Risks of cryogenic landslide hazards and their impact on ecosystems in cold environments

Polina Lemenkova

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Lemenkova Polina

UNIVERSITY OF LAPLAND
LAPIN YLIOPISTO

Charles University in Prague, Faculty of Science, Institute for Environmental Studies
(Univerzita Karlova v Praze, Přírodovědecká fakulta) Benátská 2, 128 43 Praha 2, Czech Republic pauline.lemenkova@gmail.com

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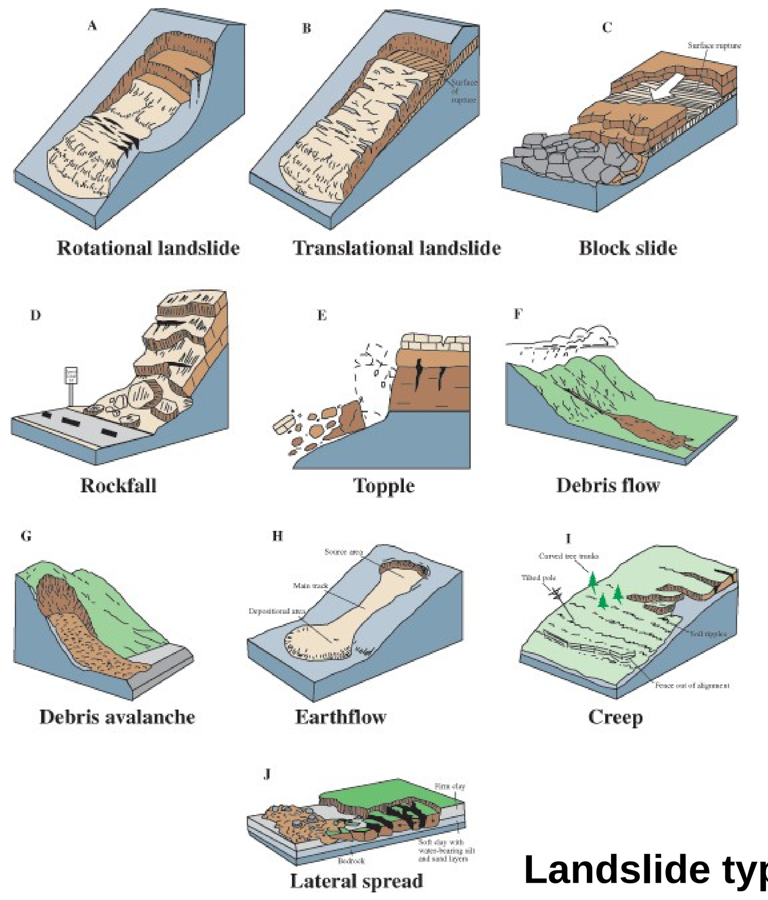
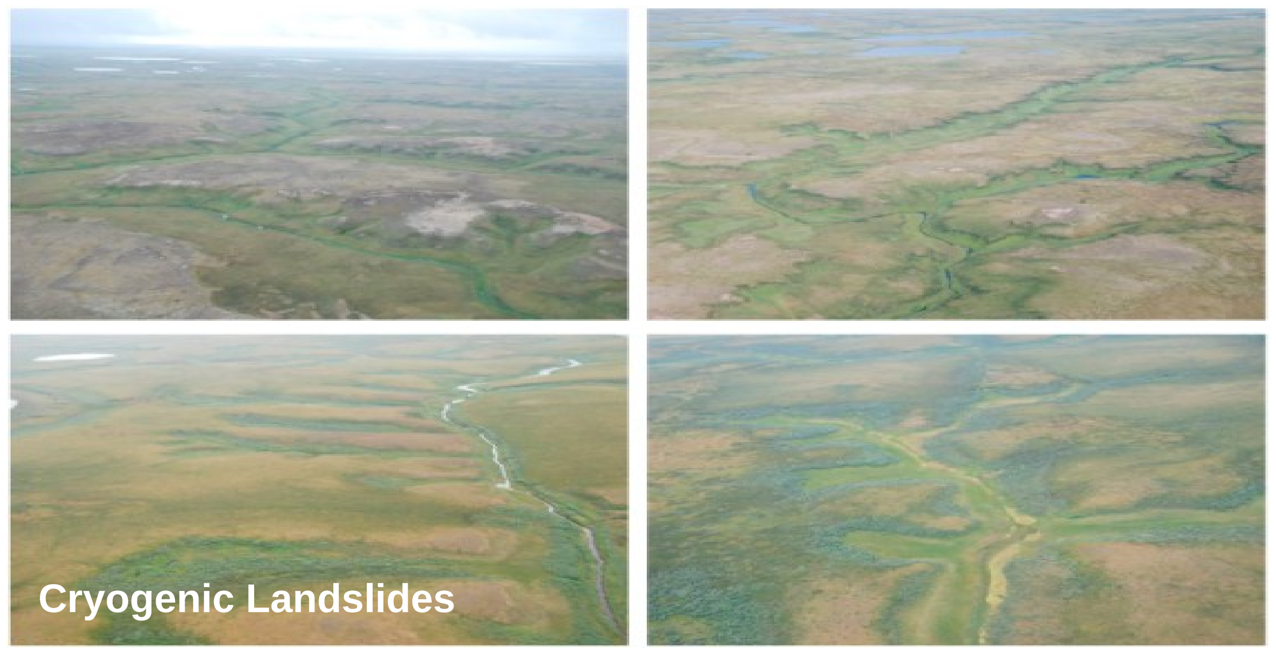
Abstract: The research focuses on monitoring landscapes downgrading in specific conditions of Arctic ecosystems with cold climate conditions (marshes, permafrost, high humidity and moisture). A specific case study of the current work is cryogenic landslides which are typical for cold environments with permafrost distribution. The research region is located in Yamal Peninsula, north Russia. This work analyses environmental consequences caused by the cryogenic landslides in northern landscapes and overall climate changes affecting sensitive Arctic ecosystems. The thaw of permafrost layer leads to the destruction of the ground soil layer and activates cryogenic landslide processes. After disaster, vegetation coverage needs a long time to recover, due to the sensitivity of the specific northern environment. As a result, land cover types change significantly within the landscapes of the regions affected by the disaster. The application of GIS software was used to analyze and process two satellite images (Landsat TM) taken at different time (1988 and 2011) in order to assess spatiotemporal changes in the land cover types of the Arctic landscapes. This work demonstrates how GIS spatial analysis can be applied to studies of the environmental disasters, as well as monitoring and mapping changes in the landscapes patterns caused by the external factors such as landslide hazards..

