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Mapping cryogenic processes and assessing the sustainability of permafrost landscapes in the North-East Arctic Siberian taiga and tundra from Landsat 8, Sentinel 2, and DEM data

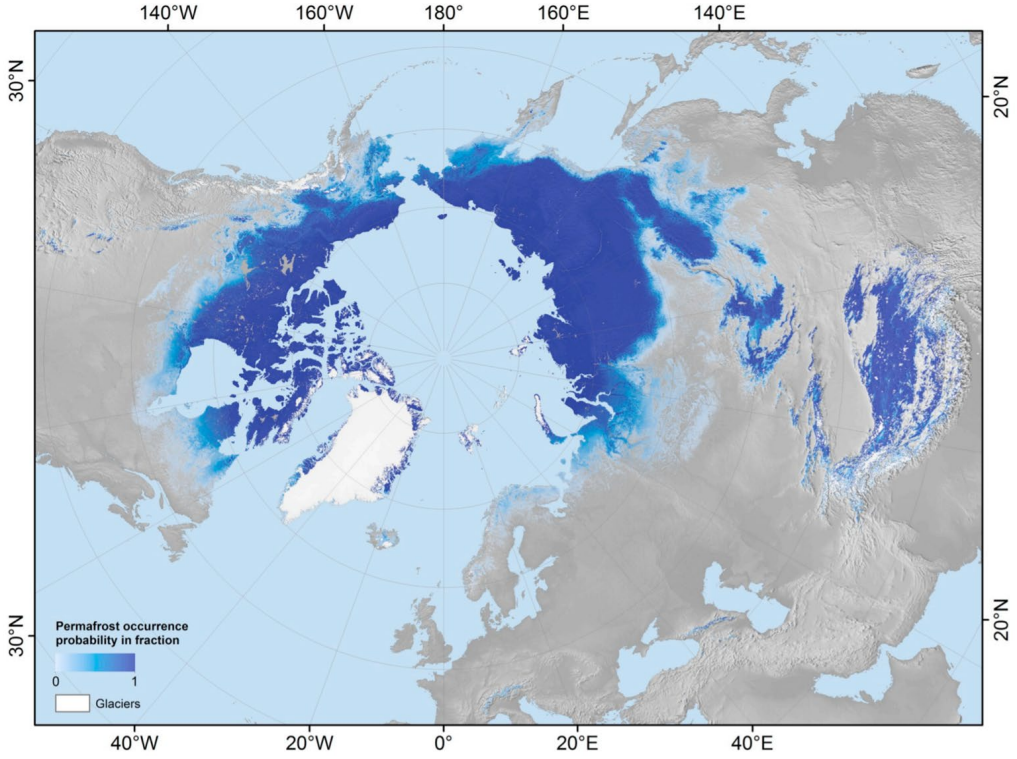
Sébastien Gadal, Moisei Zakharov, Jūratė Kamičaitytė

Introduction

Permafrost landscapes are one of the most vulnerable ecosystems in which humans live.

The **cryolithogenic and biophysical conditions** are among the most important variables for classifying ecosystem vulnerability.

These variables point to **cryogenic processes** that can be activated during permafrost degradation.



Permafrost Extent (J. Obu, et al, 2019)

