Glaciers of the Koryak Highlands: assessment of the state by satellite images and field studies

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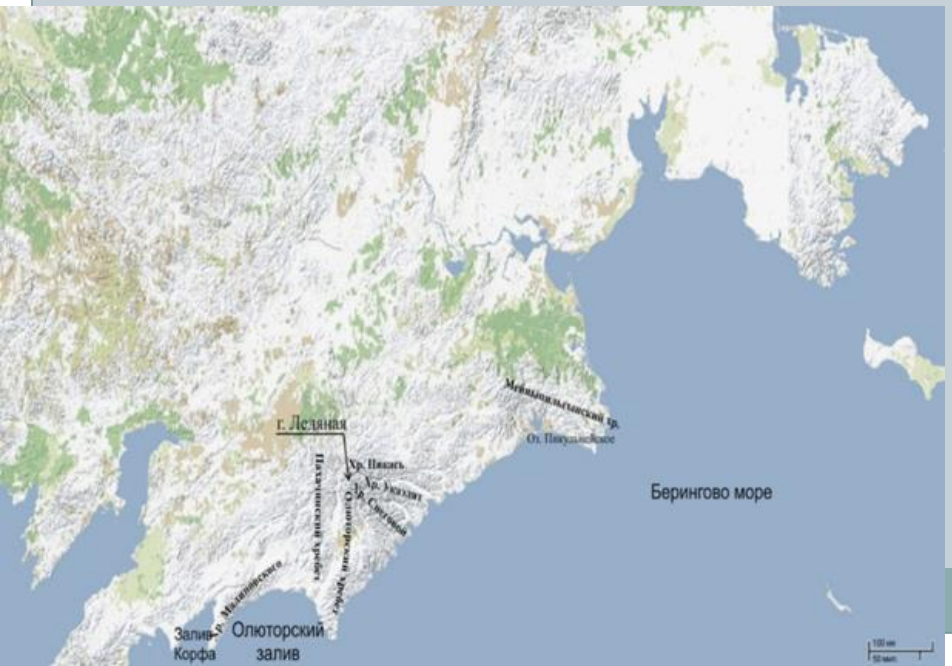
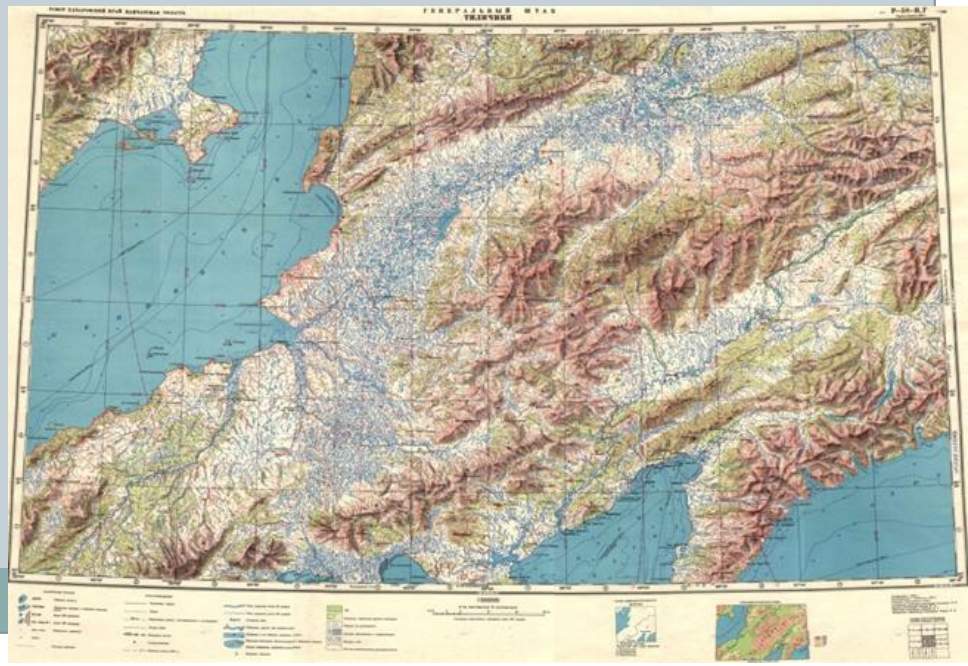
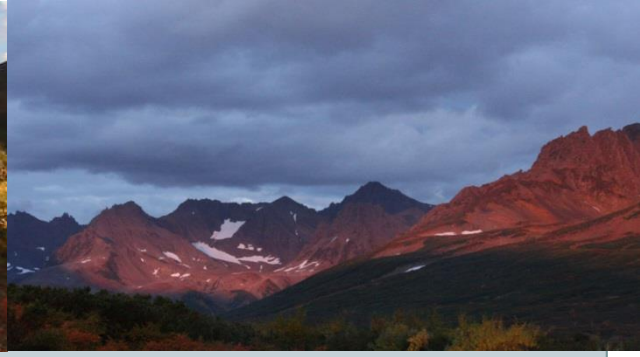
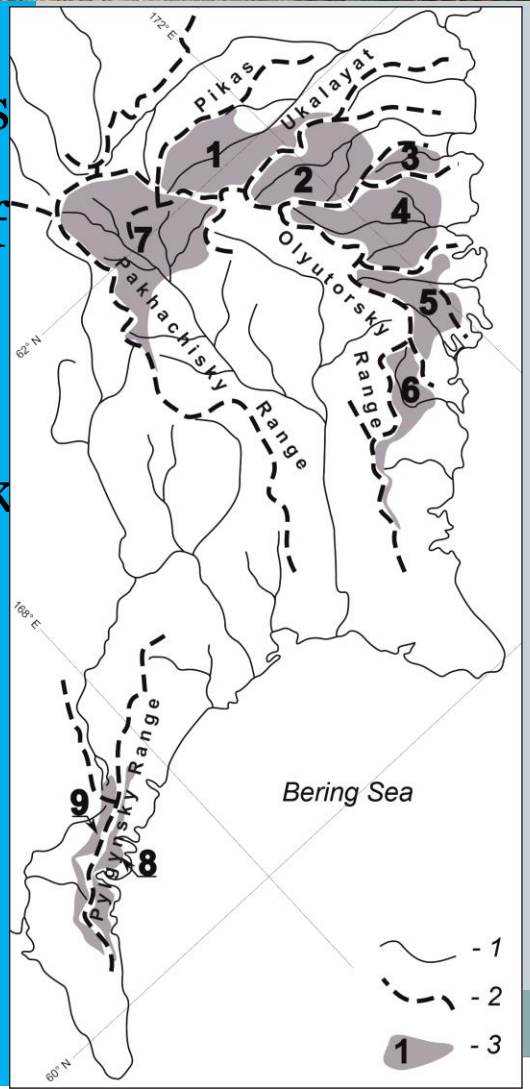








