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PILOT PROJECT FOR MONITORING FLUXES OF CLIMATE ACTIVE GASES ACROSS RUSSIA AMID THE OBSERVED AND PROJECTED CLIMATE CHANGES

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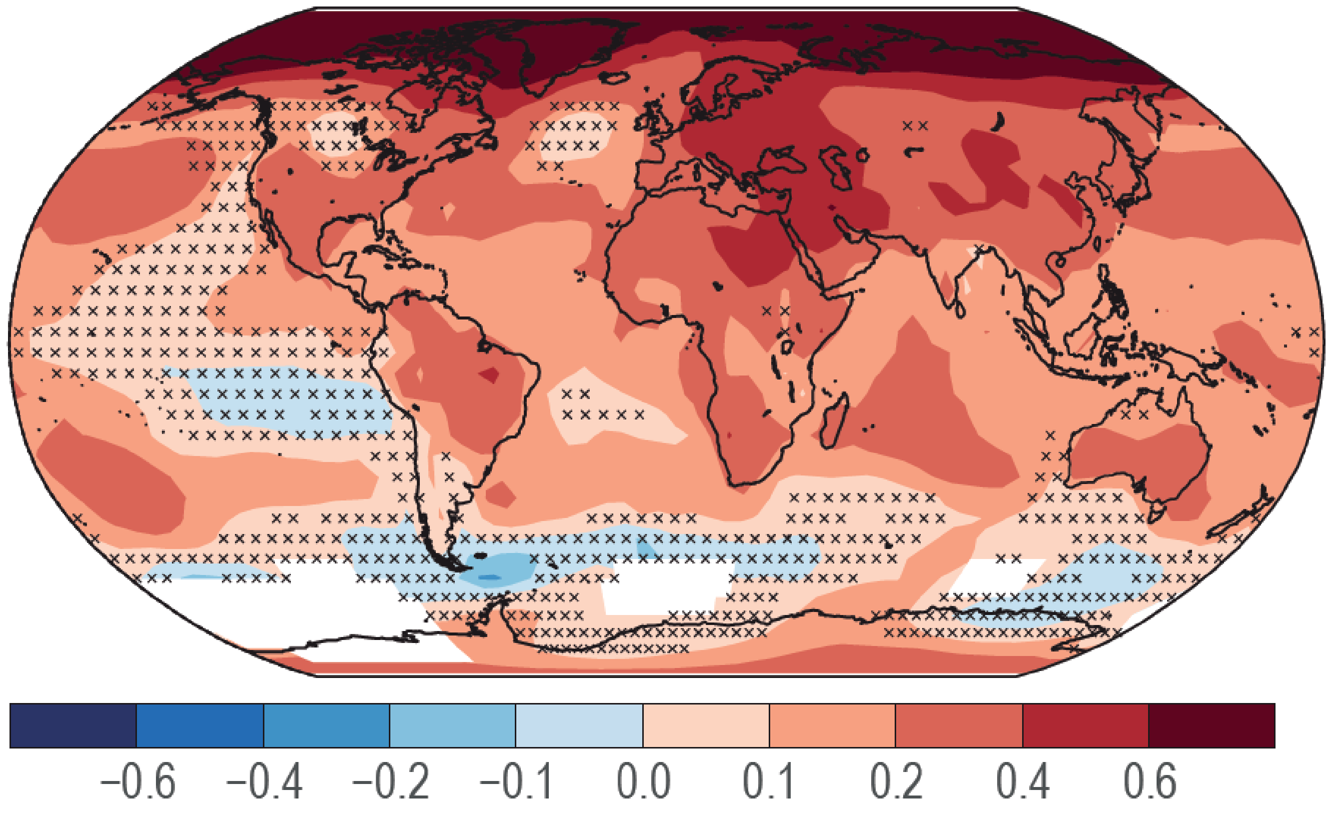
1 OBSERVED CLIMATIC CHANGES AND THE ROLE/CONTRIBUTION OF CLIMATE ACTIVE GASES

