EDITORIAL

CLIMATE CHANGE. IMPLICATIONS FOR SIBERIA

Global forecast of the consequences of climate warming in the Northern hemisphere

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An international team of researchers from Finland, Norway and the United States claims that nearly four million people and 70% of the existing permafrost infrastructure are in areas with a high prospect of permafrost thaw by the middle of the 21st century as a result of climate warming. The authors declare that even achieving the objectives of the Paris Climate Agreement will not significantly reduce the predicted effects. The data is available in the article «Degrading permafrost puts Arctic infrastructure at risk by mid-century» published in the journal «Nature Communications» on December 11, 2018. Such a large-scale study was conducted for the first time. The authors were able to reveal the global consequences of threats to the infrastructure of the Northern hemisphere due to the degradation of permafrost. It should be noted that the authors conducted the analysis on the basis of the most modern climate models and modern understanding of climate change[2].

The authors are convinced that future problems should be assessed in advance. They hope that the results of their work will be useful in planning and regulating economic activities in the Arctic and sub-Arctic territories. According to the publication, the scale of degradation of the upper permafrost layer by the middle of the century will reach significant scales (see Fig. 1 and 2). Thus, the authors write: «... by 2050 3.6 million people, which constitutes about three quarters of the current population in the Northern Hemisphere permafrost area, may be affected by damage to infrastructure associated with permafrost thaw. A substantial proportion of the fundamental human infrastructure is potentially under risk: 48–87% (mean = 69%) of the current pan-Arctic infrastructure is located in areas where near-surface permafrost is projected to thaw by mid-century. The potential risk to railways appears to be especially high … the Obskaya–Bovanenkovo railway may occur in the areas of thawing permafrost… There are currently more than 1200 settlements (ca. 40 with population more than 5000) in the zone where permafrost thaw is likely. Our results also indicate that central oil and natural gas transportation routes may be at considerable risk: 1590 km of the Eastern Siberia–Pacific Ocean (ESPO) oil pipeline, 1260 km of major gas pipelines originating in the Yamal-Nenets region, and 550 km of the Trans-Alaska Pipeline System (TAPS) are in the area in which near-surface permafrost thaw may occur by 2050" [1].

When asked about the main purpose of the research, Jan Hjort said: «I would like to highlight that we were interested to refine previous circumpolar assessments using novel geospatial data analysis techniques. Benchmark reports (e.g. Arctic Climate Impact Assessment, AMAP) have called for Arctic infrastructure hazard and risk assessments, but only regional studies have been conducted recently. Especially, we were interested to explore the magnitude of threat to infrastructure owing to climate change and permafrost thaw. Because of our spatial approach and scale of analyses (not building or meter-scale although higher resolution than ever before) we cannot exactly predict what could happen to certain buildings or parts of cities. If ice-rich permafrost thaws, it is possible that constructions may be damaged and the ground conditions may become unfavorable for new constructions – but to know for sure what will happen in a certain location, there should be done local-scale risk assess-

[1] Review of A. M. Fedorov on the article "Degrading permafrost puts Arctic infrastructure at risk by mid-century" is published in the section "Short messages".

The first author of the study is **Jan Hjort,** Professor of Physical Geography at the Faculty of Science, University of Oulu (Finland). He has 58 publications in international peer-reviewed journals. His articles were quoted 1158 times, h-index 20,00

Research interests: geomorphology, geodiversity, permafrost and periglacial processes, and spatial patterns of biodiversity. Methodologically, the main approach is geospatial data-based statistical analysis.

ments, taking into account site-specific engineering, adaptation, and construction practices. Thus, our results should be taken as "wake-up calls" and as a motivator for local-scale studies. For example, if no adaptation measures are used in the context of hydrocarbon extraction and industrial areas, extraction and delivery of natural resources may be threatened".

The authors of the article did not mention the railway Berkakit-Tommot-Nizhny Bestyah which total length is 809 km (probably due to the fact that it has not yet been put into operation), and which is situated in the risk zone of permafrost thawing.

Jan Hjort added: «Although we could show the magnitude of threat at circumpolar-scale, I think there is an urgent need for site-specific risk assessments. Moreover, it would be important to quantify the economic impacts of climate change on infrastructure at the pan-Arctic scale».

