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PAPER • OPEN ACCESS

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To cite this article: R S Shirokov and A A Vasiliev 2020 *IOP Conf. Ser.: Earth Environ. Sci.* **579** 012154

IOP Conf. Series: Earth and Environmental Science **579** (2020) 012154 doi:10.1088/1755-1315/579/1/012154

Using GIS technologies to create a scientific and information geoecological base in Western Yamal to identify the effects of climate change

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Abstract. Climate change and marine conditions affecting the formation and evolution of the permafrost zone of the shelf and the continental margin of the Russian Arctic, is an urgent problem for the Russian sector of the Arctic. The results of long-term monitoring of the permafrost zone clearly demonstrate the degradation of frozen rocks both in continental and in subaquatic conditions of the western sector of the Russian Arctic. The coastal-marine region of Western Yamal is the most vulnerable and therefore model territory with climatic changes. The assessment of the dynamics of the geoecological conditions of the coastal-marine region of Western Yamal with climate change is impossible without a GIS component. At the same time, the study of geoecological processes and their mapping becomes especially relevant for the preparation of long-term plans for the development of climate-dependent branches of economic activity. The permafrost zone of the western sector of the Russian Arctic remains poorly understood. Climate warming in the western sector of the Russian Arctic is recorded after 1970. There is an increase in air temperature and duration of the warm period, a change in the amount of precipitation, and an increase in snow thickness.

1. Introduction

The increasing interaction between nature and man, the phenomena of irrational exploitation of natural resources, technogenic disruption and industrial pollution lead to significant deterioration of the natural environment, living conditions and health of people. The tense environmental situation makes the creation of information bases, applied geoinformation systems and the use of GIS technologies intended to solve a number of issues in the field of environmental management and protection particularly relevant.

The extensive practical application of GIS technologies is most often limited to cartography and is used in navigation, in the construction of interactive maps of cities, settlements, etc. In terms of system studies the most advanced are open public geographic information systems. Google and Yandex interactive maps can be an example of such GIS. The measure of reliability of such maps can be checked independently, most modern computers and communicators have built-in GIS data interfaces. Yandex and Google maps represent similar software complexes. They already have developer programming interfaces to handle applied problems [1, 2].

The improvement of GIS efficiency in environmental monitoring opens up qualitatively new opportunities. Environmental monitoring may include both geophysical and biological aspects, which defines a wide range of research methods and techniques in its implementation. GIS technologies increase the requirements for the creation of planning and mapping materials. As a result, there is a need to obtain specific and accurate updated information on the spatial location of natural objects [3]. In order to study the existing relations and understand the principles of interaction between the components of natural and technogenic systems, it is necessary to process a huge amount of statistical and spatial information and to ensure its presence in a single geographical database.

Besides, there is a need to focus on the combination of geo-information technologies (graphic data administration) and modern technologies of processing, storage and provision of semantic (attribute) information, not only such as DBMS (database management systems), but also such as the big data and the block chain.

With the development of computer technologies and their introduction into geography and mapping, there have been significant changes in the process of map creation and analysis. The indispensable condition for storage, processing and analysis of information is development and seeding of electronic databases suitable for direct (without reformatting and addition) use in GIS.

The research is aimed at studying a new major natural phenomenon – the formation of the extensive area of cryolithozone experiencing a widespread transition from stable to unstable condition. The data of adapted monitoring geoecological observations will form the basis for the analysis of environmental changes and verification of mathematical models.

2. Materials and methods

Research methods: field, cartographic, landscape, landscape-indicative, comparative-geographical, geoinformation, mathematical-statistical. The landscape-indicative method in geoecological studies is used to refine the sensing data since the object of mapping can be hidden from direct observation and is not always reliably displayed on remote sensing materials). The indispensable condition for storage, processing and analysis of information is development and seeding of electronic databases suitable for direct (without reformatting and addition) use in GIS.

The coastal-marine region of Western Yamal as the most representative in the central part of the western sector of the Russian Arctic. Besides, it is the most vulnerable and therefore is considered the model territory in case of climate change.