- The Koryak Highlands is a poorly explored area from the point of view of glaciation and its connection to climate.
- The purpose of this work was using high-resolution Sentinel-2 images (2019), to assess the state of glaciers at this time against the background of climatic trends affecting glacier changes



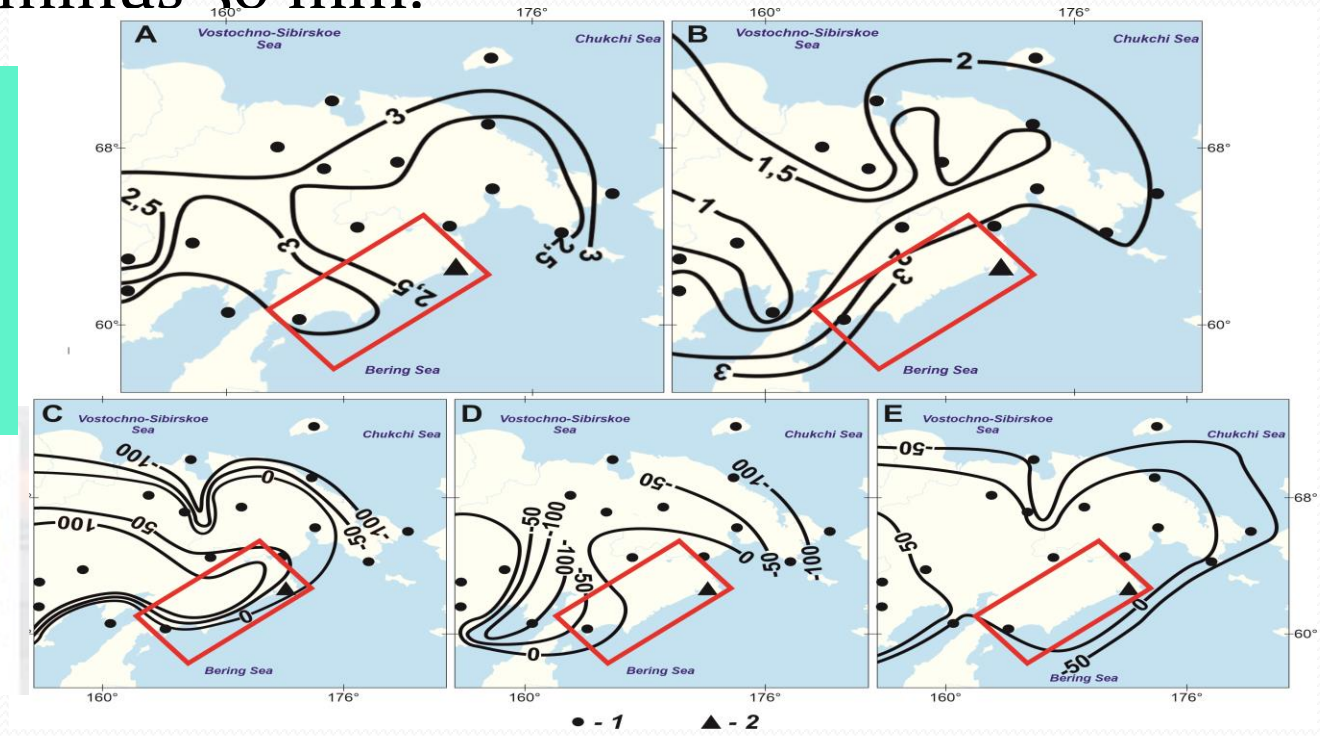
Schematic map of the Koryak Highlands: 1- rivers, 2- watersheds, 3- glacier areas