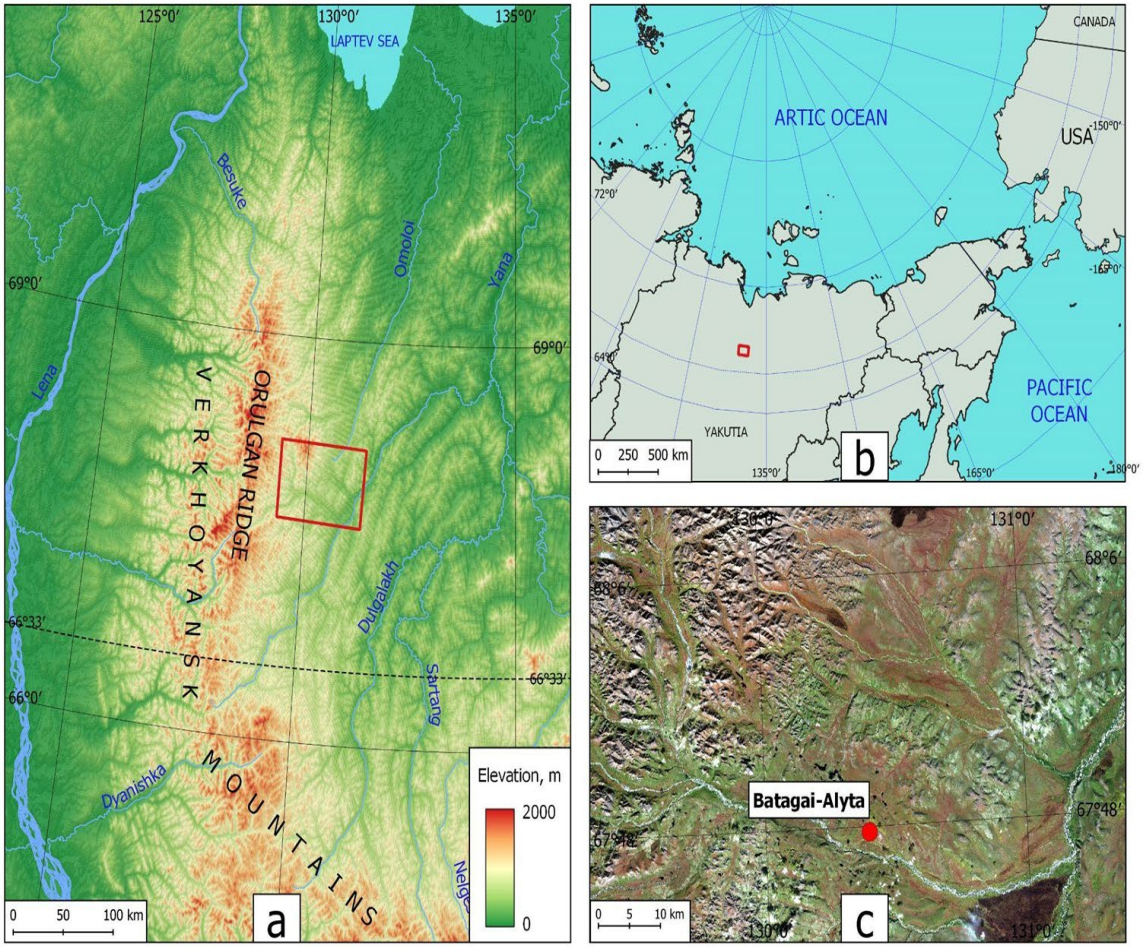
Permafrost landscape and cryogenic processes

Thaws and thermal denudation of glacial deposits
(aerial photo: S. Gadal and M. Zakharov 2017)

Thermokarst, frost cracking and ice wedge collapse
(photo: M. Zakharov 2018)

The parameters of permafrost landscapes (**ice content** and **active thawing layer**) determine the potential for activation of cryogenic processes, which most often occur as a result of wood cutting, agriculture, and forest fires.

