Possible Consequences of Global Climate Change in the Arctic Zone of the Russian Federation

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Abstract. On December 25, 2019, by an order of the Government of the Russian Federation, the National Plan of Measures for the first stage of adaptation to the climate change for the period until 2022 was approved. This plan pays considerable attention to the Arctic zone of the Russian Federation. In 2020-2021, it is planned to develop and approve a separate sectoral plan for adaptation to the climate change in the macroregion. In general, among the key problems of the socio-economic development of the Arctic zone of the Russian Federation, the unpreparedness of all types of infrastructure for the possible consequences of the global climate change is particularly notable. Climate change occurring in the macroregion is superimposed by additional anthropogenic factors, including chemical pollution, excess catch of aquatic biological resources, changes in land use, population growth, and changes in the structure of the economy. The problem of the impact of climate processes on socio-economic development is fundamental and has its positive or negative manifestations in all spheres of life. The negative manifestations of the climate change primarily include consequences for ecosystems, the environment, infrastructure, especially coastal areas, public health and traditional local lifestyles. The positive effects of climate change include reducing heating costs, expanding opportunities for agriculture and forestry, developing shipping along routes in the Northern Sea, as well as expanding access and increasing the extraction of mineral and marine biological resources.

1. Introduction

The impact of the globalization on Russia's positioning in the world focuses primarily on two areas: the problems of maritime activities and the intersection of energy security and climate change. In addition to the development of a few untouched areas of the continental part of the Earth, only the oceans and, especially, its high-latitude areas represent a reserve for human expansion of the physical space of its habitat and life.

At the same time, the importance of the Arctic spaces and resources in the life of humanity and the formation of the global gross product has increased dramatically. It is predicted that, as a result of global climate changes, in the long term, commodity flows passing through the high-latitude transport and communication routes of the Arctic may become dominant in the structure of world trade. The full-scale development of mineral and energy resources of the richest Arctic continental shelf begins, which is due to the depletion of mineral reserves of the continental part of the Earth. It directly affects the structure of global energy supply. The involvement in the industrial circulation of renewable energy sources in the Arctic using wind generation, geothermal, circulating oceanic, wave, planetary gravitational (ebb and flow) energy in combination with the development of the deep-sea bottom of

the Arctic Ocean generates a wide range of technological innovations used in various spheres of life. In the near future, according to the scenario forecasts of the UN World Food Organization, a sharp jump in demand for marine industrial fishery products will follow, in the production of which the Arctic region plays a significant role. Nowadays, the fishery for aquatic biological resources is increasing everywhere in the conventional areas of the oceans, and especially beyond their scope. The global climate-forming function of the Arctic Ocean and its importance in ecosystem dynamics, apparently determining the transition from the meridional circulation of macro-synoptic processes to the zonal (that is, the possibility of local cooling against the backdrop of global warming), prompt humanity to intensify fundamental research on its nature. The Arctic states are actively developing highly profitable (in some regions, budget-forming) tourism and recreational businesses. Climate change and a shift in economic activity on the continental shelf of the Arctic seas will lead to an increase in the role of the sea factor in the economic and social development of the Arctic zone of the Russian Federation.

By order of the Government of the Russian Federation on December 25, 2019 No. 3183-r, the National Plan of Measures for the first stage of adaptation to climate change for the period until 2022 was approved. It notes the need to develop and approve a separate sectoral plan for adaptation to climate change in the Arctic zone of the Russian Federation.

On the whole, over the past 100 years, a statistically significant positive temperature trend has been observed in general for the northern polar region and for the latitudinal zone of 60-70 ° northern latitude. The amount of precipitation in the Arctic region increased on average by about 8%, river flow into the World Ocean increased throughout the Arctic, and spring maximum is now observed at an earlier date [1]. In recent years, the average thickness of sea ice in the Arctic basin has also decreased, mainly due to a several-fold reduction in the area occupied by perennial ice. Against the background of a general reduction in the summer extent of ice formation in the Northern Hemisphere, there is a decrease in the summer ice cover of the Arctic seas through which the routes pass in the Northern Sea Route. The thermal regime of the permafrost zone is also changing, which is of particular relevance for Russia, where permafrost rocks occupy more than half (63-67%) of the country's territory and over 90% of the Arctic zone. In recent decades, Russia has seen a doubling of the number of dangerous weather and climate events, as well as an increase in adverse sharp changes in the weather [2]. For the Arctic region, the most dangerous factors are heavy snowfalls, severe frosts, hurricane winds, as well as an increase in fire hazard.