The scientific-information **geo-ecological base of Western Yamal** (hereinafter referred to as **DB_WYamal**) to identify the effects of climate change includes various geo-ecological indicators (data), namely:

• *meteorological and climatic measurements* based on the Marre-Sale weather station, such as air temperature (per minute and per hour, daily average, annual average and long-term average measurements); continuous measurements of precipitation and their average values per day, month, year, summer and winter; atmospheric pressure; soil temperature*;* wind direction data since 1999 and its mean long-term values (wind roses since 1999) [4];

• *snow cover* state – snow cover height from winter 1960/61 until the present; snow density data after 1992/93; height of snow cover and its relation to the meteorological height of snow;

• *hydrometeorological and marine hydrological observations*, including data on the duration of ice-free period; annual data on stable ice cover period and ice-free sea period (since 1942); sea water temperature of the coastal and marine region (per minute and per hour measurements, daily average, annual average and long-term average measurements); coastal-marine region seawater salinity; direction and length of sea waves; period of sea waves for every 3 hours; daily measurements of wave height during the ice-free period since 1989;

• *wind, and, as a consequence, waves*, is an important climatic characteristic for the consideration of factors affecting the dynamics of sea coasts. As a rule, the impact of storms is mainly considered. It is believed that the destruction of coasts is mainly caused by storm waves combined with large onsets.

Unfortunately, due to large intervals in observations of sea disturbance parameters it is impossible to create a complete database [5];

• *geological and geocriological structure*, permafrost temperature conditions in wells (data collected for the period from 1979 until the present from 50 wells with the depth of 10+m; over the years, the number of wells decreased for various reasons) (Figure 1); geological structure and temperature conditions of permafrost at its degradation through the transition from continental to subaquatic state and, on the contrary, permafrost neoplasms on low accumulative surfaces in wells for the period from 2006 to 2008 in 3 wells with the depth of 1-95 (100 m), 2-00 (40 m) and 3-01 (83 m) drilled by VSEGIENGEO [5, 6].

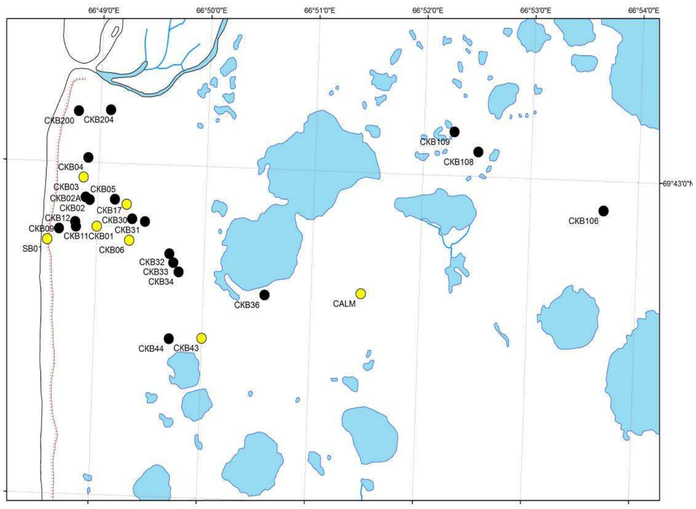

Figure 1. Layout of observation wells. The wells in which observations are carried out to the present are marked yellow

• *rock temperature in wells at CALM sites* based on CALM database and Thermal State of Permafrost (TSP), GTNP [7–9];

• *average annual temperature of permafrost*, distribution of permafrost temperature in depth, temperature condition of soil and the top horizon of permafrost and landscape in five prevalent landscapes (data collected from 1999 until the present from seven wells in 10x10 m site); all observation sites have landscape reference (indices according to VSEGINGEO classification) [10, 11];

• *geobotanical descriptions*, which included the registration of species composition on chosen hundred-meter sites, determination of abundance, design coating and height of plants, description of vertical and horizontal structure of plant communities; large-scale map charts of horizontal structure of plant communities (58 species of vascular plants and 23 species of lichens, and 21 species of mosses) created by landscape-indicative method [11–13];