According to the authors' forecasts, Yakutsk, one of the largest cities in the north of Siberia, is located in the risk zone of degradation of the surface permafrost layer (see Fig. 1 and 2). Yakutsk is a rapidly developing city with a population of 370,000, but taking into account a population of the surrounding administrative and territorial areas linked to the city by paved roads will soon amount to half a million people. It should be noted that the city of Yakutsk is built entirely on pile foundations.

With regard to the question about the risk the city of Yakutsk is exposed to, Professor Jan Hjort replied: « I don't know local conditions and I'm not a construction engineer or geoengineer. So, it's impossible to give a clear answer to your question.

Photo 1. On the left there are commissioned buildings and a high-rise residential building under construction in Yakutsk. On the right there is a pile foundation of a residential building.

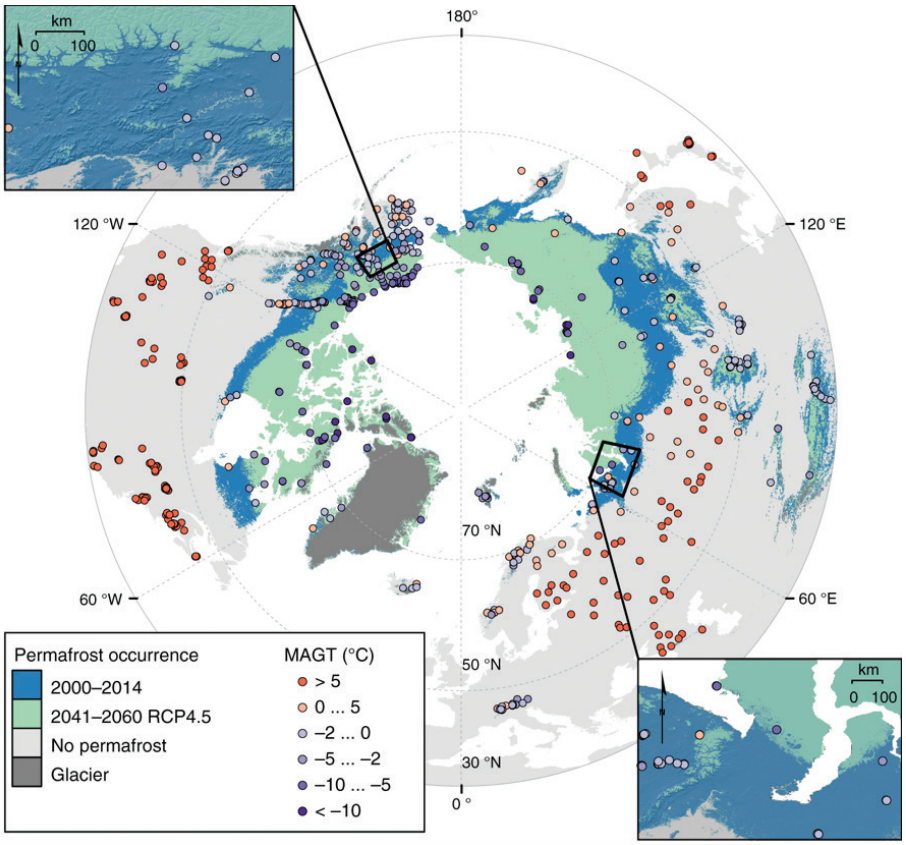

Fig. 1[2]. Distribution of permafrost in the baseline (2000–2014) and future (Representative Concentration Pathway 4.5 2041–2060) climates [Aalto, J., Karjalainen, O., Hjort, J. & Luoto, M., 2018]. Note that the baseline extent of permafrost (blue) includes future distribution (greenish). The location and observed mean annual ground temperature (MAGT) of the data points (boreholes) are shown with coloured circles.

To my knowledge, if the buildings are well founded they will survive without damage even if permafrost thaws. Our analyses show the risk level at regional scale and we highlighted that local-scale risk assessments are needed to get a picture of the very local risks. In our analyses (unfortunately not visible in the small map in the paper), the city of Yakutsk was (maybe because of the ground material) in low and medium hazard zone, it was not in the high hazard zone like many of the cities in the Northwestern parts of the Ural Mountains and Northwestern and Central Siberia. The city of Yakutsk seems to be in a lower risk level than the surrounding areas.»