Research area: The research area is geographically located on the Bovanenkovo region, the north-western part of Yamal Peninsula, West Siberia, Russia. Yamal Peninsula is a flat homogeneous lowland region with low-lying plains of heights lower than 90m. Such geographic settings create specific local environmental conditions in the region. Thus, Yamal is the worlds largest high-latitude wetland system covering in total 900,000 km² of peatlands, complex system of wetlands, dense lake and river network. Typical for this region are seasonal flooding, active erosion processing, permafrost distribution and intensive local landslides. Dominating vegetation types are typical tundra species: heath, grasses, moss, and lichens), and woody plants (shrubs and willows. the main environmental problems of this region are climate change and active landsliding, which affect on the landscapes and cause changes in vegetation coverage, i.e. land cover types.

Research problem: The specific environmental problem of Yamal region is cryogenic landslides. The processes of superficial cryogenic landslides are especially active in tundra. Distribution of the permafrost, which serves as a shear surface for sliding, highly contributes to the landslide formation in this area. Cryogenic landslides developed on the fine-grained, saline marine sediments are common destructive disastrous geomorphological hazards on the Yamal Peninsula covering ca 70% of the area).



Landslide types



Geographic specifics:

The Yamal peninsula occupies low plain. The relief of the region is almost completely flat with dense river network. This leads to the seasonal river flooding and active erosion processing that intensify local landslides formation.

The adjusting shelf area of Kara Sea is also shallow: almost 40% of the continental shelf is no deeper than 50 meters, and the sea coasts are mostly flat, flooded during the high tide. Located in the area of permafrost distribution, the soils in the region are frozen for the most of the year, with the depth of the frozen soil reaching up to 0.2 m in the north and 2 m in the south. The ecosystems of the region are adapted towards specific Arctic environment.