The climate changes observed today on Earth are unprecedented in terms of inten-sity and speed of changes in key climatic parameters, primarily surface tempera-ture. This statement is based on the conclusions of all the Assessment Reports of the Intergovernmental Panel on Climate Change (IPCC), including the latest, Sixth Assessment Report of 2021. The last decade (2011-2020) was the warmest decade in the history of instrumental observations. Moreover, starting from the 1980s, each decade has been warmer than the preceding one and, also, warmer than any previous decade since records began in 1850. The global surface temper-ature in 2011-2020 was 1.1 °C higher than in 1850-1900, while warming over land (1.59°C) was greater than over the oceans (0.88°C). Between 1976-2020 the average rate of global warming was 0.18°C per 10 years, and the average global temperature rose by 0.8°C. Importantly, the temperature rose quicker in the Northern Polar region, where the linear increase in the average annual temper-ature over 30 years (1991-2020) was about 2.64°C with trends reaching more than 0.7°C per decade (Fig. 1) as estimated by Roshydromet.

This heterogeneity of global warming is especially evident in Russia, where the increase in surface temperature significantly exceeds the global trend. According to the 3rd Assessment Report on Climate Change and its Consequences for the Russian Territories, issued by Roshydromet in 2022, the Russian land is warming up almost twice as fast as land as a whole: 0.51°C per decade, and every decade from 1981-1990 onwards has been warmer than the preceding one, and out of the 10 warmest years of all time, 9 were observed in XXI century.

Global warming significantly affects the Earth's entire climate system. The warm-ing of the oceans and the resulting melting of glaciers has led to a rise in the sea level of about 3 mm per year over the past 30 years, meaning that since the early 1990s, the average sea level has risen by



× × × – statistically insignificant changes

Fig. 1. Map of linear trends of surface air temperature for the years 1981-2020 (°C per decade) from the 6th IPCC Assessment Report

about 90 mm. In the Arctic Ocean, the area of sea ice continues to decrease: it is at its minimum in September each year, and the average over 2011-2020 decreased by 13.1% relative to the 1981-2010 average. The Arctic sea ice becomes younger and thinner.

The main cause of the observed climate changes over the past 170 years is the emission of climate active gases into the atmosphere consisting primarily of car-bon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). These gases, which are called well-mixed long-lived gases, cause the warming effect by preventing long-wave solar radiation from leaving the climate system. Halogen gases (CFCs, HCFCs, HFCs, PFCs, SF6) also contribute to it, but their effect on climate is somewhat smaller. Climate active gases are emitted into the atmosphere as a result of, firstly, human activity, and secondly, naturally occurring biogeochemical pro-cesses in the Earth's climate system. Anthropogenic emission sources of climate active gases are energy production, transport, agriculture, various industries, the relative shares of which in emissions vary from country to country, with the main source of emissions in most countries being energy production. Changes in land use and modification of landscapes also contribute greatly to the emission of cli-mate active gases. Atmospheric concentrations of the three main greenhouse gases have increased since the pre-industrial era: CO_2 by 46%, CH4 by 157% and N_2O by 22%.