It should be noted that in the world there is a so-called "climate consensus" among the scientific community. According to this consensus, up to 97-98% of scientists, actively engaged in climate change research and publishing scientific articles in peer-reviewed scientific journals, concur with the view that the observed climate change on Earth is caused by human activities, mainly due to greenhouse gas emissions from the combustion of hydrocarbon fuels [2]. The problem of permafrost degradation has long been discussed. What about Russian scientists dealing with permafrost? What do they think? Dmitry Drozdov, Deputy Director for Science at the Institute of the Earth Cryosphere of the Siberian Branch of the Russian Academy of Science told ITAR-TASS news Agency: "Such processes go on for thousands of years. Easy cooling or warming by several degrees. The Earth as a biological system has adapted to this. Landscapes at the same point become either more Northern on the surface or more Southern, and catastrophic changes

[2] Fig. from the article J. Hjort et al. [1] published under license CC BY-SA

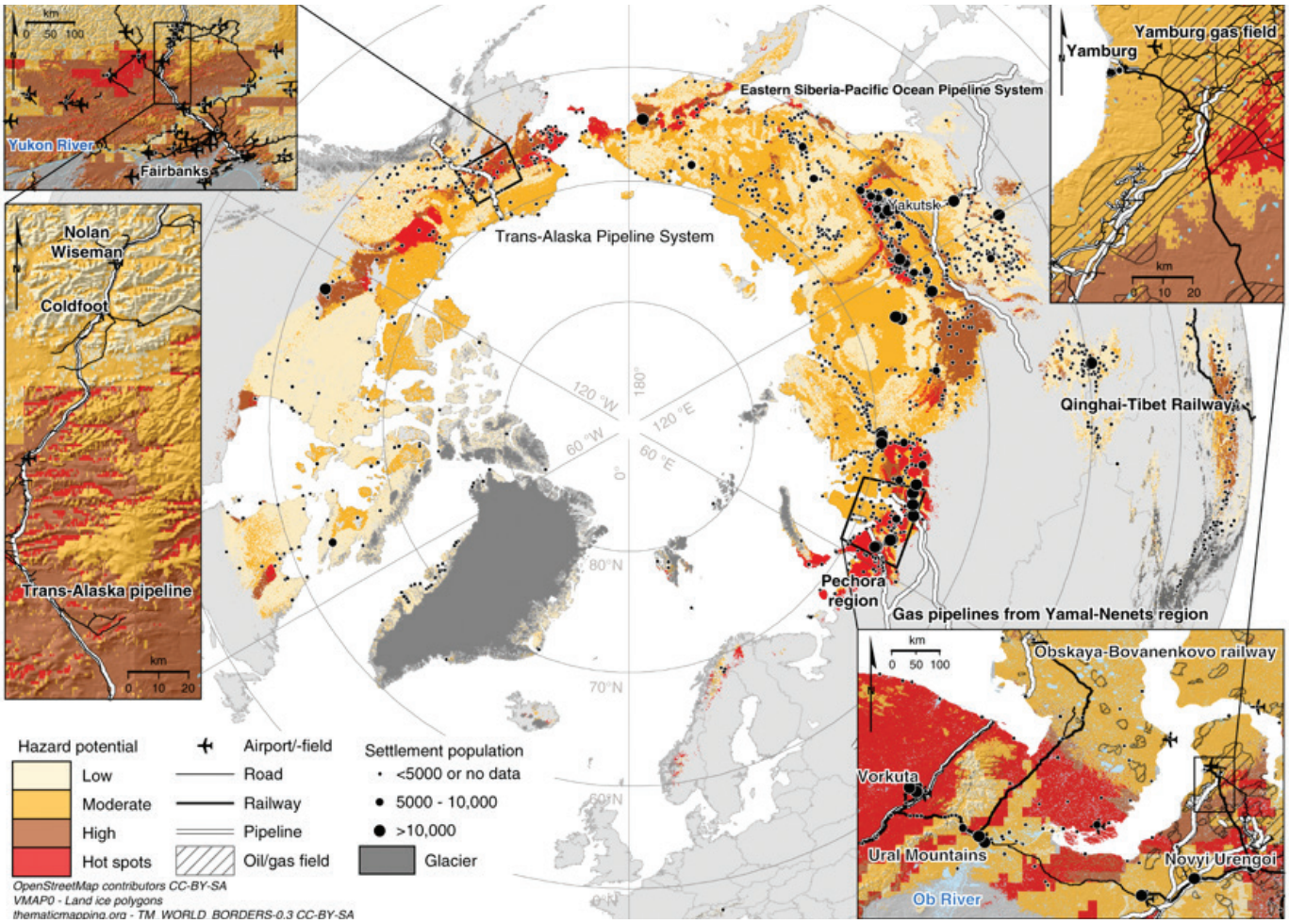

Fig. 2[2]. Pan-Arctic infrastructure hazard map with close-ups from central Alaska and northwestern parts of the Russian [3] Arctic. A consensus of three geohazard indices (settlement index, risk zonation index, and analytic hierarchy process-based index) showing hazard potential by risk level (low–high) for infrastructure damage by the middle of the century (2041–2060). Hot spots indicate areas where all three indices showed high potential for infrastructure damage [1].

do not occur." He believes that catastrophic changes will not occur within the next 100 years, but he notes that in cities such as Norilsk, Novy Urengoy, Nadym, Salekhard "...the bearing capacity of soils has already decreased by 30% over the past 30-40 years, and therefore houses that were not constructed with a large safety margin, are perspectively in a state of disrepair." The scientist claims that this fact has been known since the 1930s and recommends to construct and exploit buildings taking into account the expected climate changes [3].

Doctor of Physics and Mathematics, Professor **Yuri Mikhailovich Polishchuk,** a Chief Researcher of the Yugra Research Institute of Information Technologies well known for researches of karst lakes and permafrost, states: "According to the forecasts of the IPCC, the average annual temperature of the Earth may rise to 5°C by the end of the century. Paris Agreement[3] is aimed at keeping the growth of global average temperature below 2°C. In Russia, the average temperature has increased by 1°C since the 1970s of the last century, in the North the temperature has increased by 1.5°C. It should be noted that the World average temperature has increased by 1°C. According to the data given by O. A. Anisi-