It should be noted that the climatic changes occurring in the Arctic zone of the Russian Federation are superimposed by additional anthropogenic factors, including chemical pollution, excess catch of aquatic biological resources, changes in land use, population growth, and changes in the structure of the economy, which increase the negative effects of climate changes. In general, the problem of the impact of climate processes on socio-economic development is fundamental and has its positive or negative manifestations in all spheres of life, not only in the environmental sphere.

The purpose of this article is to assess the impact of possible global climate change on the development of infrastructure in the Arctic zone of the Russian Federation.

2. Forecast of cargo transportation volume along the North Sea Route: materials and methods

A retrospective analysis of the dynamics of the traffic flows along the Northern Sea Routes (NSR) and its extrapolation to the long-term using regression equations allows us to construct a range of inertial scenarios for the development of a macro-regional transport complex without taking into account the climatic factor. In the formation of the target (innovation) scenario, the forecast indicators of federal, sectoral, regional and corporate strategies, programs and plans were taken into account against the background of a dramatic increase in the effectiveness of state investment policy and the implementation of strategies and programs for adaptation to global climate change. Prospective sea and river freight traffic on the routes in the NSR water area was developed on the basis of the estimated level of socio-economic development of the coastal and Arctic regions, taking into account

the data of federal and regional authorities of the Russian Federation and target indicators for the implementation of strategic planning documents in force in the Russian Arctic.
In the methodological plan for the inertial scenario, regression equations were constructed. It helped to extrapolate existing trends on the basis of annually collected statistical series from 1933, as well as the main parameters of Arctic navigation over a 30-year period (starting from 1985): the volume of cargo transported in sea vessels, including bulk vessels and dry cargo vessels, the number of sea transport vessels involved in transportation and the number of transport flights operated by sea vessels [3].
For the target scenario, the additive method was used, according to which the prospective cargo base was summarized for certain types of cargo and transportation directions: import (dry cargo), export (liquid cargo from the Yamal Peninsula, crude oil and gas condensate from the Ob, Yenisei, Lena rivers, non-ferrous metals from Dudinka, timber cargo from Tiksi, Igarka, etc.), transit, export from the Arctic in cabotage, intra-Arctic cabotage (from rivers), direct delivery from the east and from the west in cabotage. The indicators of active scenarios in the existing strategic planning documents were used as a statistical base. Weights that take into account the expected results of the implementation of adaptation strategies to the possible effects of climate change for certain types of goods were determined using heuristic methods: brainstorming, expert assessments, situational analysis, etc.
Taking into account global climate changes, new trends and features of the transformation of the northern delivery are visible. A fundamentally different scheme will be required, which can only be implemented on the basis of the new northern transport system, which includes alternative transport networks and modern vehicles. It is necessary to form and develop the logistics of the northern delivery, the essence of which is the integration of production processes, logistics, transportation. Reduction of the cost of transportation is possible on the basis of the formation of multimodal transport hubs in order to extend the calendar terms of delivery, increase the volume of cargo flows in the opposite direction, introduce new information technologies, etc. The multimodal transport hub of the northern delivery is a multi-type, multi-transport complex that integrates all the necessary institutions of commodity moving (transport, terminal and warehousing, finance, insurance and telecommunication structures, etc.).
Based on the proposed methodology, two scenarios were built: inertial and target, taking into account the possible effects of climate change. In accordance with them, the predicted volumes of cargo transportation along the routes in the NSR in the range from 76.5 to 109.7 million tons were forecasted.
In modern conditions, it is urgent to carry out the transition from an extensive to an intensive method of developing the transportation system of the Russian Arctic. That means moving from mechanically expanding the capacity of the infrastructure and the fleet to increasing capital productivity and productivity for both national and domestic transport economic interests based on the latest achievements and implementation of adaptation measures. It is also advisable to proceed to the formation of a model of the transport and logistics services markets with the quality characteristics that ensure competitiveness with the best world analogues. The transition from the mechanical increase in the volume of cargo transportation (in absolute terms) to the sale on the global market of competitive transport and logistics services in line with the development of elements of the service economy of navigation along the Northern Sea Route (adaptation measures, hydrometeorology, ship repair, navigation and hydrographic support for shipping, etc.) .d.) is able to radically change the whole paradigm of the relationship of goods and transport.