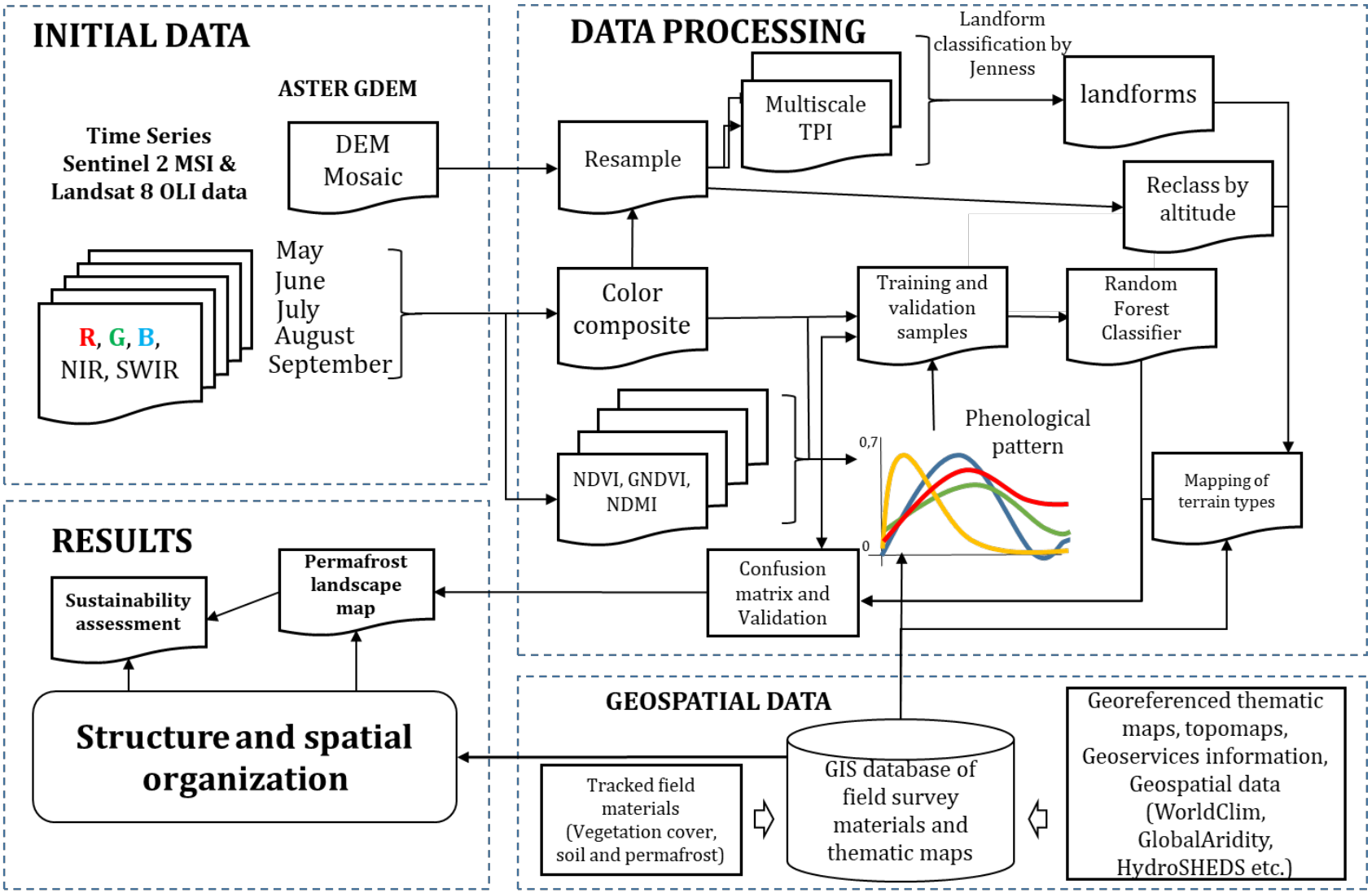
Study area and Objectives



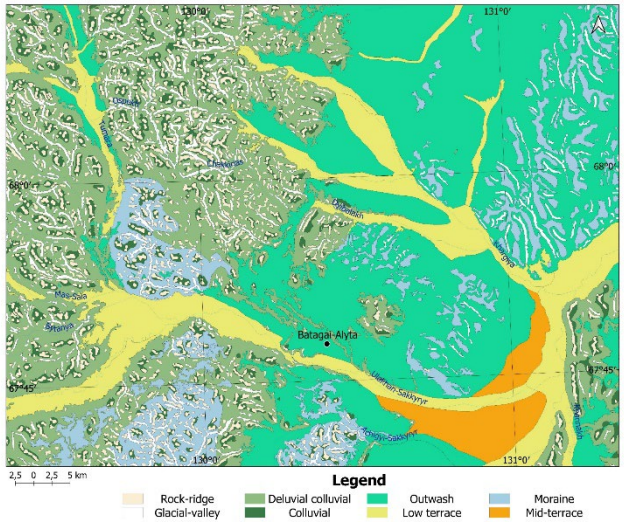
(a) Physical map of Orulgan Ridge; (b) Localisation of study area; (c) Study area RGB of Sentinel 2 july 2019

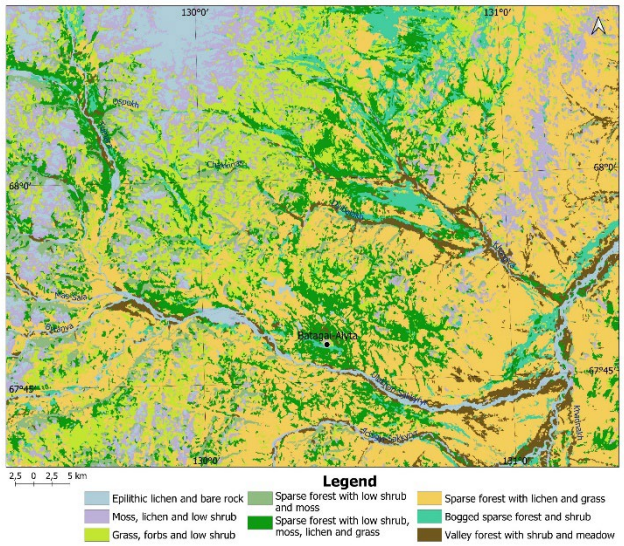
The **aim of this study** is to assess the sustainability of mountain permafrost landscapes of various types (stony mountain deserts, tundras, sparse mountain forests and northern taiga in valleys) based on data from Sentinel 2 MSI, Landsat 8 OLI/TIRS and, ASTER GDEM.