[3] Reference: The Paris Agreement was signed on April 22, 2016. Russia has signed the Agreement but has not ratified it. On 01.06.2017, the USA announced its withdrawal from the Agreement.

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mov from Russian Meteorological Service, it was evident that surface soil layers in the North warmed up to the depth 20-25 cm, but now they have warmed up to the depth of between 50-60 cm. Nevertheless we should not expect a catastrophe. For example, 10 years ago Gazprom Research Institute conducted an analysis of accidents in oil pipelines. It was concluded that 20% of all accidents occurred due to climate warming. Nowadays Gazprom is capable to confront these challenges, so climate warming does not pose a serious threat to oil pipelines.

According to our observations, thermokarst lakes have decreased in size over the past 30 years, so the methane release from these lakes will be less than was previously predicted. This should weaken methane contribution to further climate warming."

With regard to the question about the temperature in the deepest layers of the soil at a depth of 10 m Yuri Mikhailovich recommended to contact a promising young permafrost hydrologist **Nikita Ivanovich Tananaev,** who observed the deep layers of the soil in Igarka. We found him in Yakutsk and asked a few questions.

– How has the temperature changed in the deeper layers of permafrost? We are interested in the behavior of permafrost and its temperature in the deeper layers in connection with climate change in Siberia?

– Siberia is a large area, and mostly unexplored. The main sources of data on soil temperature are weather stations, but the maximum observation depth is 3,2 m. Measurements of permafrost temperature at a depth of 10 m and deeper are carried out only in a few specially equipped wells. According to observations in these wells, from the 70s-80s of the last century there has been an increase in the permafrost temperature at a depth of 10m. The level of increase has been different in various natural areas and landscapes, varying from 0.2 to 2.5 degrees. In some wells, the temperature remains approximately constant in time. The largest observation data-set, which allows comparing the years 1970 and 2010, relate geographically to Western Siberia. The initial temperature of the soil at 10 m in this region was from -5°C to -7°C, now the temperature is from -3,5°C to -5°C.

