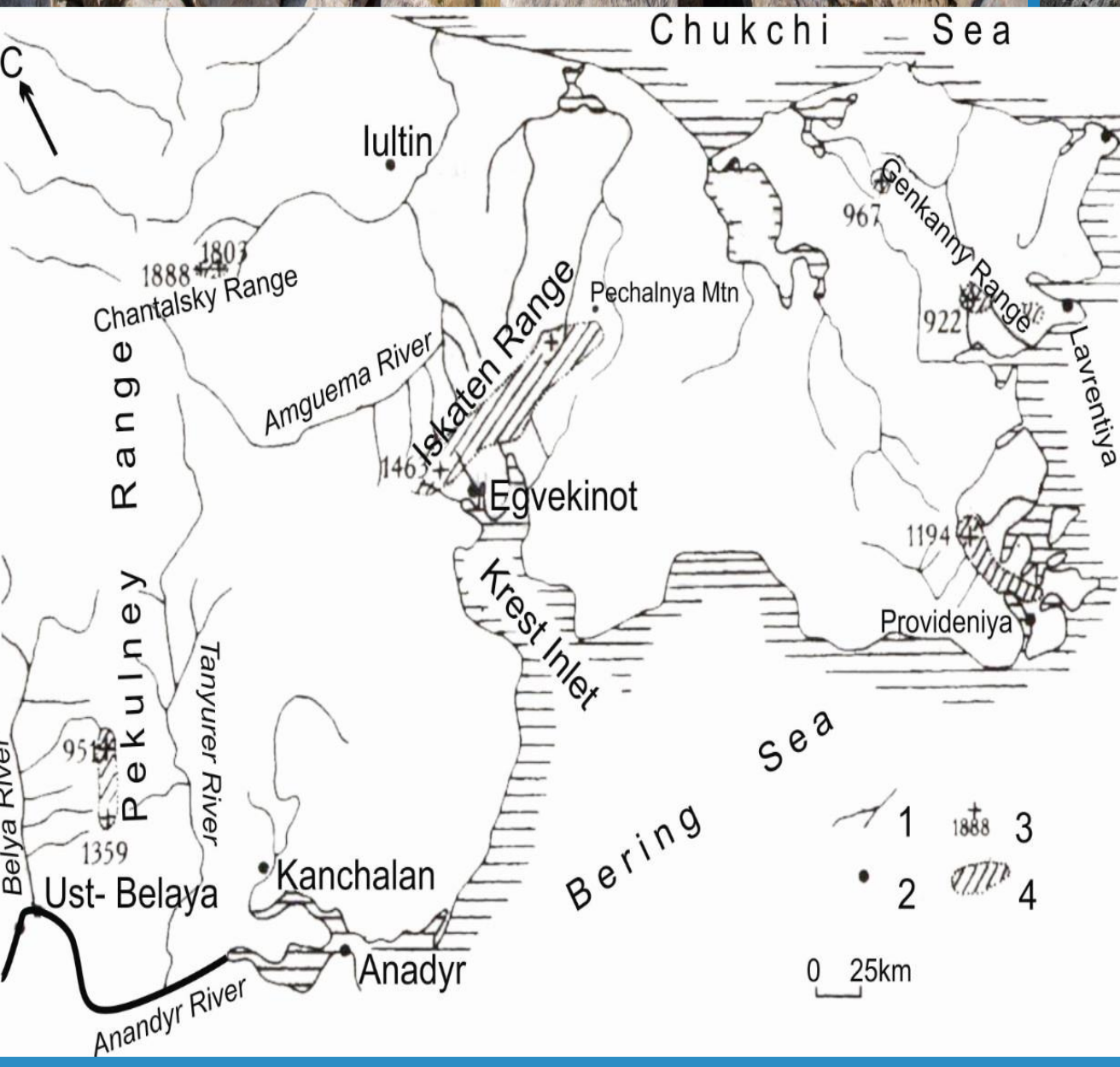
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The glaciers of Chukotka and Kolyma are small forms of glaciation. Such glaciers often do not have a clearly pronounced firn basin, small in size and thickness; have a morphological type — corrie, corrie-hanging, corrie-valley, sensitive to changes of local climate, often covered with moraine cover, which prevents them from melting during adverse climatic conditions. The purpose of this work is to assess the main parameters of the glaciers of Chukotka and Kolyma - the size and volume, and their change over time. The issue is being discussed whether these small forms of glaciation can be considered be glaciers or are they in a transitional stage, for example, to rock glaciers.

The areas of glaciers are determined for periods from the beginning of the 1980s to 2005 and up to 2017 retrieving from various satellite images and from the catalog of these glaciers investigator, R.V. Sedov. The maximum reduction is characteristic for glacial objects of the basins of the left bank of the Amguema River, Cross Gulf and Lawrence Bay. Glacier volumes are determined by the formula of S.A. Nikitin for corrie glaciers (he obtained them by measuring glaciers of Altai), and by our own method: the average thickness of the glaciers is calculated from the field of isogypsum patterns, constructed using the DEM of individual glaciers made by drone during field work, and ArcticDEM. Basing on these studies the formulas have been obtained to calculate the volumes of the small glacier forms of Chukotka and Kolyma.



The glaciers of the **Chukchi Highlands**, according to R.V Sedov, are represented by several groups.