• *meteorological*, oceanological and cartographic sites and archives (OcheanDB, oceanographers, gis-lab, noaa, meteo.infospace, cliware, aisori, etc.);

• *arctic coast dynamics* from the Arctic Coastal Dynamics (ACD) project [14, 15], namely recession of coasts and their structure; geological and geocriological structure of a sea cliff, ice content, morphology of the cliff and the seabed adjacent section, mechanism and speed of coast destruction; *dynamics of beach and shore slope surface* on coast-orthogonal fixed section by levelling method for the period from 2006 until the present [16, 17];

• GIS Barents and Kara Seas (hereinafter referred to as **GIS_BK**) – bathymetric and temperature GIS – sea depth, temperature and salinity of sea water (collected by marine organizations of Russia, USA, England, Germany, Norway and Poland from 1898 to 2005); sea water bottom layer temperatures (collected by research institutes – Arctic and Antarctic Research Institute, P.P. Shirshov Institute of Oceanology, RAS, Tyumen Research Center, SB RAS) [18]. The **GIS_BK** served the basis for the

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creation of temperature distribution and salinity of seawater bottom layer maps; 2D and 3D models of bottom temperature distribution within Barents and Kara seas based on terrain features (Figure 2) [17, 19];

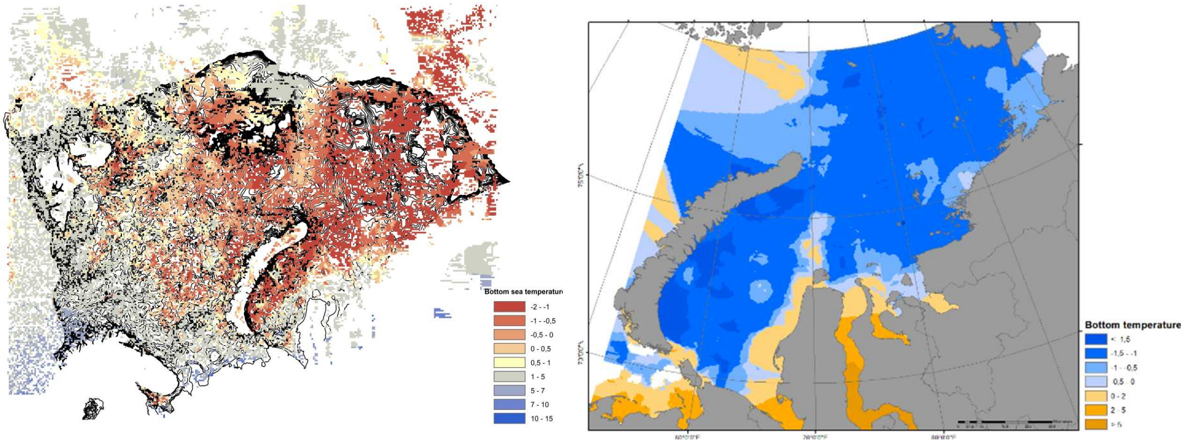

Figure 2. Bottom temperature distribution models

• **GIS – orientation map of types of cryogenic strata of a geostationary station** and the adjacent coastal-marine region created on the basis of the study of permafrost distribution and mode of occurrence in the continental part and submarine cryolithic zone (Figure 3) [19].