Permafrost soils act as thermostats, because the heat flux into the underlying soil is limited by seasonal freezing and thawing. In the layer of seasonal thawing, phase transitions occur with the release (freezing) and absorption (melting) of heat. As a result, due to these phase transitions the temperature of the soil at great depths does not change as much as it could. And below a certain depth, which is called 'zero-amplitude layer', it does not seasonally change at all. The level of depth depends on the structure of soil (clay, sand) and its humidity. It is usually in the range from 10 to 18 meters. Below the level, the temperature is constant.

There are wells where the temperature increases to a depth of 10 meters owing to rise of the temperature of the air and soil surface. Consequently the soil at a depth of 10 meters is no longer cooled to the temperatures to which it was cooled before. And the temperature starts increasing. There are several wells in the vicinity of Yakutsk, and most of them have relatively stable temperature. The data refer to the period from the mid-1980s to the pres-

Tananaev Nikita Ivanovich, Candidate of Geographical Science, leading scientific employee of the Laboratory of General Geocryology, Institute of Permafrost Study Siberian Branch of Russian Academy of Science, Yakutsk.

Laureate of the SB RAS P. I. Melnikova's prize for young scientists, project coordinator of the working group on water and climate change of the Northern Forum.

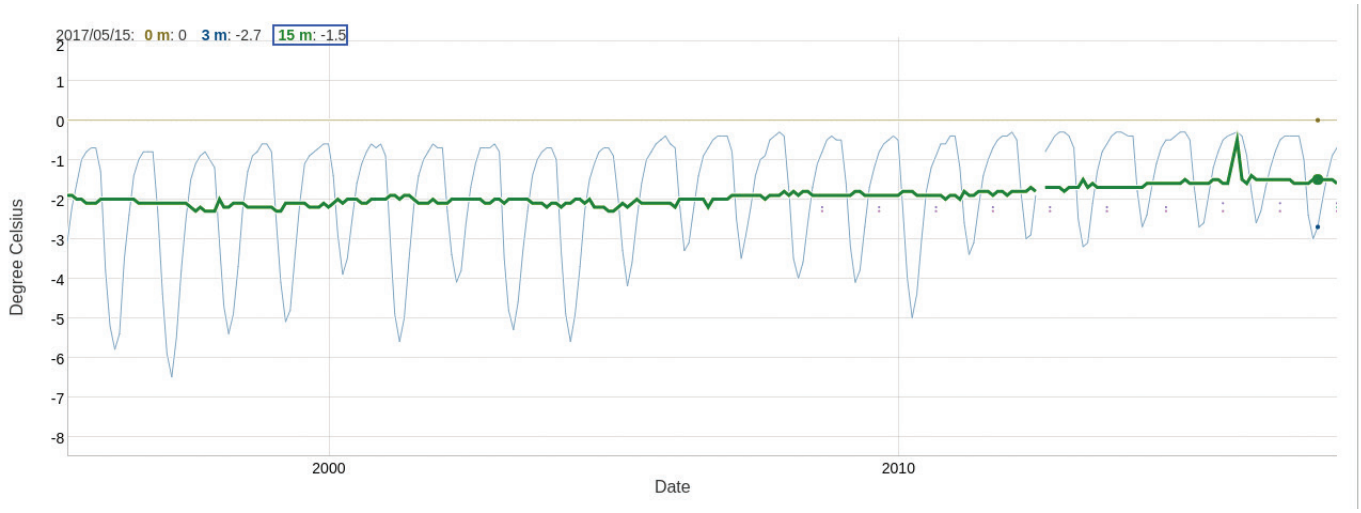
Research interests: hydrology of the cryolithozone (water balance and flow formation processes, moisture migration routes, hydrochemical tracers, including isotopes of rare earth metals); modeling of hydrological processes; statistical hydrology. Has 51 scientific publications in peer-reviewed journals, h-index 5,00

ent time, and they are available on the Internet.

– Regarding the hydrology of the cryolithozone, I read in the media that warming would cause flooding and vast areas would be washed over. Are there any scientific publications on these forecasts, and what is your opinion on the matter? What about forecasts that in case of permafrost melting the territories of eight regions of the Russian Federation are to be flooded? Zone includes Arkhangelsk and Murmansk regions, the Republic of Komi, the Yamal-Nenets district, Krasnoyarsk territory and Yakutia. Will the listed territories go under water if permafrost melts in 50 years? In particular, what will happen to Yakutia and the city of Yakutsk?