The numbers (3) indicate glacier regions within river basins: 1 – between Pikas-Ukalayat ranges, 2 – between Ukalayat-Snegovoy ranges 3 – Ilpi-Imolkanavayam, 4 - Vatyna, 5 - Anivayam - Machevna Bay, 6 - Machevna -Apuka, 7- Apukavayam, 8 - Pylgovayam - Olyutorsky Bay, 9 - Korf Bay

About tendencies of climate in the study region

- Spatial patterns of trends in mean summer T_{sum} and annual temperatures T_{year}, total precipitation P_{tot} and precipitation for the cold period P_{cp} from 1966 to 2019 were compiled: the values of T_{year} trends increase towards the Kamchatka Peninsula, T_{sum} trends change from 2 to 3°C, and P_{tot} trends - from the continent to the coastal zone, the P_{cp} trends change from 0 to minus 50 mm.

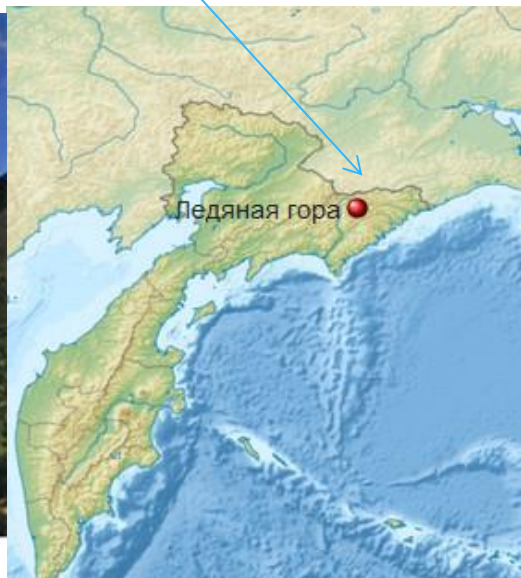
The **T** and **P** trends (linear) were determined by the regression equations for accepted error intervals of ± 0.1°C for T and ± 5 mm for P



Orography of the region of study

- **The length of the Highlands** from northwest to southeast is about 800 km, width is from **80 to 250 km**.
- **The elevation of the ridges**, as a rule, does not exceed 1500–1800 m, increasing from the outskirts to the center of the Highlands.
- The elevations of the mountains generally decrease from north to south. In the central part there is **Ledyanaya Mountain** (**2562 m**), the highest point of the Highland. Several ridges branch off it- Pikas, Ukalayat, Snegovoy. The main center of glaciation is located here.

Горы Ледяная (слева) и Зуб (справа) из долины Левого Яелваяма

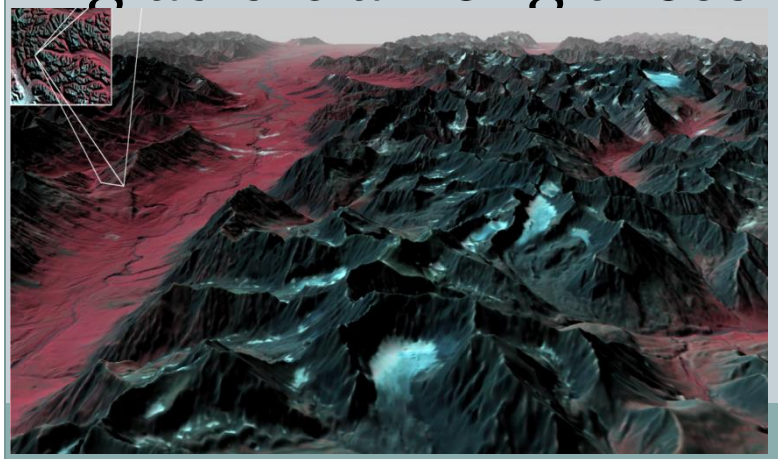


Glaciers of the Koryak Highlands - view from space, work with satellite images (Sentinel-2)

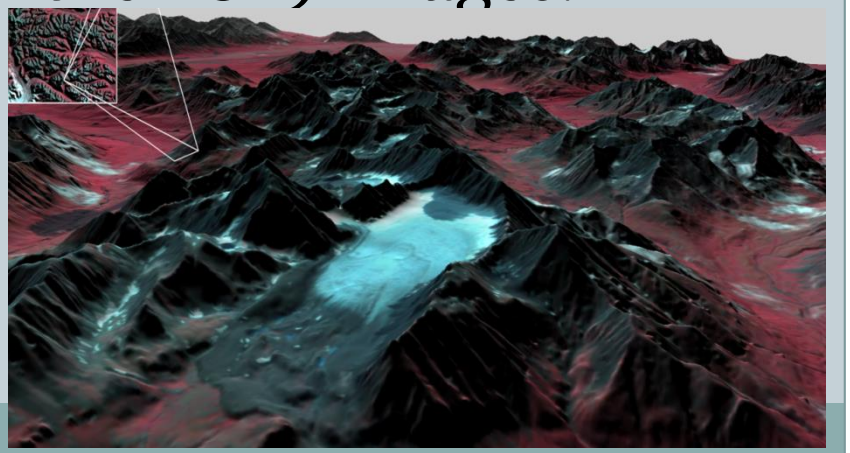
Glaciers of Ukelayat and Snegovoy ranges