2 PROJECTED CLIMATE CHANGE

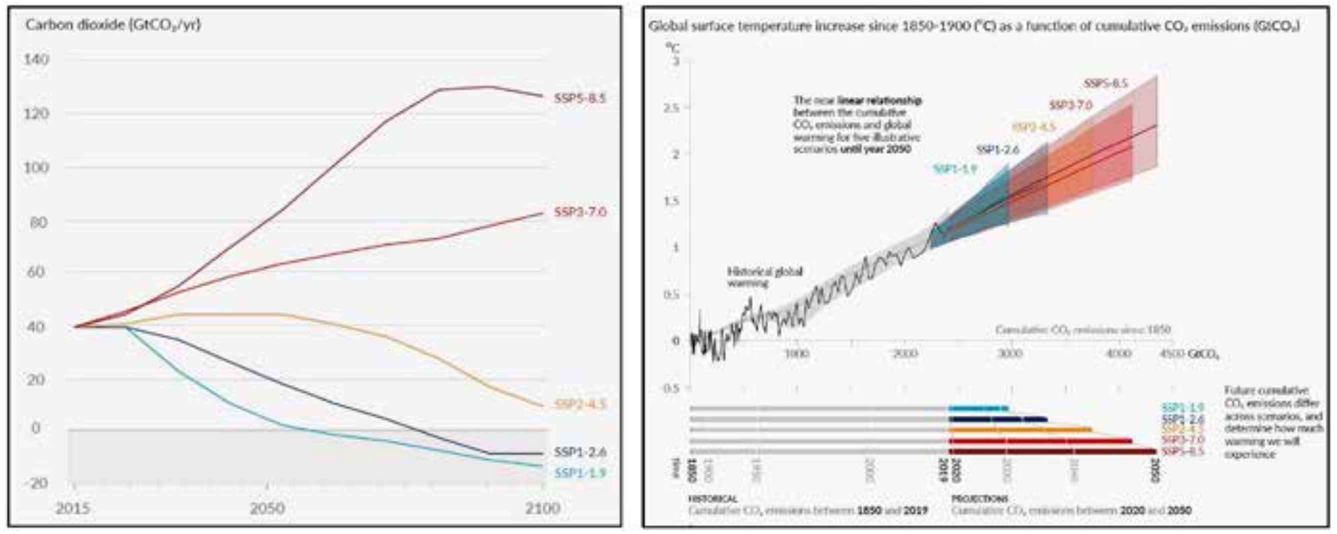
The dominant role of emissions of climate active gases on the average global tem-perature makes it possible to predict climate changes for the coming decades and the rest of the century. Such forecasts are based on experiments with climate models that take into account various factors of climate change, including concen-trations of climate active gases, which determine the so-called radiation equiva-lents (effective radioactive forcing). To increase the reliability of climate projec-tions, the IPCC currently uses over 100 models of the Earth system, which differ in configurations, parameterizations used and spatial-temporal resolution. To obtain prognostic climate characteristics with each model, normally, a number of experiments (up to 10) is run with different initial conditions. This approach has been called an ensemble approach: it gives several solutions, the spread of which allows us to estimate the uncertainties of projections associated with model con-figurations. In addition to the uncertainties of projections associated with models, considerable uncertainties of climate forecasts are associated with emission scenar-ios developed on the basis of economic models taking into account the paths of the world economy and socio-economic processes. Scenarios that are defined as «Shared Socio-Economic Pathways» (SSPs) include predictive estimates of emis-sions of climate active gases as well as predicted changes in land use and a number of other factors (Fig. 2).

The model experiments underpinning the described scenarios show that global temperature rise at the surface would exceed the threshold of 2°C, relative to the "pre-industrial" period of 1850-1900, by about the year 2043 under the scenarios SSP3-7.0 and SSP5–8.5, and the threshold of 3.0°C – by about 2060 under the scenario SSP5-8.5. At the same time, the rise in temperature in the Arctic is pre-dicted to exceed the global average by a factor of over 2.5. Under the scenarios SSP2-4.5, SSP3-7.0 and SSP5-8.5 the Arctic would be ice-free in September by 2100. Prognostic calculations performed by Roshydromet and included in the 3rd Assessment Report on Climate Change and its Consequences for the Russian Fed-eration (Fig. 3) show that in the northern regions of the country, the surface tem-perature in summer may increase, in relation to the current levels, by more than 7°C in winter and up to 12°C in summer by 2081-2100, under the harshest scenar-io SSP5-8.5.

Thus, prognostic estimates show that anthropogenic factors, i.e. greenhouse gas emissions, can lead to critical changes in both the global climate and climatic con-ditions across Russia, which would seriously affect all aspects of the country's life and economy, including agriculture, energy, and quality of life.