3. Results

Global climate transformations have no less impact on industrial fisheries than on the environment. Especially considering the fact that in many coastal Arctic regions of the Russian Federation, the fishing industry plays a budget-forming role. The fact that possible warming processes will cause large-scale changes in marine biogeocenoses and radical shifts in the species composition, up to the biological invasion of new invasive species, with unpredictable consequences, should also not be neglected. However, the main vector of scientific research in this area indicates the strengthening of favorable conditions for fishing [4]. Among them are an increase in the productivity of the food supply

for valuable species of aquatic biological resources, that is, marine predators of the upper trophic levels, and the expansion of the habitat of their populations, and the revitalization of fishing in the Beaufort Sea and in the Chukchi Sea, where commercial catch was minimized in the past. In addition, as ice cover decreases, prospects for intensifying industrial production in the Bering Sea will appear. Of course, in parallel with them, new reasons for the emergence of conflicts over the allocation of quotas are able to intensify, since stocks will migrate from the waters under the jurisdiction of one country in the waters of another. Many valuable herds of bioresources (shearing crabs, pollock, salmon, halibut), will possibly begin to move from Alaska towards Russia as the ice recedes and the water warms in the Chukchi and Bering Seas. The colonization of new pink salmon rivers is just one of many signs in this series. Together, these factors will create a positive background for the socio-economic dynamics of the Arctic regions of Russia, especially those in which industrial fishing occupies a leading position in the structure of gross regional product.

In the transport system of the Arctic zone of the Russian Federation, sustainable warming, which runs the risk of occurring despite natural climatic cycles, will increase the duration of ice-free navigation, opening up the possibility of using vessels with little ice reinforcement (lightweight and inexpensive to operate and build) or none at all. First of all, this trend is projected on the short-distance fleet serving seasonal traffic flows - the export of timber from the Yenisei River, the supply of supplies to non-equipped points in the southwestern part of the Kara Sea and the coast of Northern Chukotka, transportation along the Laptev and East Siberian Seas. An additional impetus for development will be received by river-sea shipping, including the development of export-import cargo flows along the Yakutsk-Europe line. It is also possible to foresee an increase in the duration of navigation periods, an increase in the speed of vehicles, a decrease in the distance of transportation, and the involvement of new routes in the Northern Sea Route system. At the same time, transit through the NSR, which has an enormous and an underestimated potential, will be able to revive due to the favorable geographical location of our country. Initially, transit flights will be operated seasonally, however, the navigation period will expand up to year-round and uninterrupted (“just in time”).

There is one more significant detail that needs to be taken into account when analyzing the possible impact of global climatic transformations on shipping - even in case of warming, the need for ice-breaking facilities will not change or will decrease not so intensively as other indicators of the operation of sea transport and the means providing it. Apparently, rotation of small transport vessels with powerful ice reinforcement to larger and lighter craft will also begin at a very small pace. And the explanations for this are several interconnected theses. At first, with the expanding duration of Arctic navigation, to ensure rhythmic navigation, a significant strengthening of the fleet of linear icebreakers and icebreaking transport vessels will be required. Secondly, in all climatological forecasts, as a rule, we are talking about perennial pack ice, and one-year ones, as they formed earlier, are formed now, not only in the shallow Arctic with its harsh winters, but also thousands of kilometers south - on Caspian Sea, the Yellow Sea, etc. Thirdly, with the inexorable approaching time of the full-scale development of offshore hydrocarbon deposits, demand for icebreaking support for transshipment of oil products in the freezing seas (Baltic, White, Okhotsk) will begin to grow. Fourthly, in the context of a decrease in thickness and a decrease in the area of sea ice, and due to the less stable conditions for navigation, improved service support, including icebreaking support, ice forecasts and technologies creating ice maps will be required. Fifthly, the involvement of foreign operators on the NSR routes will lead to an increase in engineering standards for Arctic navigation vessels in comparison with other watercraft designed for the high seas, in terms of their more advanced ice qualities. Sixthly, an increase in ice mobility in the narrow places on the routes may complicate shipping.