The glaciers of the Koryak Highlands

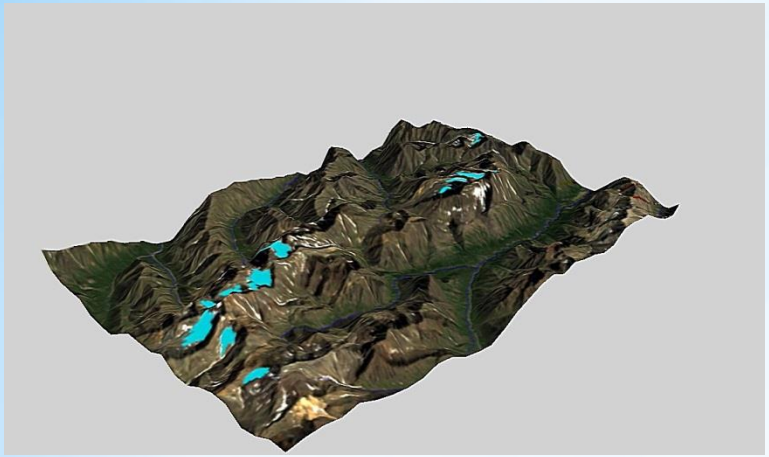
- which are located in the northeast of the Asian part of Russia, on the Bering Sea coast between Anadyr Bay and the Kamchatka Peninsula, are now preserved in the bottoms of cars and troughs.
- Areas of the most of the Koryak glaciers are from 0.3 to 0.5 km². If we assume that small glaciers are those with an area of 0.1 km² or less, then there are 84 glaciers among those found in the 2019 images.