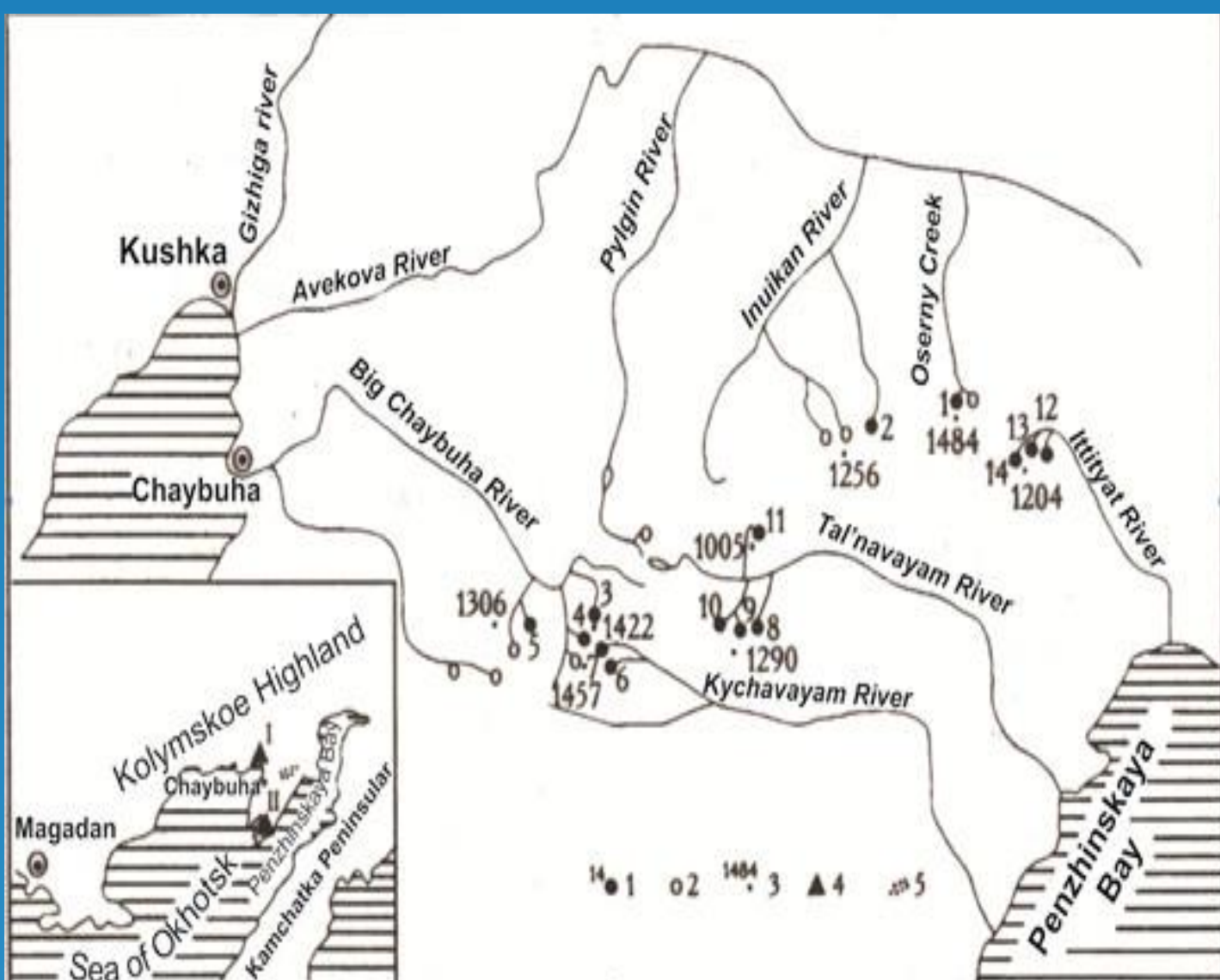
The 1st group of 3 glaciers is in the north-east of the Chukotka Peninsula on the Tenialny ridge.

The 2nd group, of 14 corrie glaciers, is in the Providence massif, equilibrium line altitude (H_{ELA}) here is from 400 to 550 m.

The 3d group, in the Cross Bay over Iskaten Range consisted of 21 glaciers with H_{ELA} - from 500 to 1000 m.

The 4th group of 4 corrie glaciers on the Pekulney Range, glaciers ~ 0.3 km² in size. The average H_{ELA} was 740 m.