Figure 2. Five main scenarios of greenhouse gas emissions for which climate prediction experiments were conducted within the framework of the 6th IPCC As-sessment Report. The scenarios are expressed in Gt of CO_2 per year. The SSP1-1.9 scenario assumes a sharp reduction in emissions to almost zero by 2050. The SSP5-8.5 scenario assumes aggressive economic development with emissions in-creasing until 2070 and their subsequent stabilization.

Five illustrative sce-narios of global surface temperature increase by 2050 show that even under the scenario SSP1-1.9, with a drastic reduction in emissions, the temperature rise would exceed 1.5ºC, and possibly 2ºC.



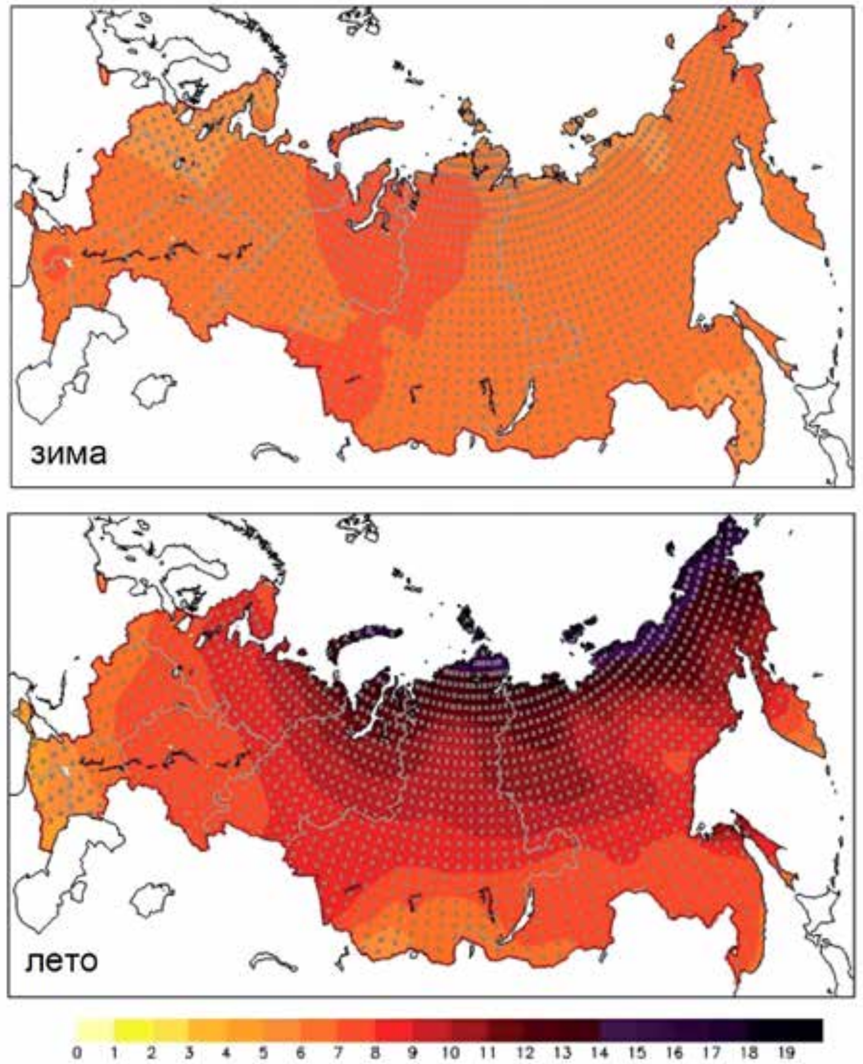


Fig. 3. The projected increase in surface air temperature (°C) in Russia for 2081-2100 under the harshest scenario SSP5-8.5 for winter (above) and for summer (below), according to the 3rd Assessment Report of Roshydromet on climate change and its consequences for the Russian Federation.

3 INTERNATIONAL EFFORTS TO MITIGATE GLOBAL WARMING

Taking into account the noted critical consequences of global warming, the inter-national community, starting in the 1990s, began to make efforts to reduce green-house gas emissions. The first significant milestone of such activity was the Kyoto Protocol, which was adopted on December 11, 1997, but, given the complex rati-fication process, entered into force on February 16, 2005. Currently, the Kyoto Protocol unites 192 Parties.