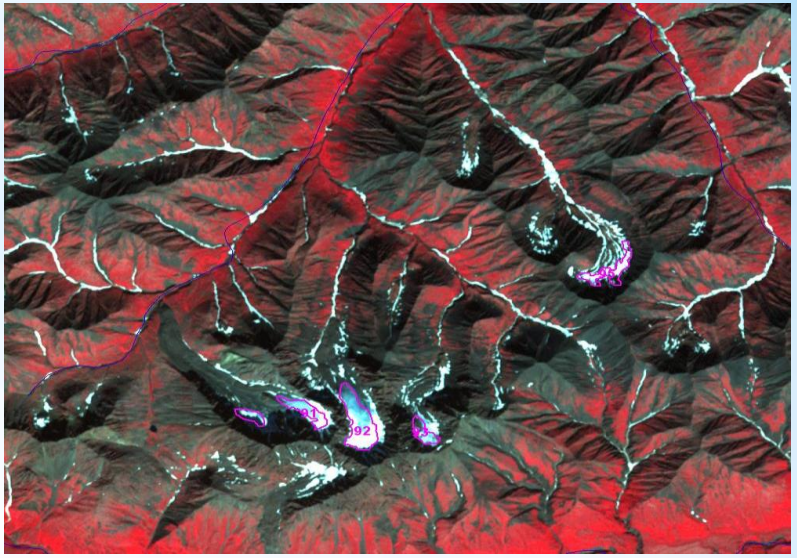


Glacier 558 by the Ussr Glacier Inventory



Snegovoy Glacier



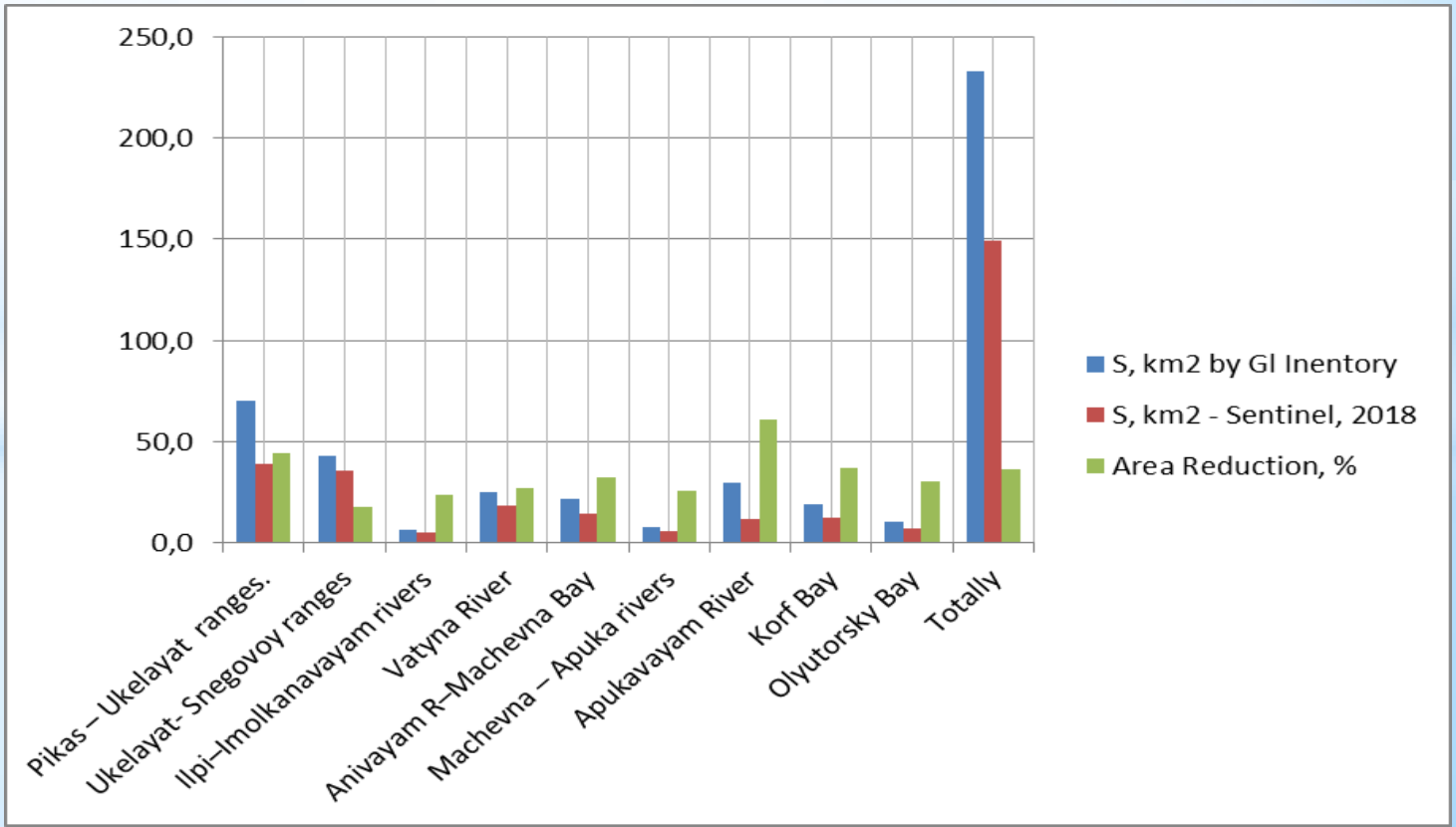


* In (Ananicheva, 2003), for the first time since the 1950s, the areas and the number of existing glaciers of the Koryak Highlands were determined by the Landsat and ASTER images).
* **The following results were obtained:**
* **Number of glaciers - 237**
* **Glacier area according to the Inventory (1950-AFS), km^2 - 176.6**
* **Glacier area according to images in 2003, km^2 - 54.4**

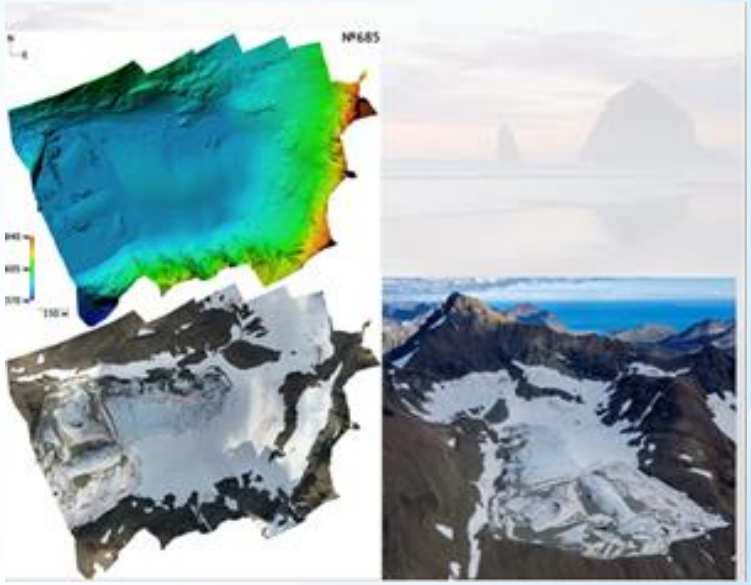
Data / Methods of this work

* Based on Sentinel-2 images from 2018 and 2019 the glaciers of the Koryak Highland located by a large group of its northern part and by a smaller group of the southern part were analyzed
* Sentinel-2A/2B images were used to decipher the glaciers. Sentinel-2 data is provided by the ESA (https://scihub.copernicus.eu).
* At the beginning of the work, the Sentinel-2 images of 2018, which were available at that time, were deciphered to obtain glacier area, ELA (or firn line).
* In 2019, the situation happened to be better for capturing this region due to the weather conditions and the absence of early autumn snowfall. The presence of a highly detailed substrate has become a key factor in determining the size of small glaciers, less than 0.1 km^2.
* The equilibrium line altitude (ELA,) were calculated using the simplified Kurovsky method for all glaciers. The estimates for this parameter are determined with an error of 5 to 15%.

* When analyzing space images of Sentinel-2 **in 2018**, three groups of objects were identified: glaciers with open ice (type 3),
* glaciers covered with a debris cover (type 2), and possibly objects related to rock glaciers (type 1).
* Due to the large extent of the glaciers' coverage by the debris cover, there was uncertainty regarding the accuracy of interpreting their sizes; therefore, the glacier area and their confidence interval were determined.



* The snow line values from aerial photographs of glaciers taken from the UAV during the expedition in Sept 2020 showed a small difference between it and the ELA calculated by the Kurovsky method, it does not exceed 3%.