Methods & Materials



Modeling and mapping of permafrost landscape





TPI-based landform classification and terrain types

Terrian type	Landscape class: Mountain desert	Mountain tundra		Mountain woodland				Intrazonal
	Land cover classes (geobotanic unit): Epilithic lichen and bare rock	Moss, lichen and low shrub	Grass, forbs and low shrub	Sparse forest with lichen and grass	Sparse forest with low shrub, moss, lichen and grass	Sparse forest with low shrub and moss	Bogged sparse forest and shrub	Valley forest with shrub and meadow
Rock-ridge	1 -11...-13 / 0,5–1,0	3 -8...-11 / 0,7–2,0						
Glacial-valley		16 -2...-5 / 0,6–1,4					17 -2...-5 / 0,8–1,4	
Colluvial	2 -11...-13 / 1,0–1,5		4 -8...-11 / 0,7–2,0			10 -2...-6 / 2,0-3,0		
Deluvial colluvial			5 -8...-11 / 0,5–1,5	7 -2...-6 / 1,5–2,5	8 -2...-6 / 1,5–2,5	9 -2...-6 / 2,0-3,0		
Outwash				12 -4...-8 / 0,8–1,4	11 -4...-8 / 0,8–1,4		13 -4...-8 / 0,8–1,4	
Moraine			6 -8...-11 / 0,7–2,0	14 -0,5...-1,5 / 1,5–2,5		15 -4...-8 / 0,8–1,4		
Mid-terrace				18 -3...-5 / 0,8-1,2		19 -3...-5 / 0,8-1,2		
Low terrace					20 -2...-6 / 0,7-1,2		21 -1...-4 / 0,7–1,2	22 -2...-6 / 0,7–1,2