– First of all, vast areas will go under water due to sea level rise. It is not clear with floods because the damage caused by them is increasing, but this is partly due to the fact that the number and density of population is growing. Moreover, people begin to populate areas that have always been flooded before. You may find some publications on this matter, it is a much-discussed topic. Yakutsk, of course, is not in danger in terms of the flooding, but the problem of water cut and waterlogging is relevant. It is connected not only to climate change, but to the way the city and public utilities are organized. There is no storm water sewage and no drainage in Yakutsk, water stagnates and causes waterlogging. In the journal "Science and Technology in Yakutia", there were several articles on this topic, and we study such problems at the Institute of Permafrost.

– Climate has been discussed by the scientific community for more than 100 years. Can the



Soil temperature change at a depth of 3 (thin line) and 15 m (bold line) at the Tuimada well near Yakutsk from 1996 to the present (Source: DB GTN-P, https://gtnp.arcticportal.org/)

so-called "climate consensus" collapse under the pressure of "climate skeptics" and supporters of "global cooling"? What is your opinion? The denouement of the drama will become clear soon, in 30 years. As the Greek philosophers said: "Time is the best judge"

– Climate discussion is important, because we begin to understand our planet better. The climate consensus will be contested for a long time, and the longer the better. There is a principle of actualism, that is like a law of induction but only in Natural Sciences. This principle says that nature will develop in the future according to the same laws and within the same limits as it has done before. So, according to the principle of actualism on our planet within 100 thousand years there is a warm period which lasts 15 thousand years, and then it is followed by 85 thousand years of cold period (glacial), I give approximate duration. We live during a warm period, and about 10 thousand years out of 15 have already passed. So if everything goes as it used to go before, then in five thousand years it will start getting cold. The problem is that all the previous cycles took place without our intervention. How much can human activity affect the life of the planet as a system? It is still unclear, and scientists are trying to reveal it.

– What is your opinion on the article "Degrading permafrost puts Arctic infrastructure at risk by mid-century" in the journal "Nature Communications"?

– As for the infrastructure and the topic of the article in Nature Communications, I will say the following. Soil temperatures in cities differ from the ones in out-of-town territories very much. It is difficult to predict in advance. The vital activity of people plays a very important role. At our Institute of Permafrost Study, a young employee recently presented his PhD thesis on the example of Yakutsk. In Igarka all the houses collapsed because people left them, and all the houses fell into disrepair.

– In 1989, the population of Igarka was 18 820 people, and in 2017 there were 4 754. What is it? Did people leave after the collapse of the Soviet Union? Or did they leave because of climate disasters?

– In Igarka there were a few large companies: sawing and transshipment complex (STC), seaport, and hydrographic enterprise. As soon as the STC was closed, people began to leave. The closure of the complex was caused by a general decline in the economy and the ban on timber rafting in the Yenisei basin due to environmental reasons. Now in Igarka there are mostly people who have nowhere to go, or those who are accustomed to their way of life with hunting, fishing, etc.

Thus, there is a more restrained approach to the consequences of climate warming among the Russian specialists studying permafrost. The motives of heroic epics of the indigenous peoples of the North glorify a dream about an evergreen country with the Sun that don't, with waters that doesn't dry up, and where the cuckoo birds are constantly singing and wild pigeons are mourning. But when we built grand houses and a great railway it is better to meet the ice age, which we can tolerate, as we have done it before for thousands of years. In the next article we discuss the so-called "Little ice age" with well-known scientists from Russia and foreign countries.

REFERENCES

1. Jan Hjort, Olli Karjalainen, Juha Aalto, Sebastian Westermann, Vladimir E. Romanovsky, Frederick E. Nelson, Bernd Etzelmüller, Miska Luoto. Degrading permafrost puts Arctic infrastructure at risk by mid-century. Nature Communications, 2018; 9 (1) DOI: 10.1038/s41467-018-07557-4

2. Anderegg WR, Prall JW, Harold J, Schneider SH. Expert credibility in climate change. Proc Natl Acad Sci U S A. 2010 Jul 6; 107(27):12107-9. doi: 10.1073/pnas.1003187107.

3. RIA News. The scientist told how to change the lives of Russians due to global warming. 3 November 2018, 03: 24. https://ria.ru/20181103/1532075584.html. Access 10.02.2019 G.