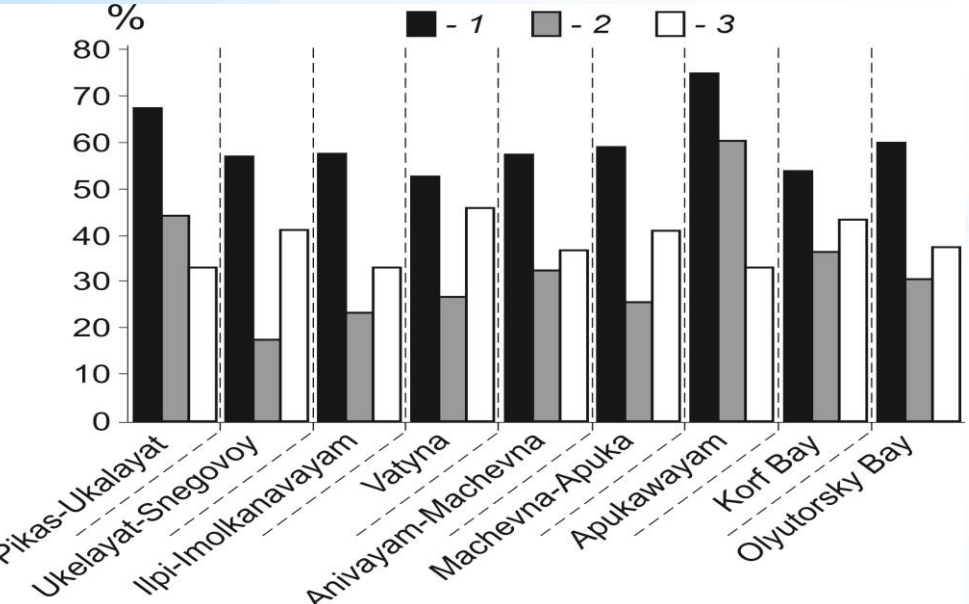


The images can also decipher the snow line at the end of the ablation period, therefore, to check the applicability of this method, we also measured the snow line altitude at this time for the 50 largest glaciers (areas from 3.36 to 0, 29 km^2) and for them it was calculated using the Kurovsky method.

The mean relative difference between these values - 2.0 ± 0.2
However, under the conditions of the ontemporary glaciation of the Koryak Highlands, this value is close to the firn line of glaciers.

Results / Discussion

* In 2019 we were able to obtain more accurate estimates (thanks to the Sentinel-2, 2019 images and the highly detailed substrate), which differ from the results of the 2018 survey.
* For basins, such as the area between the Ukalayat and Snegovoy ridges, the basins of the Ilpi, Vatyna rivers, and Apukawayam River, the difference between the relative area reduction of glaciers in comparison with the Inventory, the data for the 2018 Sentinel-2 images and those for the 2019 images is significant (Fig. 3, columns 2 and 3).
* The reduction in the area of these glaciers D_{led} (in%), in comparison with the Inventory estimates, was for different basins from 35 to 74%



These basins are characterized by the largest number of glacial objects covered with debris material with hard-to-define contours, and small glaciers (<0.1 km^2) are more widespread in these areas.

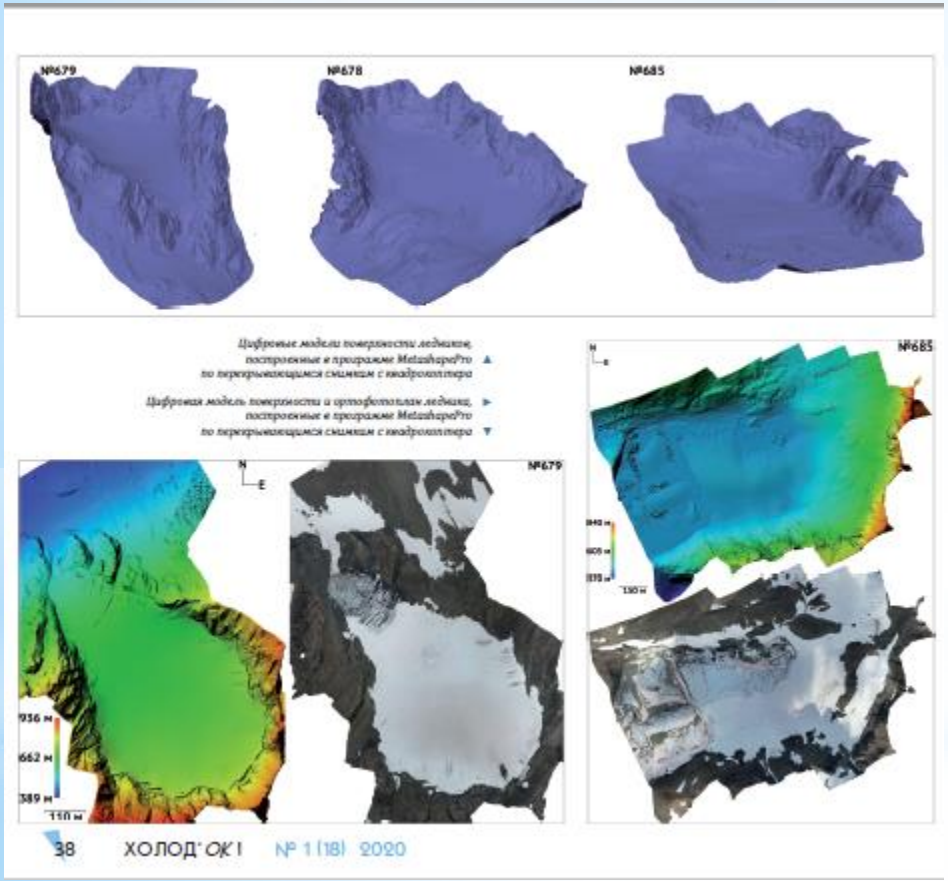
* The Inventory of glaciers on the Koryak Highlands was compiled according to topographic maps and aerial photography, the number of glaciers in it is almost 2.5 times more than was found in the satellite images.
* Apparently, many rock glaciers were mistaken for living glaciers.