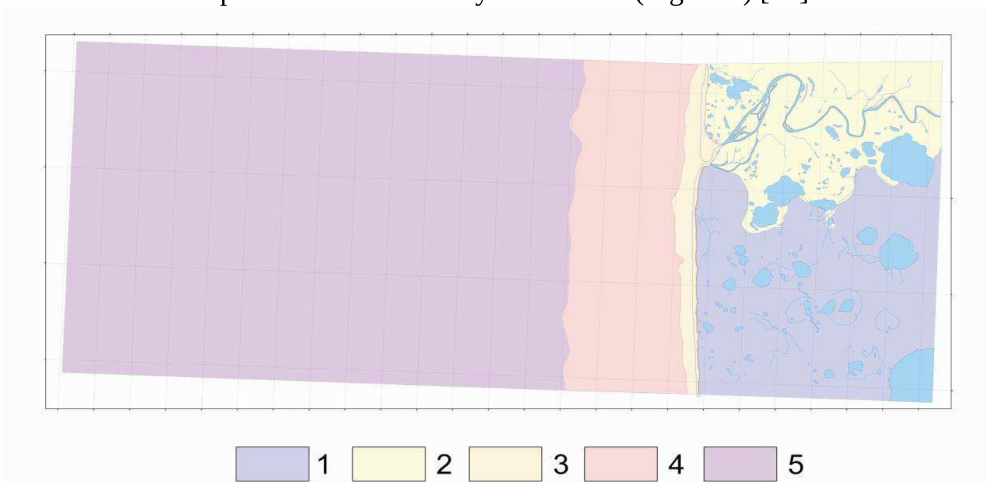

Figure 3. Map of types of cryogenic strata of a geostationary station: 1-5 – types of cryogenic strata:
1 – continental permafrost of the third sea terrace, hard frozen to a depth of 90 m, underlain by negative-temperature non-frozen plastic rocks. The temperature of the permafrost in different landscapes ranges from -4.5 °C to -7.5 °C. The layer depth of annual heat rotations reaches more than 10 m;
2 – continental IMF floods and floodplains of the river. Marre Yaha, hard frozen to a depth of 40 m, underlain by negative-temperature non-frozen plastic rocks. The temperature of the permafrost in different landscapes ranges from -2.5 °C to -4.5 °C. The depth of the layer of annual heat rotations is about 10 m.
3 – degrading high-temperature permafrost, wedging into the sea at a distance of 200-300 m from the coastline. The average annual temperature of the permafrost in the transit region, depending on the degree of salinization, varies in a relatively narrow range and amounts to -1 ÷ -2 °C. The depth of the layer of annual heat revolutions does not exceed 3 m.
4 – talik or massif of unfrozen rocks with temperatures above the temperature of the beginning of freezing - thawing. The complete thawing of SMMP in this area is associated with intense heating of sea water in a shallow area.

5 – island SMMPs separated by unfrozen negatively temperature massifs of rocks. SMMPs are in a quasi-equilibrium thermal state. The average annual temperature of the SMMP is close to the temperature of the onset of freezing and thawing and, as a rule, is below -1 °C.

3. Conclusion

The Scientific and Information Geoecological Base of Western Yamal (**DB_WYamal**) was used for geoecological assessment of the environmental condition of the coastal and marine region of Western Yamal and made it possible to develop the following:

• criteria to assess the environmental condition and its components, such as climate, landscape, terrain, permafrost, soil, vegetation;

• formats and primary filling of geocriological monitoring databases in continental conditions according to previous observations;

• integrated (integral) assessment of environmental condition and its components of the coastal-marine region of Western Yamal in case of climate change;

• GIS-orientation map of distribution, conditions and degradation rates of subaquatic cryolithozone for the Kara Sea based on the **GIS of Barents and Kara Seas (GIS_BK)**;

• algorithm of **DB_WYamal** replenishment in formats suitable for use in GIS;

• analytical maps of spatial-temporal distribution of bottom temperature and salinity of water on the basis of bathymetric and geological data of the shelf zone features of the northern seas;

• refinement of analytical GIS-orientation geo-ecological maps based on the analysis of climate parameters of Western Yamal and hydrodynamics of the Kara Sea;

• geoecological models (map charts) of environmental change assessment.

Thus, the application of a set of methods will achieve the main objective – geoecological assessment of environmental condition of the coastal and marine region of Western Yamal in case of climate change. This will result in further geoecological score-rating assessment of degraded cryolithozone – geographical distribution, thermal mode, new properties of frozen and thawing rocks both in continental conditions and in the area of subaquatic frost of the Kara Sea.

4. Acknowledgments

The study of the conditions and parameters of permafrost degradation was carried out with the support of the Russian Foundation for Basic Research, grant No. 18-05-60004, the assessment of changes in geo-ecological conditions was carried out with the support of the Russian Foundation for Basic Research, grant No. 19-35-90049

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