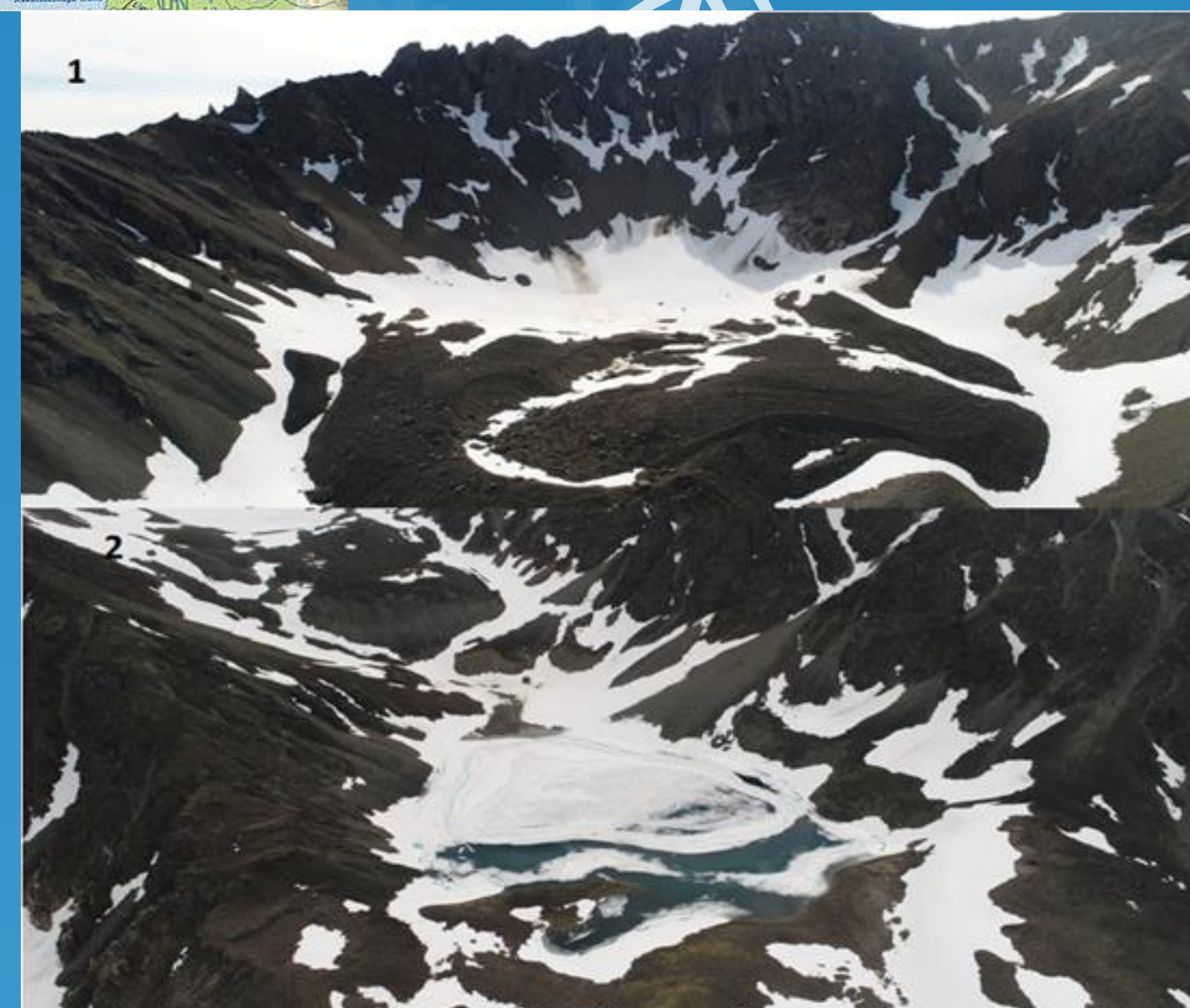
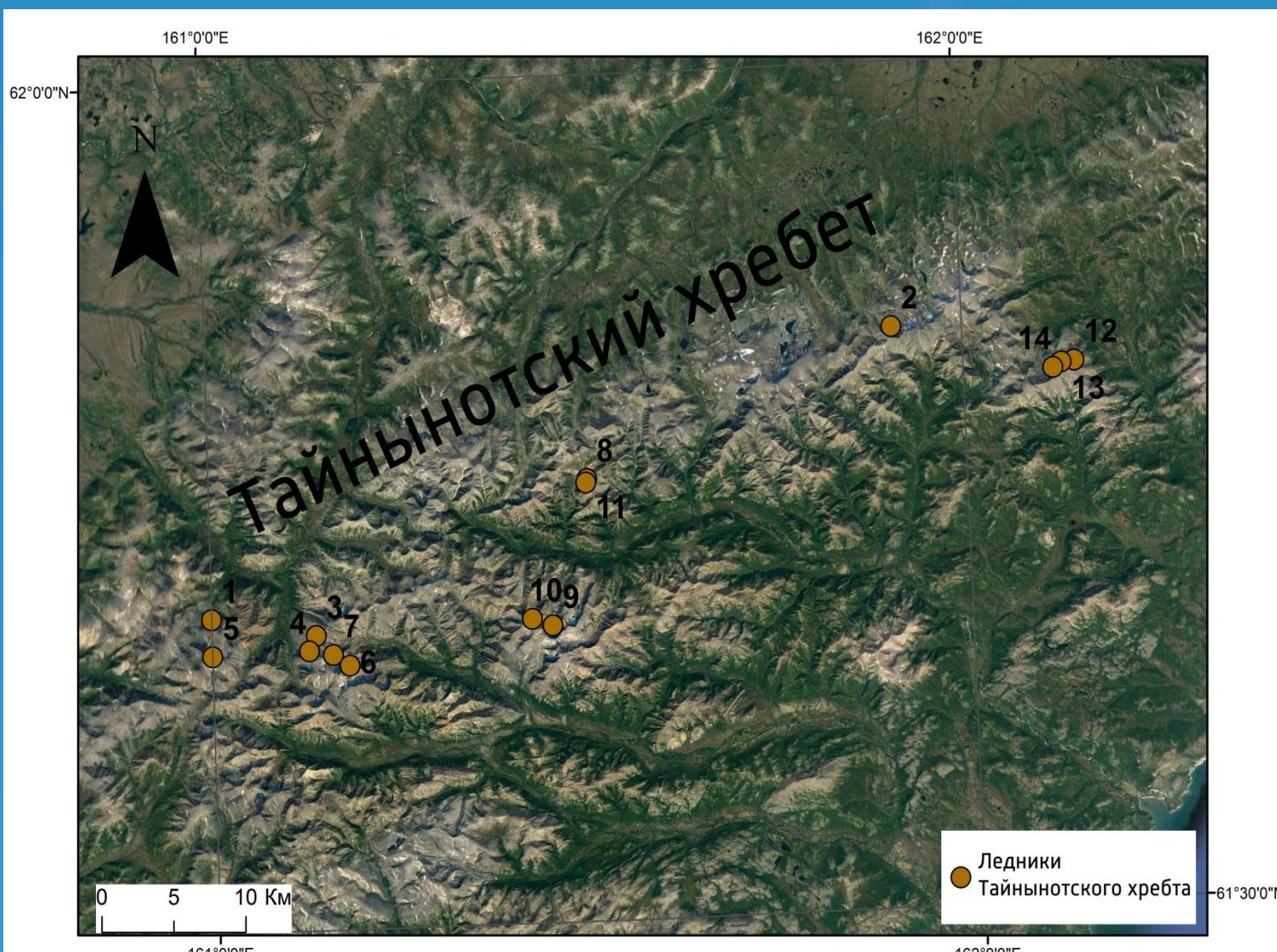
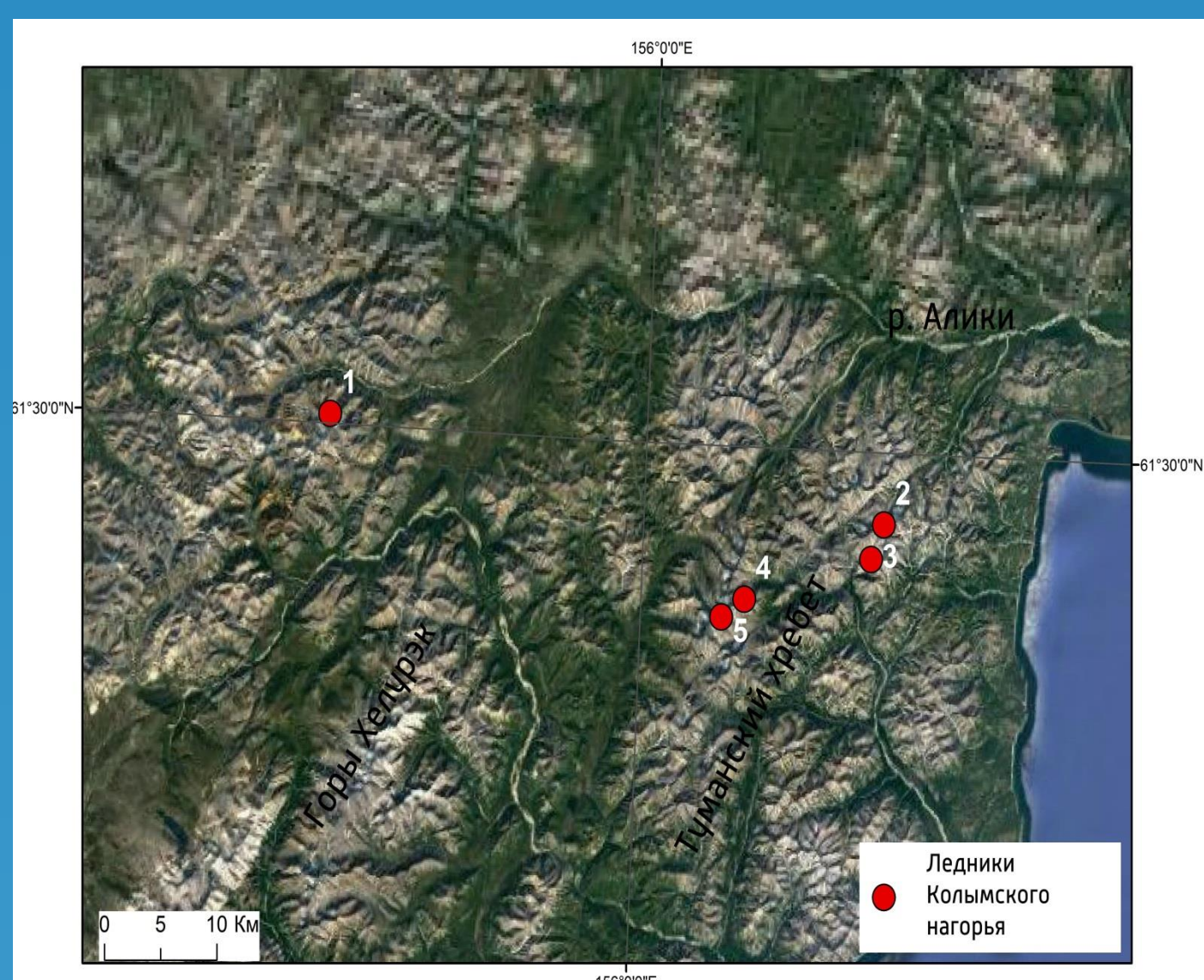