Negative effects of landslides. Cryogenic landslides have origin in thawing of underground permafrost layer, which destructs upper soil layer and vegetation coverage. The development of permafrost results in scarce vegetation coverage. Several years after landslide formation the vegetation coverage changes gradually, dominated by grass, moss, lichen and shrub, then by sedge and finally by willow meadows. As a result, landslide-affected areas of bare slopes are usually occupied by willow shrubs, which can serve as an indirec indicator for former landslide processes in this area. Moreover, different stages of the vegetation coverage provide information about the age of the landslides: early-stage vegetation (primitive mosses or lichen) indicate recent landslide formation while meadow and willow shrubs with high canopy points to the final stage of the landslide activities. Besides type and age of vegetation coverage, the salinity of ground waters as well as sediment chemical content indicates the relative age of the landslides.

Methods:

The research main method consists in Landsat TM image classification, spatial analysis and thematic mapping, technically performed in ILWIS GIS software. The choice of Landsat scenes for land cover mapping is explained by their well-known advantages of application in geosciences and cartography, almost 40 year old history of the image record, and free availability.

The Landsat scenes are a series of imagery received from the Earth-observing satellites jointly managed by NASA and the U.S. Geological Survey (NASA, 2011), which provide free of charge and regular updates of satellite imagery with 30-m resolution. In the current work we used orthorectified Landsat Thematic Mapper (TM) data files in Geographic Tagged Image-File Format (GeoTIFF) acquired over the area of Bovanenkovo region, Yamal Peninsula. The images have a time span of 23 years: 1988 and 2011, taken in growing season, i.e. summer to early autumn, with clearly visible vegetation coverage.

The research workflow.

1. Data capture and converting import of .img file into ASCII raster format (GDAL). After converting, each image contained collection of 7 Landsat raster bands.

2. Pre-processing: Enhancement of visual color and contrast. Geographic referencing of Landsat scenes included setting of UTM projection (Universal Transverse Mercator), Eastern Zone 42, Northern Zone W, WGS 1984 datum (Georeference Corner Editor).

3.Creating Area Of Interest (AOI). The area of interest (AOI) was identified and cropped on the raw images This area shows Bovanenkovo region in a large scale which best represents typical tundra landscapes.

