Exogenous Challenge in Yakutian Permafrost Areas: Analysis and Forecast

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Abstract. The paper discusses exogenous processes and dangers associated with their intensification on the plains and in the mountains of Yakutia in the XXI century. It has been established that these processes result from natural and climatic anomalies caused by changes in the climate. The first wave of hazardous exogenous processes swept over the plains of Central Yakutia at the beginning of the XXI century (from 2002 to 2004). This wave was triggered by a series of dry summers, which caused forest fires of unprecedented scale and the subsequent intensification of freeze-thaw processes in the areas impacted by the fires. The second exogenous wave which impacted the area a decade later (from 2012 to 2015) was triggered by positive anomalies caused by an increase in atmospheric humidity. The impact of this wave was especially vivid in mountainous areas, in the spurs of the Verkhoyansk Range in particular, where significant damage was caused to roads and other linear structures. A key role in the intensification of slope processes was played by seasonal flooding and suprapermafrost water processes which triggered large-scale landslides of Quaternary sediments. It has been found that climatic and exogenous anomalies can be attributed to solar maxima and minima in 11-year (Schwabe-Wolf) solar cycles. It can be expected that the next exogenous wave will hit the area at the maximum of the current 11-year cycle from 2023 to 2025.

1. Introduction

Despite the active exploration and development of strategically important natural resources (gold, diamonds, gas, oil, coal, etc.) located in Yakutian permafrost areas, the prospects for the development of the local mining sector in the XXI century remain uncertain. The cause of this uncertainty is the lack of a reliable method for predicting the behaviour of permafrost layers in a changing climate. Moreover, today there are no reliable methods for substantiating future trends in climate change.

2. Problem statement

It is known that the behaviour of permafrost areas is determined by extreme climate indicators, as well as by the presence of ice, which tends to go through phase transitions, in permafrost layers. The instability and mobility of permafrost stimulate the development of various natural (freeze-thaw)
processes affecting large masses of matter and amounts of energy, which can lead to dangerous and even catastrophic results.

The aim of the study discussed here is to find patterns in the development of dangerous climate fluctuations and ways to react to challenges posed by exogenous anomalies in Yakutian permafrost areas.

It should be noted that it is essential to start thinking about problems which may be caused by warming air temperatures in areas where permafrost is widespread, especially in the alluvial plains and the mountains of Yakutia (more than 30 percent of the Sakha Republic (Yakutia) area). A good example is the melting of ice in the Arctic, where, after three decades of warming, the Arctic Ocean lost 25 percent of its ice cover in 2007 alone. Multiyear ice resisted melting, but the process reached a critical point, after which it accelerated.

3. Materials and discussion

To date, a certain amount of information has been obtained on how natural and geological processes and phenomena in Yakutian permafrost areas are influenced by changes in the climate [1-5]. They make it possible to evaluate, to some extent, the reaction of permafrost to climate change. In particular, an increase in thawing and an increase in the temperature of the rocks at the bottom of the annual heat exchange layer make suprapermafrost water processes as well as natural and geological processes more intense [2,5]. Anomalies in atmospheric humidity play an especially important role here, as they are able to create conditions for exogenous catastrophes which have not yet gone beyond the local scale but may do so in the future [3].

According to our observations, the first wave of exogenous process intensification came to Central Yakutia, as it did in the Arctic, more than a quarter of a century after the intensification of global warming in the late 1970s. It was registered between 2001 and 2003 in the valley of the Middle Lena, where, under the influence of permafrost thawing, suprapermafrost water processes became more intense, which caused massive rockslides down the steep sides of the valley, with bedrock being exposed. This process was particularly intense in the Kangalassky Stone area on the southeastern flank of the Kangalassky lignite deposit near Yakutsk, the largest lignite deposit in Yakutia (Fig. 1).

![Figure 1](image1.png)

(a) (b)

Figure 1. Rockslides on the left side of the Lena River valley in the Kangalassky Stone area: (a) – landslide slope deposit, view from the northeast; (b) – landslide surface, view from the southeast.

The same situation happened in the Erkeeni area, 75 kilometres south of the Kangalassky area. Suprapermafrost water processes there became more active due to thermokarst activity in the open areas of ice-rich depositional plains and ancient river terraces of the Lena-Tatta interfluve.

At approximately the same time, exogenous processes occurred on the roads of Yakutia, including the Lena highway (Yakutsk – Bolshoy Never) and the Kolyma highway (Yakutsk – Magadan) (Fig. 2). These are the roads that provide access to the gold deposits in the East of Siberia and connect the
Republic of Sakha (Yakutia) with the Far East, Central Russia, and the Magadan Region all year round.

Figure 2. Lena highway, Yakutsk – Aldan section, July 2003 (photo by Aleksandr N. Fedorov).

Somewhat later, from 2011 to 2014, exogenous processes became more intense in the mountainous region of Eastern Yakutia. They manifested themselves most prominently in the area of the Batagaika cassiterite deposit (Verkhoyansky District). There, in the Batagayka river basin thermal erosion caused a giant sinkhole which exposed an ice core with a height of about 20-30 m and a length of more than 4 km (Fig. 3).

Figure 3. The ice core in the vicinity of the Batagaika cassiterite deposit (photo by Innokenty Starostin, summer 2014).

The scale of disruption in the Batagaika area has clearly shown, on the one hand, how dangerous ice layers and ice cores in permafrost areas can be and, on the other hand, what a big problem we may encounter if global warming continues.

4. Conclusion
The study of why exogenous processes in the plains and mountains of Yakutia became more intense at the beginning of the XXI century has shown that these processes were influenced by natural and climatic anomalies caused by changes in the climate. The first wave of hazardous exogenous processes which swept over the plains of Central Yakutia at the beginning of the XXI century (from 2002 to 2004) was triggered by a series of dry summers, which caused forest fires of unprecedented scale and the subsequent intensification of freeze-thaw processes in the areas impacted by the fires. The second exogenous wave which impacted the area a decade later (from 2012 to 2015) was triggered by positive anomalies caused by an increase in atmospheric humidity. The impact of this wave was especially
vivid in mountainous areas, where significant damage was caused to roads and other linear structures. Taking into account the fact that both of the anomalies can be attributed to solar maxima, we can expect that we may witness another anomaly at any time from 2023 to 2025.

5. References
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