The Kyoto Protocol put into effect the United Nations Framework Convention on Climate Change, obliging industrialized countries and countries with economies in transition to limit and reduce greenhouse gas emissions in accordance with agreed individual goals. The Kyoto Protocol defined a list of major greenhouse gases, set mandatory emission reduction targets for 37 industrialized countries and countries with economies in transition, as well as for the European Union, and introduced mechanisms to monitor compliance with obligations. At the same time, many of the provisions of the Kyoto Protocol were advisory only.

Overall, these targets represented an average 5% reduction in emissions compared to 1990 levels during 2008-2012 (the first commitment period). In 2012, the Do-ha Amendment to the Kyoto Protocol was adopted in Doha (Qatar) for the second commitment period of 2013–2020. However, the Kyoto Protocol could not meet. The challenge of achieving carbon neutrality in the foreseeable future, due to the non-mandatory nature of its many provisions and the lack of strict implementation control mechanisms. Anthropogenic emissions and, accordingly, greenhouse gas concentrations in the atmosphere, continued to grow.

As a follow-up to the Kyoto Protocol, on December 12, 2015, the Paris Agreement was approved under the United Nations Framework Convention on Climate Change and became the first legally binding international treaty on climate change. The Agreement was signed by 196 parties and entered into force on November 4, 2016.

The goal of the Paris Agreement is to limit global warming to 2 (and possibly 1.5)°C compared to pre-industrial levels. To achieve this goal, the participating countries must achieve climate neutrality in greenhouse gas emissions by the mid-dle of this century. The Paris Agreement legally obliges all signatories to apply large-scale efforts to combat climate change and adapt to its consequences.

To implement the Paris Agreement and reduce greenhouse gas emissions, coun-tries need to perform deep economic and social transformations: develop new methods of producing energy, new technologies for various types of economic ac-tivities aimed at reducing emissions, including technologies that increase the ab-sorption capacity of natural ecosystems, primarily forests and agricultural land.

The successful development of such technologies requires efforts in a number of directions. Firstly, detailed monitoring of the fluxes of climate active gases in var-ious ecosystems is needed to produce high-precision estimates of basic greenhouse gas fluxes in order to assess the effec-

tiveness of certain technologies that contrib-ute to their absorption. Having such estimates, it is possible to start planning the development of greenhouse gas sequestration technologies tailored to particular types of landscapes and, thus, strengthen the role of natural ecosystems in the ab-sorbing of greenhouse gases from the atmosphere.

Returning to the emission scenarios discussed above (Fig. 2), the IPCC 6th As-sessment Report showed that under the SSP5-8.5 scenario, terrestrial and ocean ecosystems can "cope" with only 38% of greenhouse gas emissions into the at-mosphere. Under the SSP1-1.9 scenario, this figure is 70%. That is, in order to achieve carbon neutrality, 62% of emissions from the former scenario and 30% from the latter should be utilized - by using some new industrial technologies and the introduction of smart ecosystem management. Given the impracticability of fully implementing the SSP1-1.9 scenario, we should focus at least on the SSP1-2.6 or SSP2-4.5 scenarios, necessitating utilization of 35% and 46% of green-house gas emissions by industrial and ecosystem technologies, respectively.