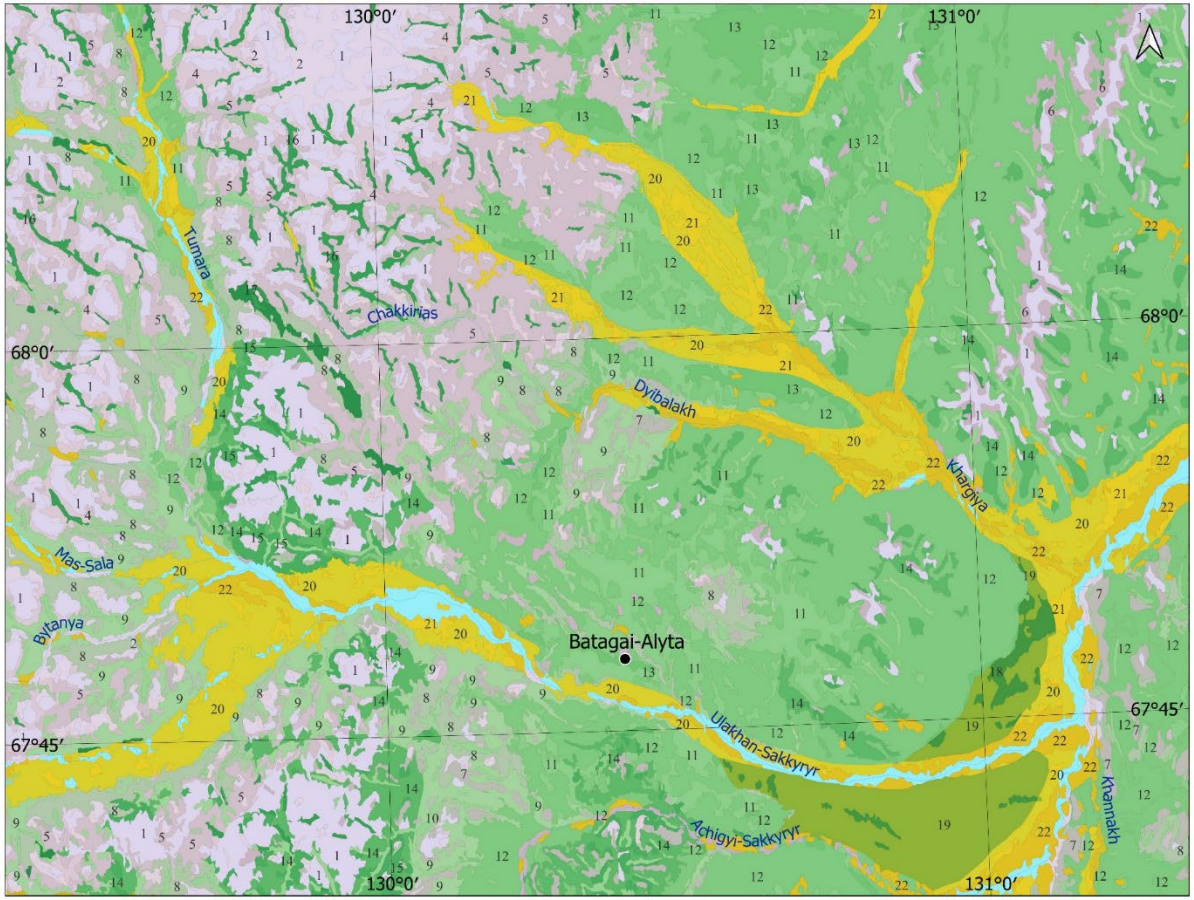
Permafrost landscape type

Ground temperature, °C

Active layer thickness, m

Land cover classification by Random Forest

Modeling and mapping of permafrost landscape



Permafrost landscape types map (Zakharov et al., 2022)

Terrian type	Landscape class							
	Mountain desert	Mountain tundra		Mountain woodland				Intrazonal
	Land cover classes (geobotanic unit)							
	Epilithic lichen and bare rock	Moss, lichen and low shrub	Grass, forbs and low shrub	Sparse forest with lichen and grass	Sparse forest with low shrub, moss, lichen and grass	Sparse forest with low shrub and moss	Bogged sparse forest and shrub	Valley forest with shrub and meadow
Rock-ridge	1	3						
Glacial-valley		16					17	
Colluvial	2		4			10		
Deluvial colluvial			5	7	8	9		
Outwash				12	11		13	
Moraine			6	14		15		
Mid-terrace				18		19		
Low terrace					20		21	22