The developers of the mineral and energy resources of the continental shelf also consider the hypothesis of a reduction in the area of pack ice as favorable events, but not too significant. However, these perennial formations can be dangerous for drilling platforms erected at sea, as well as cause accidental damage to the pipelines. As well as icebergs, the likelihood of collision with artificial structures is sharply increasing, especially since cases of their occurrence in areas of northern offshore fields are already becoming more frequent (today, specialists notice dozens of New Earth icebergs

weighing up to 3.5 million tons, with that the maximum iceberg of the twentieth century for this zone was estimated at 1 million tons). Subsoil users plan to create special services for monitoring the ice situation and emerging new risks. However, the area of distribution of pack ice does not intersect with promising areas of intensive hydrocarbon production and is unlikely to simplify field development. In addition, the pace of today's warming, if it takes place on a scale that is not only of scientific but also of applied importance, does not have a significant effect on the seasonal ice cover of the Arctic seas and is not able to interfere with annual ice formation. There is likely a slight increase in the ice-free period of work, which does not remove the requirements for the design and construction of exploration, production and transportation facilities, based on the most severe ice conditions.

At the same time, some scientists consider that there is now a thermal peak, after which a natural cooling will inevitably begin [5]. There are facts about a new stage in the development of macrosynoptic processes. This stage consists of the transition from meridional to zonal circulation [6]. For example, there have been tendencies for a decrease in air temperature in the Western Arctic and large positive anomalies in the main parameters of the ice regime in the Barents and Kara Seas. Most of the studies indicate the groundlessness of alarmist climatological forecasts [7]. In addition, an increase in the influx of fresh water brought by rivers into the Arctic Ocean, due to melting glaciers and an increase in the amount of precipitation, will reduce the rate of formation of more salty and dense water during the formation of sea ice [8]. A drop in the rates of thermohaline circulation can lead to a slowdown in the flow of heat by the Atlantic Ocean (primarily the Gulf Stream) to the north - a regional phenomenon - amid global warming of the entire Planet [9]. To the maximum extent, this phenomenon can affect the Murmansk region, since it can significantly complicate the ice conditions in the Kola Bay and jeopardize the development of the Murmansk transport hub. Based on the interannual variability of ice conditions observed over the previous 50-60 years, it can be expected that conditions difficult for navigation will periodically arise in the next 20-30 years on the NSR routes, especially in the Straits of Vilkitsky, Shokalsky, Dmitry Laptev, Sannikov and Long. The negative phenomena caused by the growth of wind-wave activity, namely the frequency of ice storms, will intensify. Thus, long-term planning of socio-economic development of the Arctic zone of the Russian Federation is required in the face of continuous and multidirectional climate changes, because, for example, the prospects of the transport network in the Arctic are based on the basic installations of existing modes of transport and technologies for the construction of appropriate communications (including pipeline transport, power lines, etc.), which were planned in a stable climatic situation. However, the number of changes that will occur will transfer to the new quality of the evaluated results (inaccessibility of the territory, inapplicability of technology, economic inexpediency of actions, etc.). It is highly likely that existing settlements, ports and airports in the Russian Arctic will face the need to transfer them to other territories, and the construction of new infrastructure facilities planned for implementation in strategic decisions loses all meaning even at the pre-project preparation stage.

Coastal erosion is likely to intensify, as rising sea levels and a decrease in ice will allow higher waves to reach the coast. Along some sections of the Arctic coastline, permafrost thawing will weaken land, increasing its vulnerability. Flood risk in coastal wetlands is projected to increase, affecting people and natural ecosystems. Melting of the ground will lead to the destruction of roads, buildings and other infrastructure. Oil and gas production, as well as logging will be intermittently interrupted due to the reduction in the period when the winter roads and tundra are frozen enough to carry out industrial transportation. As the frozen ground melts, buildings, roads, pipelines, airports, and other objects are likely to collapse, requiring repairs, maintenance, and financial investments. Future development will require new design approaches to take into account the effects of warming, which will increase construction and operating costs. Permafrost degradation will affect ecosystems, leading to soil failures, drainage of lakes, swamping and tree fouling in some Arctic regions. In this situation, all of today's port, settlement (urban) and transport (including pipelines) infrastructures of the Arctic and Arctic territories are in a high-risk zone. It becomes dangerous for living in terms of possible technological disasters.