1 - areas of distribution of active and dead rock glaciers, predominantly of the slope, less often of the crimson type; 2 - areas of modern glaciation according to the data of previous researchers; 3 - the main watershed and border between the Arctic and Pacific glaciological regions; 4 - areas of discovery and field study of stone glaciers (Galanin, 2005)

We tried to make the possible reassessment of glacier areas in the glacier Inventory for this region, based on the fact that its author - N.M. Svatkov, studied several glaciers around Ledyanaya Mountain in during field works .

Among the glaciers observed by him with a relatively large area (1.5-2.0 km^2), the retreat by 2019 amounted to 45 to 55%.
These estimates can be considered more realistic for glaciers of this size.

* We have compared ortho-photo plans of glaciers made from aerial photographs from UAVs during the expedition and satellite images for four glaciers: Nos. 678, 679, 680 and 685.
* **The difference in area is from 2 to 12%.**



During field research to the glaciers of the Pylginsky Range, Sept 2020, the southern part the Koryak Highlands, the following works were done:

- survey of 4 glaciers by a drone (UAV) and processing of spatial data by GIS.

- field identification of glaciers contours in the valley of the Ev'vayam River (over 30 km) and in the watershed part of the range;

- taking samples for OSL analysis on supposed moraines of the past stages of glaciation to determine their age and sampling for cosmogenic dating.

*The total glacier area of the study area is 49.59 km^2. The glaciation area by basin is given in table. 1, the mean glacier area is in Table 2.

Table 1 Aspect of the glaciers of the Koryak Highlands for 2019, in%, of the total number of glaciers in the group

Basins	Area of glaciers, km^2	Number of glaciers	Glacier aspect						
			N	NW	W	NE	E	S	SW
ikas – Ukelayat ranges.	11.40	34	29.4	23,6	2,9	29,4	11,8	2,9	0
kelayat- Snegovoy anges	10.30	36	30.6	22,2	11,1	30,6	5,6	0	0
pi-Imolkanavayam vers	1.10	8	25.0	75.0	0	0	0	0	0
atyna River	6.76	17	17.6	41.2	17.6	0	0	11.8	11.8
nivayam R-Machevna ay	4.74	34	20.5	41.2	16.7	5.9	2.9	2.9	5.9
Machevna – Apuka rivers	1.85	17	29.4	47.1	17.6	5.9	0	0	0
pukavayam River	3.76	25	20.0	12.0	32.0	8.0	0	8.0	20.0
orf Bay	6.32	27	33.3	22.3	25.9	7.4	0	0	11.1
lyutorsky Bay	3.36	14	14.3	35.8	21.4	0	0	5.9	28.6
otally	49 59	212							

*Table 2 Morphological type of glaciers in the Koryak Highlands for 2019, in%, of the total number of glaciers in the group

Basins	Number of glaciers	Mean glacier area, km²	Corrie	Corrie-valley	Valley	Twinned	Hanging
Pikas - Ukelayat ranges.	34	0.33	28.6	18.8	**56.3***	0	0
Ukelayat-Snegovoy ranges	36	0.29	25.0	18.6	**56.3**	0	0
Ilpi-Imolkanavayam rivers	8	0.14	**75.0**	25.0	0	0	0
Vatyna River	17	0.4	**70.6**	5.9	17.6	0	5.9
Anivayam R-Machevna Bay	34	0.14	**91.2**	8.8	0	0	0
Machevna - Apuka rivers	17	0.11	**94.1**	5.9	0	0	0
р.Апукаваям	25	0.15	**72.0**	20.0	4.0	4.0	0
Korf Bay	27	0.23	**48.2**	33.3	0	0	18.5
Olyutorsky Bay	14	0.24	**64.3**	7.1	7.1	14.4	7.1

* In the northern part of the Highlands, between the Pikas and Ukealat ranges, valley glaciers of the N aspects are preserved and prevail,
* to the S, between the Ukelayat and Snegovoy ranges, most of the glaciers are of the corrie-valley type.
* Further to the S, the cirque glaciers prevail of the NW aspect and in the valley of the Apukawayam River, there are corrie glaciers, confined to the slopes of the W aspect.
* Korf Bay - the glaciers of the W and NE aspect are equally divided, the Olyutorsky Bay is more confined to the NW aspect.
* This alternation correlates well with an increase in heat input, the presence of relief host forms, and the height of ridges that decrease from N to S.