Sustainability assessment

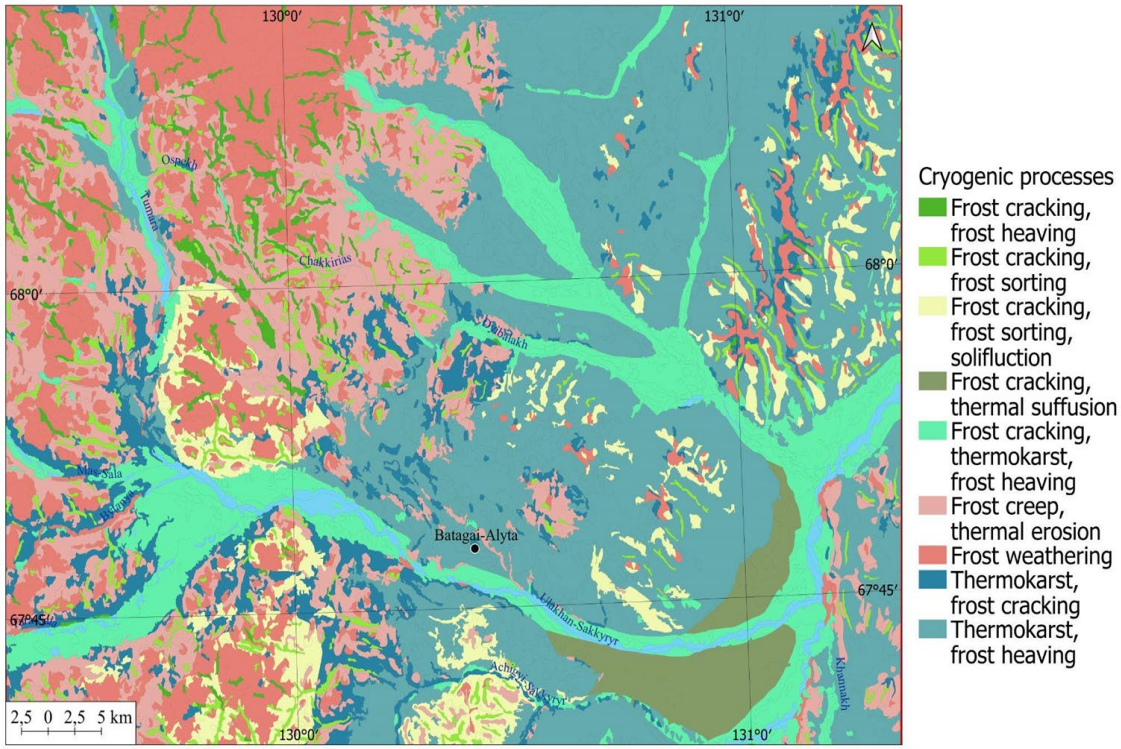
Mountain desert	Tundra	Sparse mountain forest	Mountain valleys	Boreal forest valleys
1. High sustainability, low ecological potential, low ice content				
1. Rocky peaks with epilitic-lichen; 2. Steep colluvial slopes with epilitic-lichen	3. Flat peaks and high colluvial-eluvial slopes with lichen tundra; 4. Steep colluvial slopes with dwarf shrub-lichen-moss tundra		16. Glacial-accumulative glacial mountain valleys with tundra meadows and participation of dryad-moss-lichen tundra	
2. Low sustainability, low ecological potential, high ice content				
			17. Glacial-accumulative and alluvial mountain valleys with bogs and marshy meadows	
3. Moderately sustainability, ecological potential is average, ice content is average				
		7. Gentle deluvial-colluvial slopes with larch moss-lichen; 8. Gentle deluvial-colluvial slopes with larch shrub-moss and moss with yernik; 12. Gentle outwash terraces with larch lichen and moss-lichen; 14. Gentle and medium-steep moraine slopes with larch lichen and moss-lichen;		18. Medium-altitude erosion-accumulative terraces with larch lichen woodlands and participation of meadows
4. High sustainability, high ecological potential, low ice content				
	5. Gentle deluvial-colluvial slopes with forb-dryad tundra in combination with dwarf shrub-moss-lichen mountain tundra with yernik	9. Medium-steep deluvial-colluvial slopes with larch dwarf shrub-moss; 10. Steep colluvial slopes with larch dwarf shrub-lichen; 11. Gentle outwash terraces with larch shrub- moss-lichen and moss with yernik		21. Low accumulative alluvial terraces with marshy meadows and yernik; 22. Low accumulative alluvial terraces with a complex of alder-willow communities, larch and poplar
5. Low sustainability, high ecological potential, high ice content				
	6. Gentle slopes and medium moraine slopes with mixed-grass-dryad mountain tundra with yernik	13. Gentle outwash fluvioglacial terraces with bogs and larch moss; 15. Gentle and medium-steep moraine slopes with larch dwarf shrub-moss-lichen		19. Medium-altitude erosive-accumulative terraces with marshy meadows and yernik

Landscape units are ranked according to the combination of ice content, ecological potential and cryogenic processes.

Mapping of cryogenic processes

Terrian type	Cryogenic processes
Rock-ridge	Frost weathering
Glacial-valley	Frost cracking, frost sorting
Colluvial	Frost cracking, thermokarst, frost heaving
Deluvial colluvial	Frost creep, thermal erosion
Outwash	Frost cracking, frost sorting, solifluction
Moraine	Thermokarst, frost cracking
Mid-terrace	Frost cracking, thermal suffusion
Low terrace	Thermokarst, frost heaving

Linking cryogenic processes to terrain types (Fedorov et al. 2018)



Map of the distribution of cryogenic processes

Conclusion

- Sustainability assessment requires the inventory of landscapes and a **detailed spatial structure.**
- The modeling the time series of multisensor remote sensing data.
- Based on the results of the assessment of permafrost parameters and ecological potential, we have identified **five groups of permafrost landscapes types** in terms of sustainability.
- The greatest danger is presented by landscapes with a **strong ice content.**
- The **methodological approach** is in demand in the design of road infrastructure in the permafrost zone and forecasting the dynamics of mountain permafrost landscapes in the context of climate change.

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Thank you for your attention

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