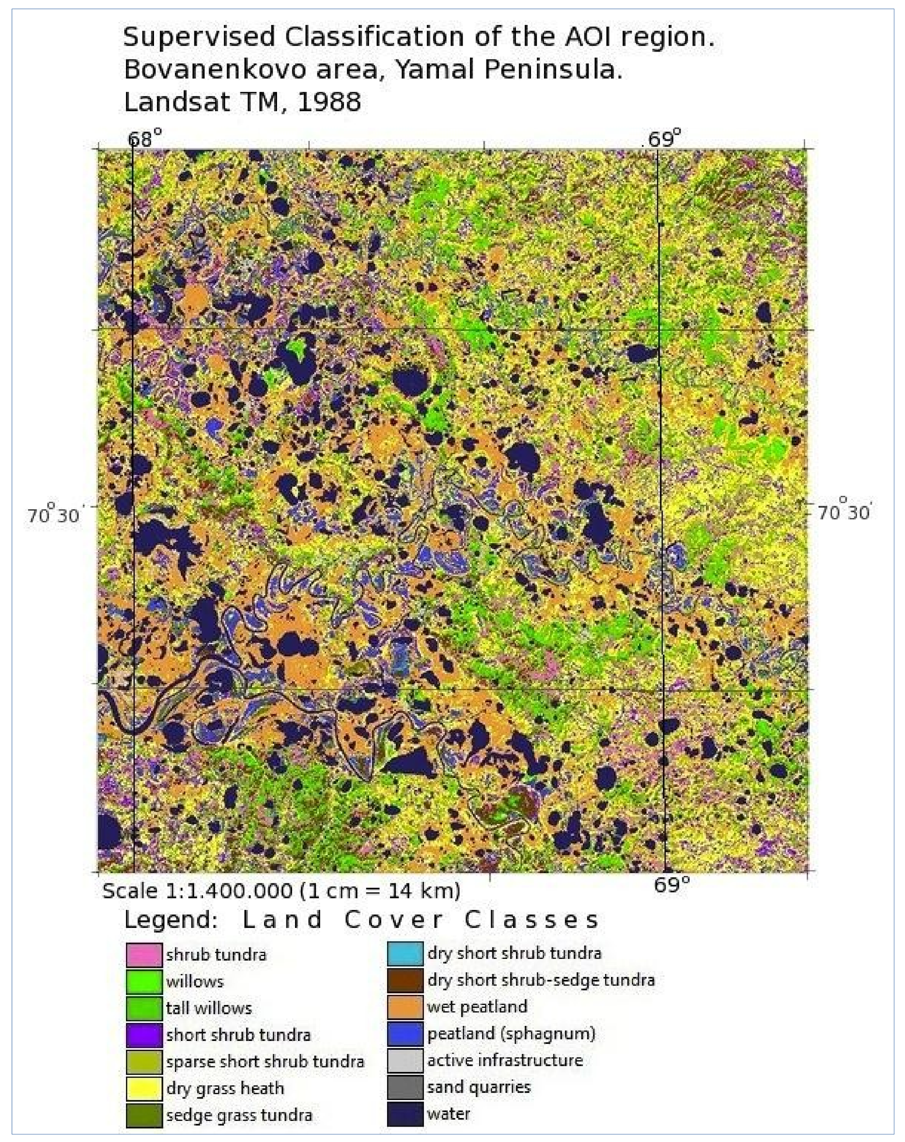
4.Supervised Classification. The images were classified by Minimal Distance method. This method is based on the spatial analysis of spectral signatures of object variables, i.e. vegetation types at various landscapes. The classes sampling was performed using Sample Set tool in ILWIS GIS. Training pixels for each land cover type were selected as representative samples and stored as classification key. They have contrasting colors, visually visible and distinguishable on the image.

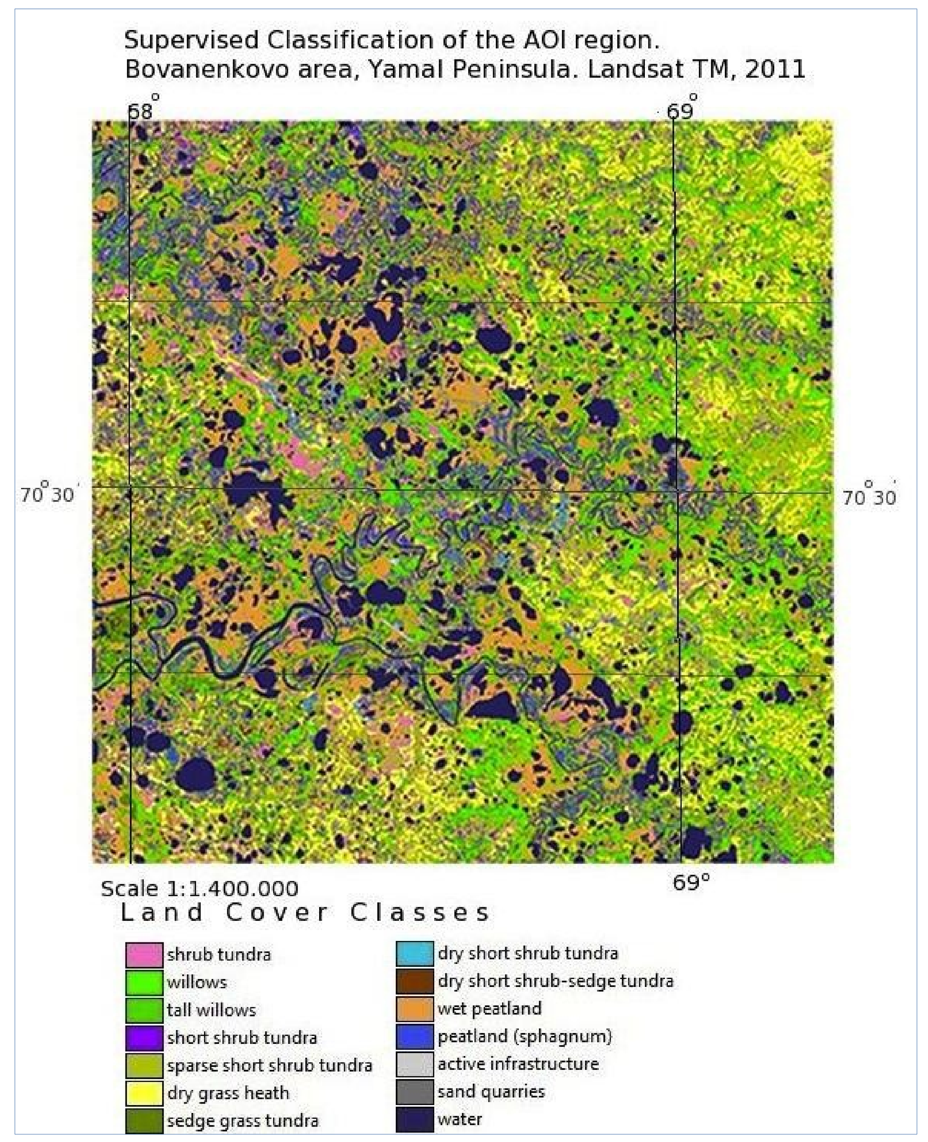
Land Cover Types:

The defined classes include following landscapes types: *shrub tundra, willows, tall willows, short shrub tundra, sparse short shrub tundra, dry grass heath, sedge grass tundra, dry short shrub tundra, dry short shrub sedge tundra, wet peatland, peatland (sphagnum)*. The pixels were associated with land cover classes using their digital numbers, similar to key samples.

Land Cover Class	Nr. of pixels, 1988	Nr. of pixels, 2011	Area, ha , 1988	Area, ha , 2011
Shrub tundra	220447	168226	1146,3	874,7
Short shrub tundra	165079	270158	858,4	1404,8
Willows	192645	457004	1006,9	2376,4
Tall willows	103954	71952	540,5	374,1
Sparse short shrub tundra	176511	759380	917,8	3948,7
Dry grass heath	641420	231719	3335,3	1204,9
Sedge grass tundra	27545	57052	143,2	296,6
Dry short shrub tundra	8984	16993	46,7	88,3
Wet peatland	761231	531809	3958,4	2765,4
Peatland (sphagnum)	120328	93979	625,7	488,6
Dry short shrub-sedge tundra	173693	92242	903,2	479,6

Table 1. Land cover classes as detected on the images of 1988 and 2011.





Classification results. Left: 1988 (initial situation). Right: 2011 (current situation)

Results: Willows covers 2750,57 ha in 2011, which is more than in 1988, when it covered 1547,52 ha (both 'tall willows' and 'willows' classes). Noticeable is increase in tundra vegetation: 'short shrub tundra', 'sparse short shrub tundra' and 'dry short shrub tundra' have more areas covered in 2011 comparing to 1988: almost 5442,00 ha vs 1823,00 ha. Increase of wooden vegetation class goes along with shrunk of grass and heath areas: 'dry grass heath' occupied area of 3335.39 ha in 1988, while currently it covers 1204.94 ha. Slight decrease can be noticed in the 'peatlands' and 'wet peatlands' classes: 3958.40 ha against 2765.41 ha in 2011 by 'wet peatlands', and 625.71 ha in 1988 versus 488.69 ha by 'peatland (sphagnum)' class (Tab.1).

Conclusions. Analysis of the results shows noticeable overall increase of woody vegetation (willows and shrubs) which are not typical for local environment, and decrease of peatlands, grass and heath areas. This illustrates both environmental and climatic factors affecting landscapes. Environmental factors include active cryogenic landsliding, typical for this area. Climatic factor includes increase of annual average temperatures, which leads to permafrost thawing and process of greening in Arctic, i.e. the unnatural increase of woody plants. Gradual changes in plant species patterns and distribution affect landscape structure in Yamal. Triggering factors for these processes include complex climatic-environmental changes in Arctic and local cryogenic processes (e.g. successive change in vegetation recovering after cryogenic landslides).

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