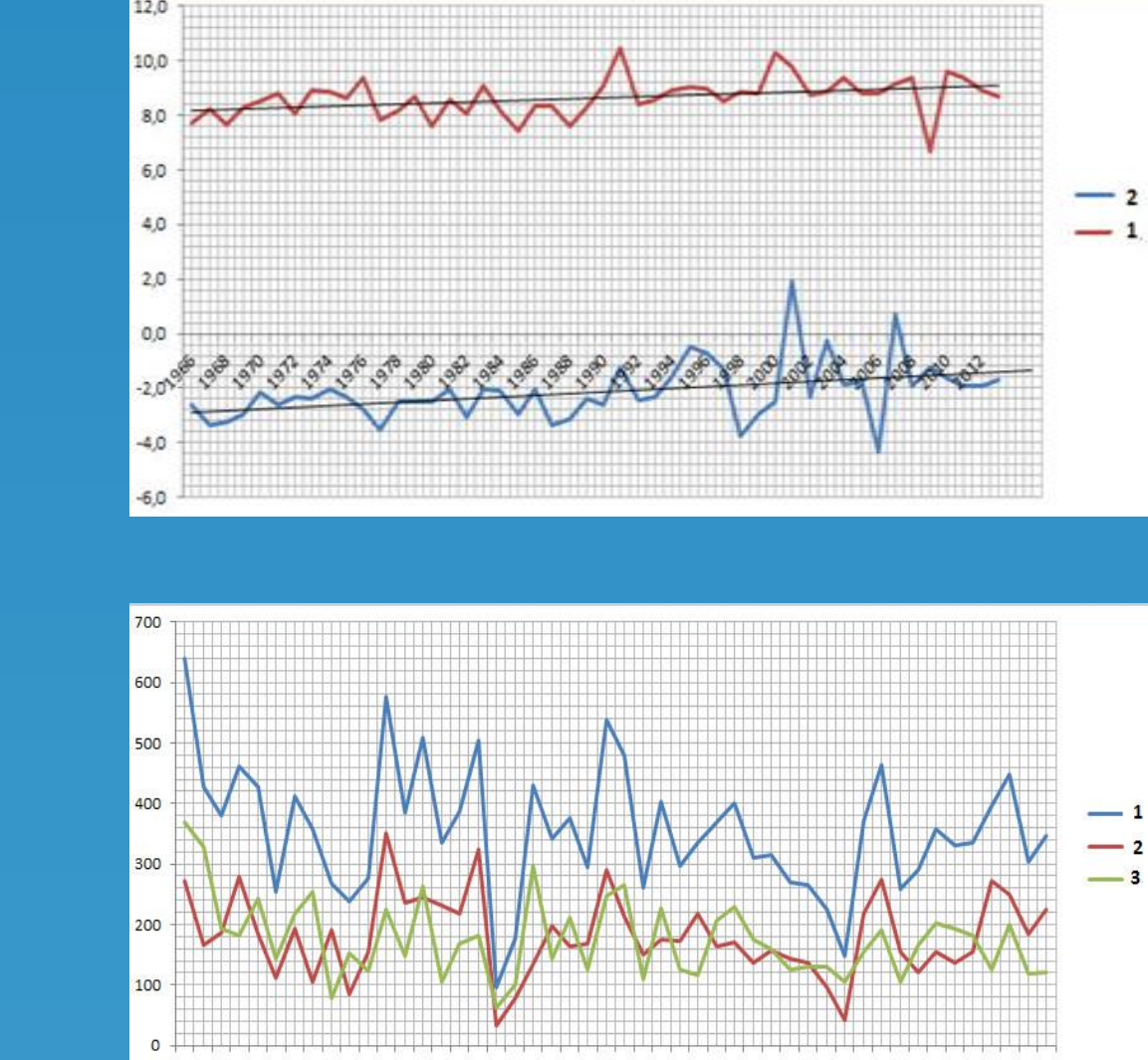
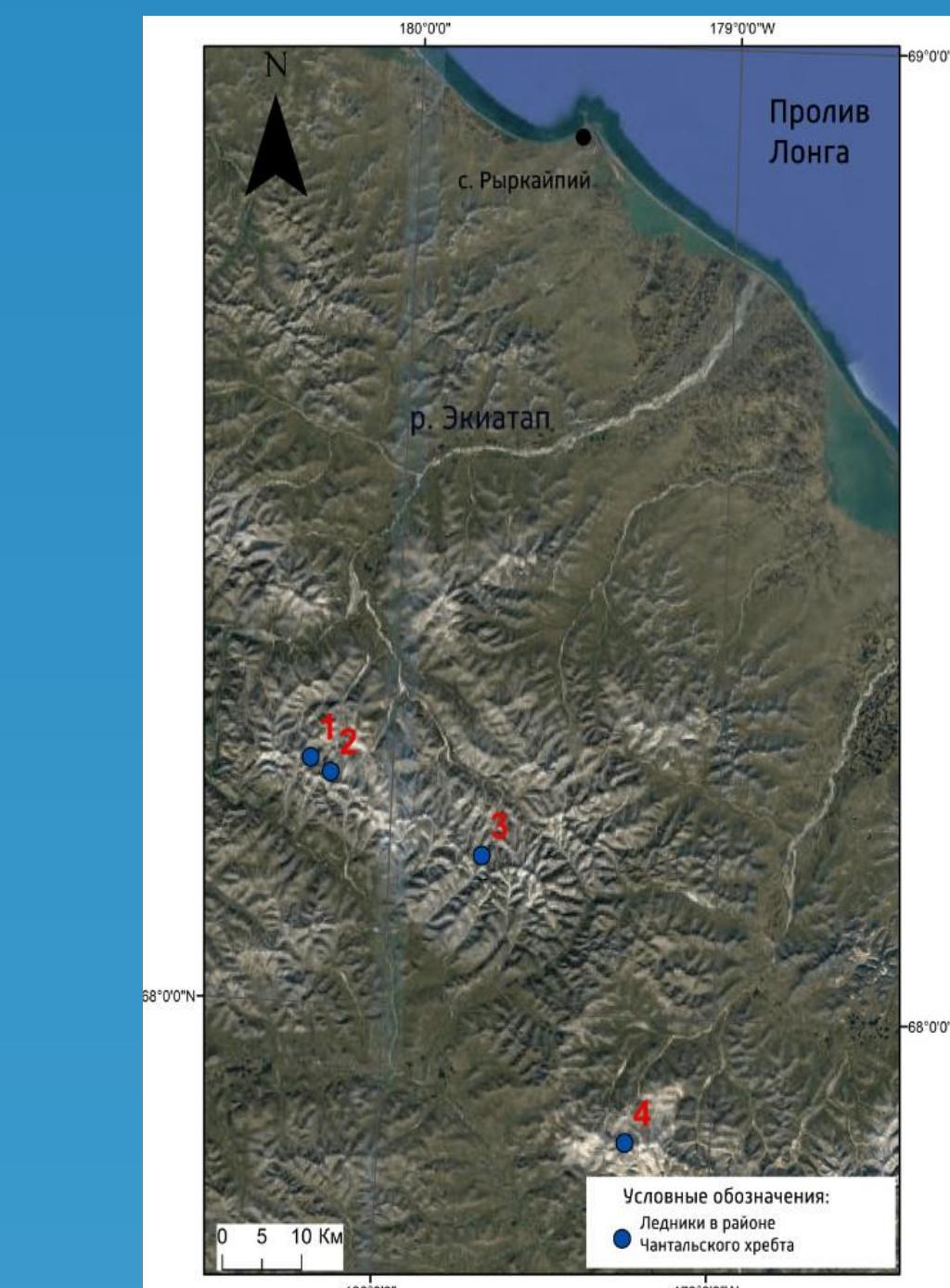
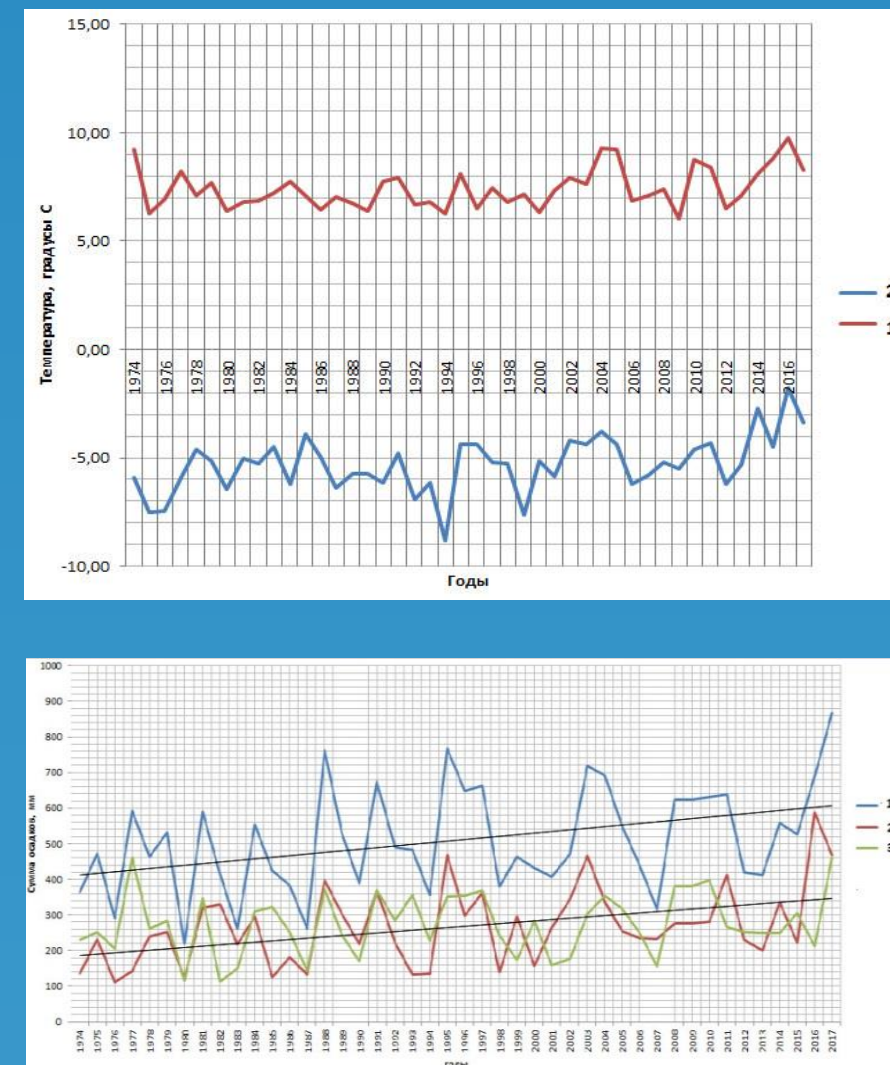