Thus, climate change can be both negative and positive. The negative manifestations of climate change primarily include consequences for ecosystems, the environment, infrastructure, especially for coastal areas, public health and traditional local lifestyles. The positive effects of climate change include reducing heating costs, expanding opportunities for agriculture and forestry, developing shipping routes along the Northern Sea, as well as expanding access and increasing the extraction of mineral and marine biological resources (Table 1).

Table 1. Assessment of the impacts of climate change on the environment, ecosystems, economy and population of the Arctic zone of the Russian Federation

Areas of impacts	Negative effects	Positive effects
Possible consequences for the environment		
Ecological systems	Biological invasion of invasive species and exacerbation of existing problems of intraspecific competition. Reducing biodiversity, changing the species composition of freshwater aquatic organisms. The spread of pathogens and pests. Reducing the habitat of polar bears, marine mammals, some species of avifauna. Undermining the food supply and traditional migration routes of reindeer. An increase in the number and intensity of natural hazards, an increase in fire hazard, and the appearance of dust storms.	Possible increase in local diversity of aquatic bioresources.
Environment	Increased methane emissions due to permafrost thawing. An increase in the concentration of pollutants in the atmosphere, onshore water bodies and marine areas.	
Possible consequences for the economy		
Marine fishing	Decrease in productivity and stocks of some types of aquatic biological resources and other hydrobionts.	Increased productivity and stocks of some types of aquatic biological resources, migration of more southern species of aquatic organisms.
Mining	The increase in the amplitude of wind waves, the appearance of debris from icebergs from degrading glaciers.	Facilitation of access to new deposits of mineral and energy resources.
Energetics	Increased load and increased risk of	Reduce heating costs

Table 1. Assessment of the impacts of climate change on the environment, ecosystems, economy and population of the Arctic zone of the Russian Federation

Areas of impacts	Negative effects	Positive effects
	accidents at facilities due to sudden changes in temperature and an increase in the number of natural hazards.	
Transport	The likelihood of the formation of difficult ice conditions in some straits that limit ice-free navigation on the routes in the water area of the Northern Sea Route.	Development of navigation along the Northern Sea Route. Summer access to most of the coastal waters.
Infrastructure	Risks in the operation of structures, including trunk pipelines, due to permafrost thawing.	
Forest industry	Increased risk of forest fires, the spread of pests.	Extension of forest coverage
Agriculture	The occurrence of risks associated with an increase in the number and intensity of weather anomalies.	An increase in the growing season and an increase in the yield of a number of crops.
Tourism	An increase in the number of avalanches and other dangerous natural phenomena.	Opportunities for the transition to new cultures with a more southerly distribution.
Possible consequences for the population		
Public health	Strengthening meteopathic reactions due to increased weather instability. An increase in the number of respiratory diseases associated with an increase in temperature and humidity. Increased psychological and social stress associated with changes in the environment and lifestyle. Distribution of areas of infectious diseases. Deterioration in air quality.	Reducing the discomfort of living near the southern border of the Arctic zone of the Russian Federation.
Traditional Indigenous Lifestyle	The risk of worsening conditions for traditional types of employment of the indigenous population and ethno-forming industries (hunting, fishing and reindeer husbandry). An increase in the incidence due to a change in diet and lifestyle.	