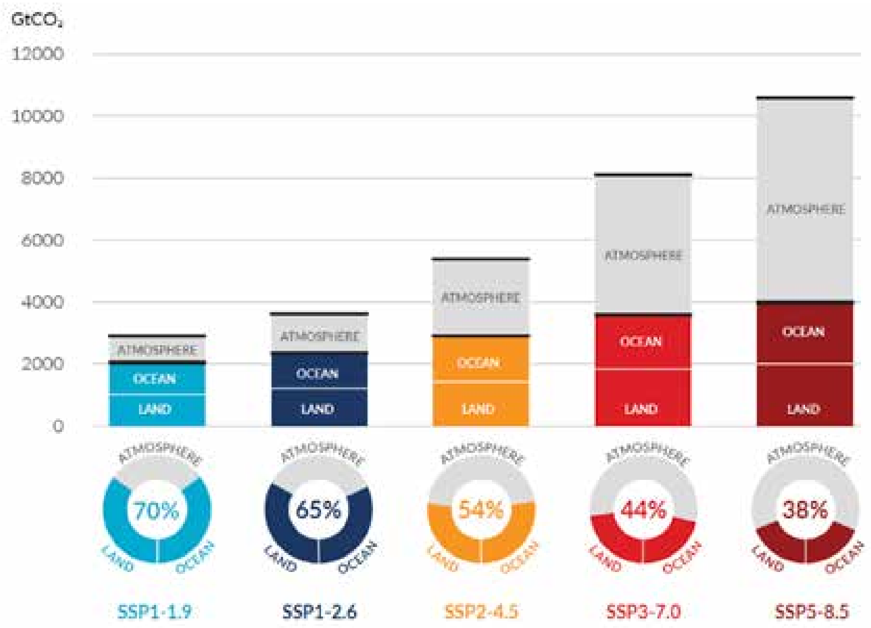


Figure 4. Total cumulative co_2 emissions (Gt) absorbed by land and oceans (shown in color) and remaining in the atmosphere (gray) under the five emission scenarios until 2100, according to the 6th IPCC Assessment Report.

4 PILOT PROJECT OF THE MINISTRY OF SCIENCE AND HIGHER EDUCATION OF THE RUSSIAN FED-ERATION ON MONITORING THE FLUXES OF CLIMATE ACTIVE GASES IN THE RUSSIAN FEDERATION

The pilot project of the Ministry of Science and Higher Education of the Russian Federation is aimed at assessing the balance of greenhouse gas fluxes for various ecosystems of Russia and the development of technologies for the sequestration of greenhouse gases.

When assessing the share of individual countries in gas emissions, the main indica-tor will be net emissions (I.e. the difference between emissions and absorption). Thus, the assessment (inventory) of the net emissions of climate active gases by each country boils down to performing reliable quantitative accounting of both man-made or natural sources and sinks of gases. In the current conditions, this is not a purely scientific or environmental matter, but it also presents a political and economic challenge, since it requires a degree of trust towards national monitor-ing systems of climate active gases and the inventories of gas emissions and se-questrations. Any lack of clearly defined standards for measuring and calculating emissions and absorptions may cast doubts on the countries' inventories of cli-mate active gases and produce political and economic tensions.

In other words, if the country does not develop technologies for taking inventory and monitoring gases it may face the need to accept «on faith" the estimates ob-tained by the satellite monitoring, which might be impossible or difficult to veri-fy, and the estimates based on models, which may not be accurate or reasonably approximated over large territories. This might lead to the weakening of the Rus-sia's position when discussing financial and economic issues related to the imple-mentation of international agreements and the expected introduction of cross-border carbon regulation of trade flows. A weak and ill-founded negotiation posi-tion may result in significant financial losses for the country (estimated between 4 and 24 billion dollars per year according to various sources).

In order to build an effective monitoring system for climate active gases and pro-vide it with effective technologies and techniques all over Russia, the Ministry of Science and Higher Education of the Russian Federation launched, in 2021, an ex-tensive project to create a network of scientific and educational measurement su-persites for the development, testing and validation of technologies for quantify-ing emission and sequestration potentials of various types of ecosystem. The stra-tegic goal of the pilot project is to assess the potential of Russian ecosystems for the sequestration of climate active gases. At the same time, the project will solve several tasks. Firstly, we will obtain reliable integral estimates of the fluxes of the main greenhouse gases for certain types of landscapes across Russia, which is es-sential for international reporting. Secondly, we will get an assessment of the po-tential of various types of landscapes for greenhouse gas absorption. And, finally, we test sequestration technologies that are most effective in various landscapes and the create a roadmap for the implementation of climate projects in natural ecosys-tems of Russia.