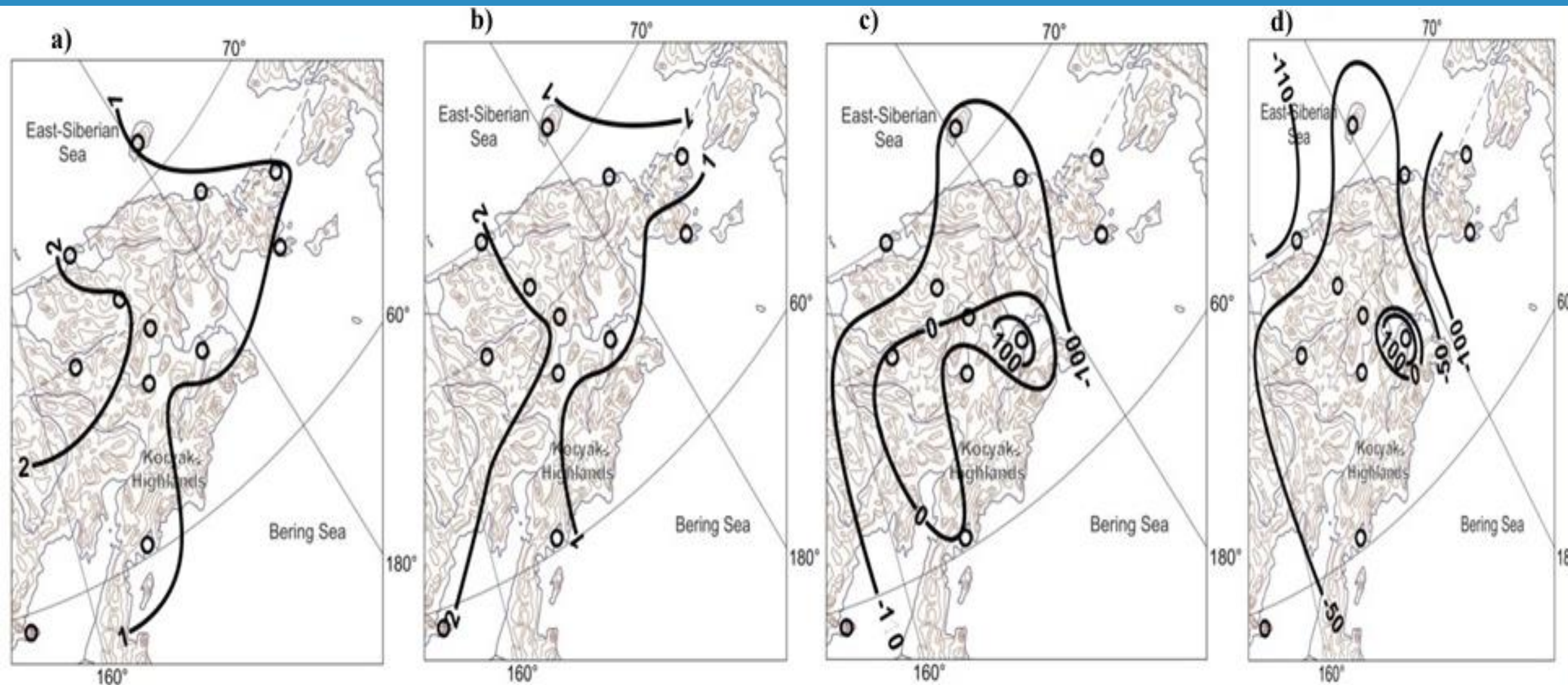
In the 5th group is 5 glaciers ranging in size from 0.1 to 0.5 km² - on the Chantalsky Range in the basin of the Amguema River with an average H_{ELA} 1400 m (Sedov, 1997).