At the same time, the implementation of an active (target) scenario, involving the development of strategies and programs for adaptation to the global climate change, together with an increase in the efficiency of state investment policy, as shown by the calculations, will dramatically increase key indicators of the macroregion. For example, the constructed scenario forecast of the volume of cargo transportation along the routes in the water area of the Northern Sea Route indicates that it is possible to achieve the corresponding indicator at the level of 109.7 million tons by 2030 if the target scenario is realized against 76.5 million tons with inertial scenario, assuming completion of already planned activities and extrapolation of existing trends without taking into account the climatic factor.
Thus, for the effective development of the Arctic zone of the Russian Federation, a deep modernization and updating of the expedient state of basic infrastructures are required, taking into account global climate changes. To solve these problems, it is advised to develop an intelligent information-analytical system for ensuring activity and forecasting the development of production and social infrastructure in the difficult climatic conditions of the Arctic on the principles of trinitarian and multifactor models [10].

4. Conclusion

In order to reduce economic costs, increase the sustainability of socio-economic infrastructure to possible negative climatic processes, it is now necessary to take appropriate response measures and adapt to observed and predicted climate changes. Both of these tasks must be solved jointly and comprehensively: adaptation measures should be integrated into the socio-economic development programs of the regions and sectors of the economy of the Russian Arctic. Climate change is not only a scientific or environmental problem, but to a much greater extent an economic one. Adaptation measures have a direct impact on the development of energy, agriculture, forestry and other sectors of the economy, affect the international trade in energy resources and technologies. Therefore, the solution to this problem directly affects the socio-economic and political interests of the Arctic and extraterritorial countries. For the Russian Arctic, global climate change creates (taking into account the size of the territory, geographical location, economic structure, demographic problems and foreign policy interests) a situation that requires the formation of a comprehensive and balanced state approach to climate problems and related issues in advance based on a comprehensive scientific analysis of environmental, economic and social factors.

5. References

[1] Backman A. 2013. SWERUS-C3, a multi-diciplinary Swedish – Russian – US research program aiming to investigate the linkages between Climat – Cryosphere and Carbon interactions. *Theory and practice of marine activity*, special volume, ed. Fetisov G.G. (Moscow: SOPS) pp. 75-85.
[2] Donskoy S.E., Chilingarov A.N., Barbin V.V., Shnaider A.G. and Konovalov A.M. 2015. Strategy for development of the Russian Arctic. *Russian North: modernization and development*, ed. Pankov D.V. (Moscow: State Duma Committee on regional policy and problems of North and Far East), pp. 8-39.
[3] Konovalov A.M. 2015. *Strategic planning of the Arctic zone of the Russian Federation development*, ed. Fetisov G.G. (Moscow: SOPS), pp. 251-321.
[4] Konovalov A.M. and Baturova G.V. 2013. *Arctic strategy of Russia* (Saarbrucken: LAP), pp. 26-132.
[5] Mikhailichenko V.V. 2013. Analisys of transit on Northen sea route. *Theory and practice of marine activity*, special volume, ed. Fetisov G.G. (Moscow: SOPS) pp. 25-33.
[6] Hinzman L.D., Deal C.J., McGuire A.D., Mernild S.H., Polyakov I.V. and Walsh J.E. 2013. Trajectory of the Arctic as an integrated system. *Ecological Applications*, chapter **23(8)**, pp. 1837-1868.
[7] Harris C., Arenson L.U., Christiansen H.H., Etzelmüller B., Frauenfelder R., Gruber S., Haeberli W., Hauck C., Hölzle M., Humlum O., Isakswen K., Kääb A., Kern-Lütschg M.A.,

Lehning M., Matsuokai N., Murton J.B., Nötzli J., Phillips M., Ross N., Seppälä M., Springman S.M. and Mühll D.V. 2009. Permafrost and climate in Europe: Monitoring and modelling thermal, geomorphological and geotechnical responses. *Earth Science Reviews*, chapter **92**, pp. 117-171.

[8] Reichler T. and Kim J. 2008. How Well Do Coupled Models Simulate Today's Climate? *Bulletin of the American Meteorological Society*, No. **3**, pp. 303-311.

[9] Dixon P.G., Allen M., Gosling S.N., Hondula D.M., Ingole V., Lucas R. and Vanos J. 2016. Perspectives on the Synoptic Climate Classification and its Role. *Interdisciplinary Research Geography Compass*, volume **10(4)**, pp.

[10] Kudzh S.A., Tsvetkov V.Y. 2019.Trinitarian systems. *Russian Technological Journal*, No **7 (6)**, pp 151-167.