Within the framework of this pilot project, carbon measurement su-

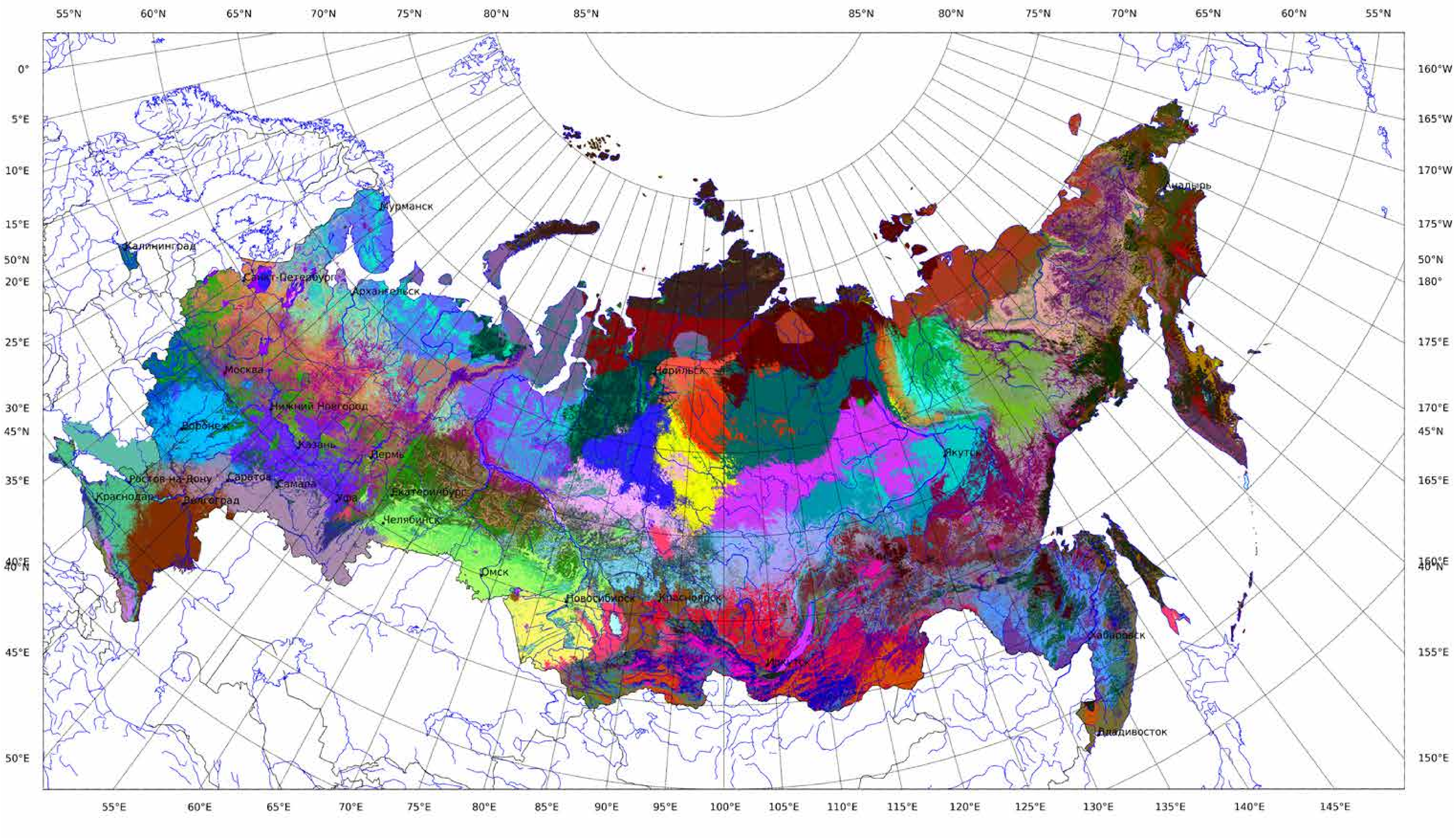
persites are be-ing created across a wide range of natural ecosystems, which are both gas emitters and absorbers. Such areas are various types of forests, swamps, permafrost, coastal waters, areas of active agricultural production, etc. At each supersite, pre-cision measurements of the fluxes of the main climate active gases, heat and mois-ture fluxes based on pulsation and chamber methods, and direct emissions from the soil surface are performed. Such measurements are taken by a network of ground sensors as well as by remote observations using unmanned aerial vehicles equipped with essential sensor kits – multi- and hyperspectral cameras, radars, li-dars, etc. The composition and configuration of measuring instruments depend on the characteristics of a measurement site. Occupying relatively small areas, total-ling tiny fractions of the Russian territories, but being representative of the types of landscapes that make up sizeable percentages of the country's area, the measur-ing supersites will form an effective observation network for solving the tasks outlined above.