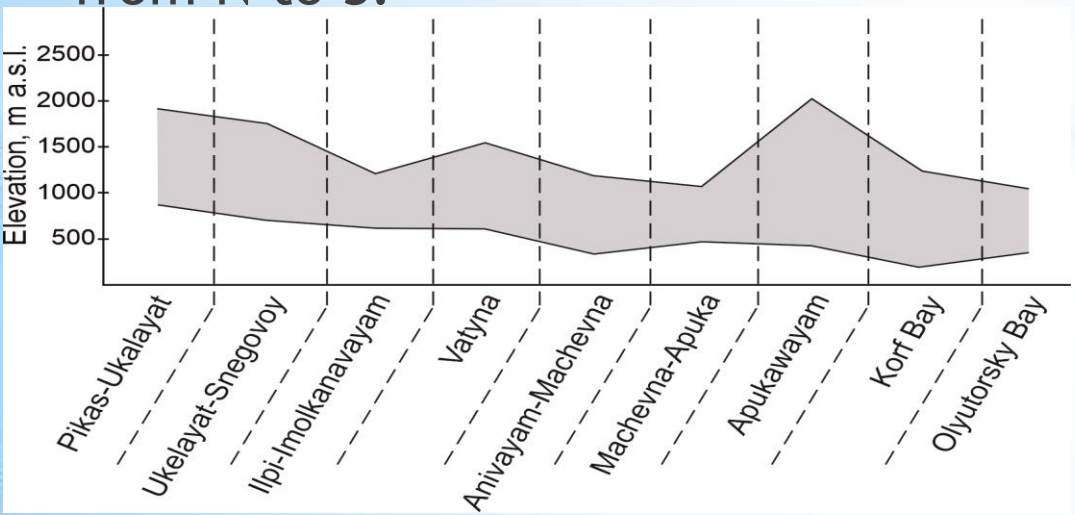


FIG The range of relief elevations (from the minimum to the maximum elevation point)

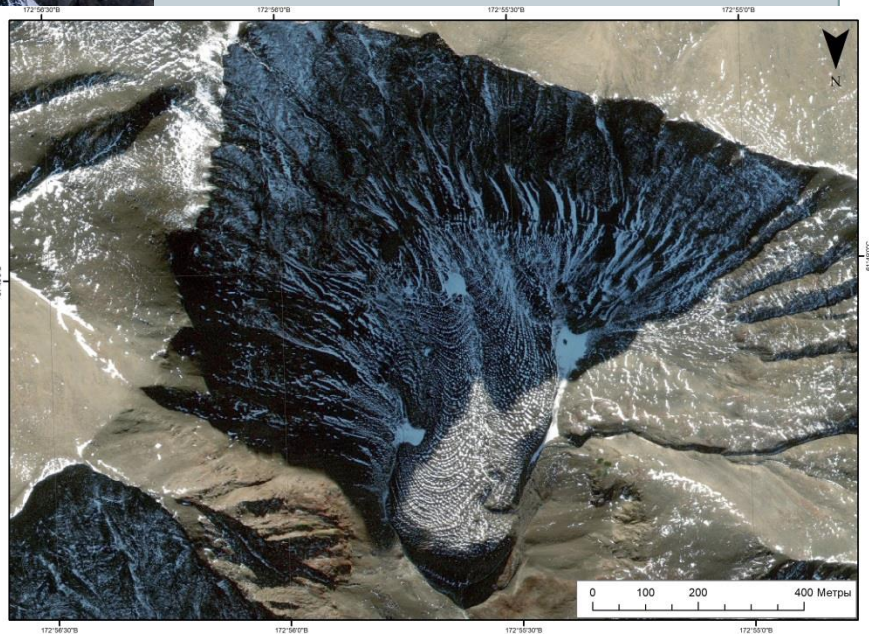
*The rise of the firn line to date for various highland basins is **400-500 m**, the heights of the ends of the glaciers approximately doubled.*

Conclusions

- The areas of the glaciers of the Koryak Highlands, their characteristic altitude parameters were determined by Sentinel-2 images of 2018 and 2019; data for these years were compared with those indicated in the USSR Glacier Inventory. I
- In the Koryak Highlands **there are now 212 glaciers with a total area of 49.6 km²**, these are mainly the corrie glaciers of the Northern aspects. In the basins adjacent to Ledyanaya Mountain, valley glaciers prevail (53% in the group), the rest are dominated by corrie glaciers. For the basins identified in the Glacier Inventory for this region, a relative reduction in the glaciers area was obtained (from 35 to 74%).
- These data require verification against other data.
- The firn line altitudes were determined, which were compared with the Glacier Inventory. Changes in this parameter of individual glaciers varied from several **tens of meters to maximum values of 400-500 m, the heights of the glaciers tongues are approximately twice more.**
- During an expedition in 2020 to the valley of the Evayam River four glaciers were studied using UAVs, the presence of moraines of the Holocene and Pletocene was fixed.

Thank you for reading and attention!

**Glacier 679,
photo from drone**



The rock glacier , photo from Sentinel-2