Glaciers of the **Kolyma Highlands**, according to R.V. Sedov (1997) consist of two groups:

5 are - on the eastern slope of the **Kolyma Highlands** near the western coast of the Sea of Okhotsk, the H_{ELA} is 700 to 1500 m,

14 corrie glaciers are in the northern part of the Tygonos Peninsula, 61°35' and 61°50' N), H_{ELA} from 700 to 1000 m



Methods for the areas and volumes of the glaciers of Chukotka and Kolyma calculations

Temperature and precipitation, Evgiknot, chukotka

Temperature and precipitation, Taigonos, Kolyma

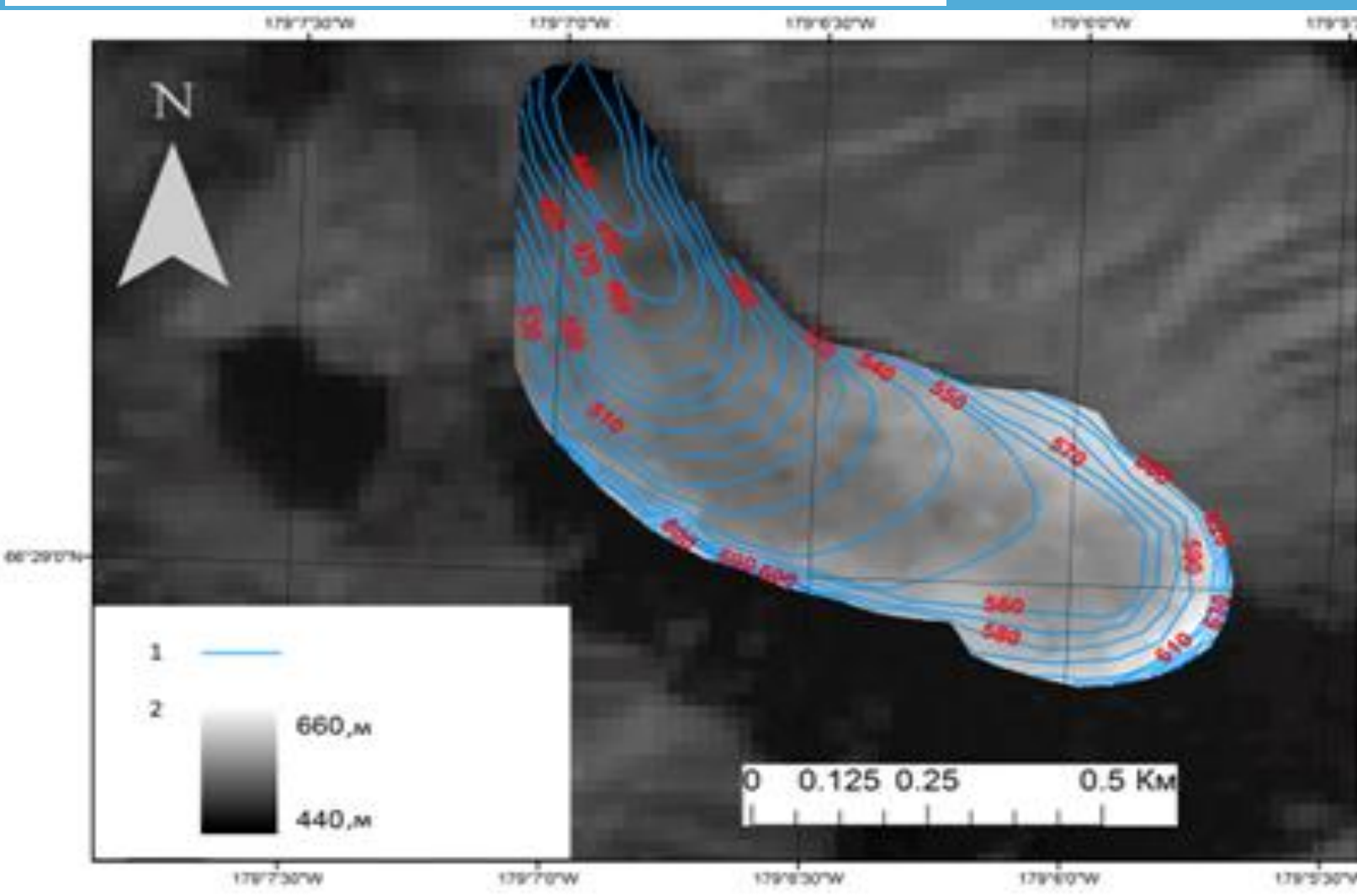
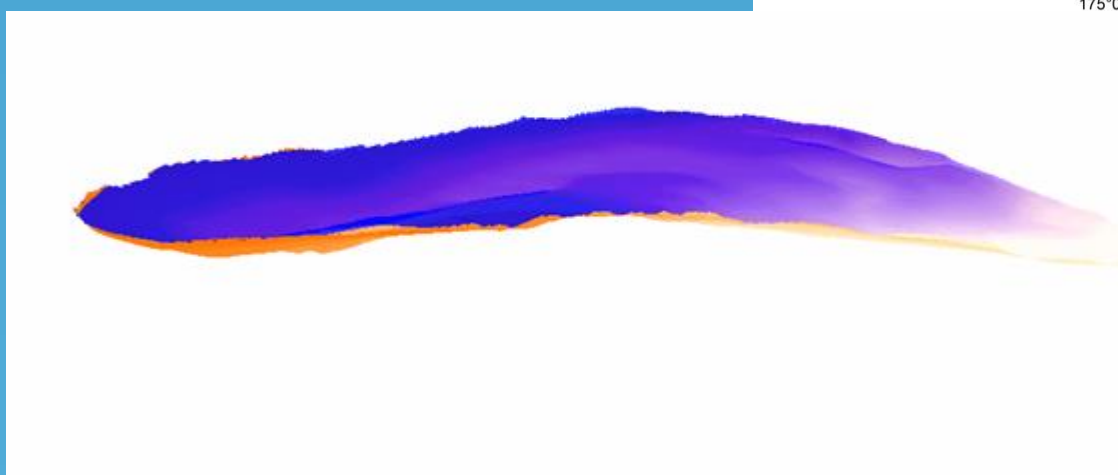
Field trip to the area of the Equikinot basin, the Cross Gulf, Chukotka in August 2018

A number of satellite images were used to analyze the glaciers of Chukotka and Kolyma, such as: CORONA (Resolution 5–10 meters), 1975, Landsat - 7 (Res. 15/30 m), 2005, Sentinel (Res. 10 m), 2017. Using ArcGIS software, the boundaries of small forms of glaciation were digitized and their areas were calculated for the respective periods of **1975, 2005, 2017**.

These data we compared with the areas indicated by R.V. Sedov, on the beginning of the 1980s, as well as among themselves in order to analyze the areas of glaciation change.

The mean area of the Chukotka and Kolyma glacial systems for different periods

The name of the glacial system	Data R.V. Sedov, early 1980s	Data of LandSat, 2005 1980-2005			Data of Sentinel-2, 2017 2005-2017		
	Average area, km2 (number of glaciers)	Average area by 2005, km2	Number of glaciers	Retreat, km2	Mean area by 2017, km2	Number of glaciers	Retreat, km2
Peculney Range	0.3 - (4)	0.21	4	0.09	0.17	4	0.04
The left bank of Amguema River	0.22- (5)	0.13	5	0.11	0.09	4*	0.02
Cross Gulf	0.41 - (21)	0.27	21	0.14	0.23	21	0.05
Providence Bay	0.16 - (14)	0.17	14	0.01	0.15	14	0.02
Lawrence Bay	0.1 - (3)	0.06	3	0.04	0.05	3	0.00
Kolyma (Takhtoyam sk)	0.34 - (5)	0.25	5	0.09	0.19	5	0.06
Kolyma (Chaybuha)	0.14 - (14)	0.10	14	0.04	0.08	14	0.01
Number of glaciers	66		66				



The formulas are as follows:

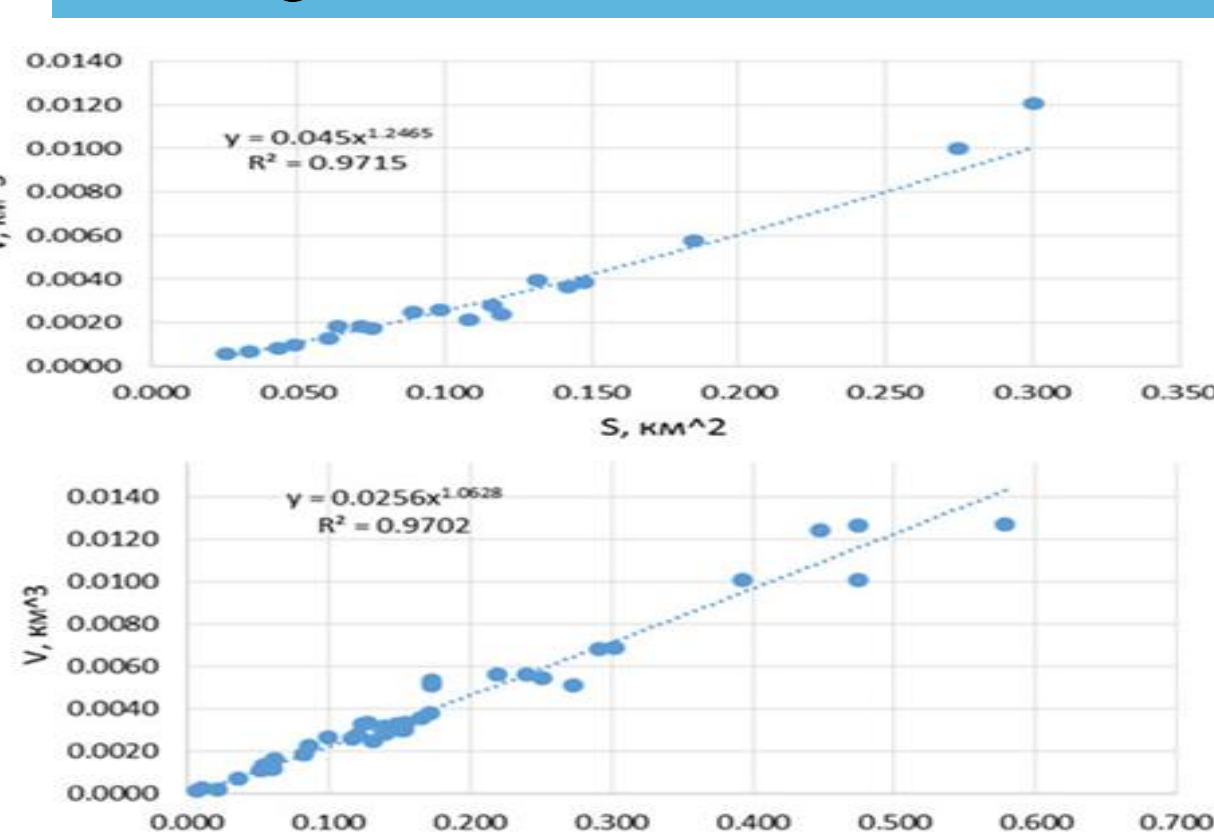
For Chukotka glaciers (corrie type):

$$V = 0.0263 * F^{1.0785}, \text{ correlation coefficient } r = 0.981$$

For Kolyma glaciers (Corrie type):

$$V = 0.045 * F^{1.2465}, \text{ correlation coefficient } r = 0.986$$

The 3D models have been built for them, in Agisoft and Sputnik software. These models were basis for calculation of the glacier volume. The problem was how to estimate the underground part of the glaciers. To solve this problem, a digital elevation model (DEM) - ArcticDEM was used; it served for the construction of isohypsum of the valleys, in which there are no small glacial relief forms. These valleys are characterized by southern, eastern, and western aspects. We made the assumption that in general the shape of the bottom of the neighboring valleys is the same as that of those with glaciers. The distribution of relief heights and slopes were calculated for these obtained valleys' topography shapes. For the upper zones the large slopes (from 1.25 to 2.0) are characteristic, in areas below the valley slopes - from 0.2 to 0.4. So, we used, by analogy, these isohypsum forms of subglacial topography under the studied open-air glaciers. Combining the edge points of elevations and taking into account the shape of the bottom, we constructed the bed isogypses of glaciers by ArcGIS. These calculations were carried out for each region studied.



	Mean V by the isolines of the bed, km ³	Mean V by the by S.A. Nikitin, km ³	Number of glaciers
Chukotkahighland S:			
Cross Gulf	0.0048	0.0049	20
Providence Bay	0.0040	0.0040	10
The left bank of Amguema River	0.0018	0.0020	4
Pekulney Range	0.0038	0.0039	4
KolymaHighlands:			
Chaibuha, Taigon os Peninsular	0.0020	0.0020	14
Tokhtoyamsk	0.0067	0.0068	5

Changes in the volume of glaciers by groups for different periods of time, calculation by Nikitin's formula for Altai

$$V = 0.0487 * F^{1.244}, (r = 0.91) \dots (1)$$

In terms of percentage, the differences for individual glaciers and groups appeared to be in the range of 8.1–12.6%.

Changes in the volume of glaciers by groups for different periods of time

Years	Mean volume up to 1980	Onset of 1980s-2005	Mean volume up to 2005	Onset of 1980x - 2005	Средний объем к 2017 году	2005-2017
Glacier system	V, км3	Reduction, км3/ye ar	V, км3	Reduction, %	V, км3	Reduction, км3/ye ar
Chukotka:	-	0.004	0.005		0.004	0.004
Pekulney Range	-	1.7-04		43.9		3.3-04
The left bank of Amguema River	0.005	0.005	0.003		0.002	0.002
		2.2-03		67.7		1.6-04
Cross Gulf	-	0.020	0.007		0.006	0.004
	-	8.7-04		75.5		3.3-04
Providence Bay	0.005	0.0038	0.004		0.004	0.0036
		1.7-04		11.3		3.0-04
Lawrence Bay	0.002	0.0023	0.001		0.001	0.0013
		1.0-04		46.0		1.1-04
Kolyma Highlands (Tokhtoyam sk)	-	0.012	0.008		0.007	0.007
	-	4.2-04		43.5		5.8-04
Kolyma Highlands (Chaibuha)	0.009	0.003	0.003		0.002	0.002
				38.6		