The observations carried out at the supersites will be integrated into international observation and research programs, including the EU-Copernicus CO2 Human Emissions project (CHE), FLUXnet, Advanced Global Atmospheric Gases Exper-iment (AGAGE), WMO Global Atmospheric Watch (WMO-GAW), Global Cli-mate Observing System (GCOS) and others. In the future, the measurement su-persites will grow from purely monitoring sites to experimental sites for landscape modification, where the effectiveness of the absorption potential of various types of ecosystems will be assessed.

Such experimental work may include sowing highly absorbing crops, changing the type of soil, studying the sequestration potential of mariculture and other technologies. The most successful projects may later turn into climate projects im-ple-mented by industrial partners of supersites. A full evaluation of the results of the monitoring system created on the measurement supersites will be possible in a decade, although many key assessments will be available and ready to use in 3-4 years.

Being scientific and educational structures, the measurement supersites also per-form capacity building for the development and maintenance of a climate moni-toring system. The task of monitoring climate active gases is interdisciplinary, and requires the involvement of specialists in a variety of fields – climatology, mete-orology and oceanography, numerical modeling, measurement technology, ma-chine learning, etc. This required the adaptation of existing and development of new master's and postgraduate programs consolidating knowledge from different fields. This involved joint efforts of leading universities and research institutes to create new educational formats related to the measurement supersites.

GENERAL MAP OF BIOME CLUSTERING IN RUSSIA FOR THE ANALYSIS OF REPRESENTATIVENESS OF OBSERVATION SITES



CLUSTERING OF BIOMES OF RUSSIA FOR ANALYSIS REPRESENTATIVENESS OF OBSERVATION SITES

Obtaining information about the spatial distribution of greenhouse gas fluxes and, ultimately, integral estimates of fluxes and components of the carbon budget of Russia is impossible without a detailed account of the landscape heterogeneity of the country's territories. To obtain integral estimates of fluxes using discrete measurement data, it is necessary to develop a methodology for spatial data interpolation based on a set of factors that take into account regional climatic conditions, vegetation structure and species composition, soil cover structure, topography, etc.

Well-equipped stations for monitoring greenhouse gas fluxes in Russia are quite rare, which prevents the use of conventional statistical methods for interpolating discrete observation data. The measured fluxes are representative mostly for very small areas around measuring towers, which creates a challenge of scaling the data to larger areas and their further interpolation using nonlinear models with a set of parameters describing climatic and geomorphologic conditions, the structure of soil and vegetation cover. Complex models with a large number of input variables usually accumulate errors in parameters and initial data, and these accumulated errors can significantly outweigh the advantages of accounting for the features of the simulated nonlinear processes. To streamline the spatial data interpolation, the calculation of ecosystem functioning parameters, and, ultimately, the calculation of carbon fluxes can be achieved by constructing regional linear models. The operational unit of modeling in such cases can be an ecoregion featuring similar climate, topography, soil and vegetation cover properties.

Statistical modeling methods were used in the study to formalize the process of eco-region definition. A set of variables characterizing the topography, climate, structure and condition of soil and vegetation cover as well as vegetation parameters are given in the Table.

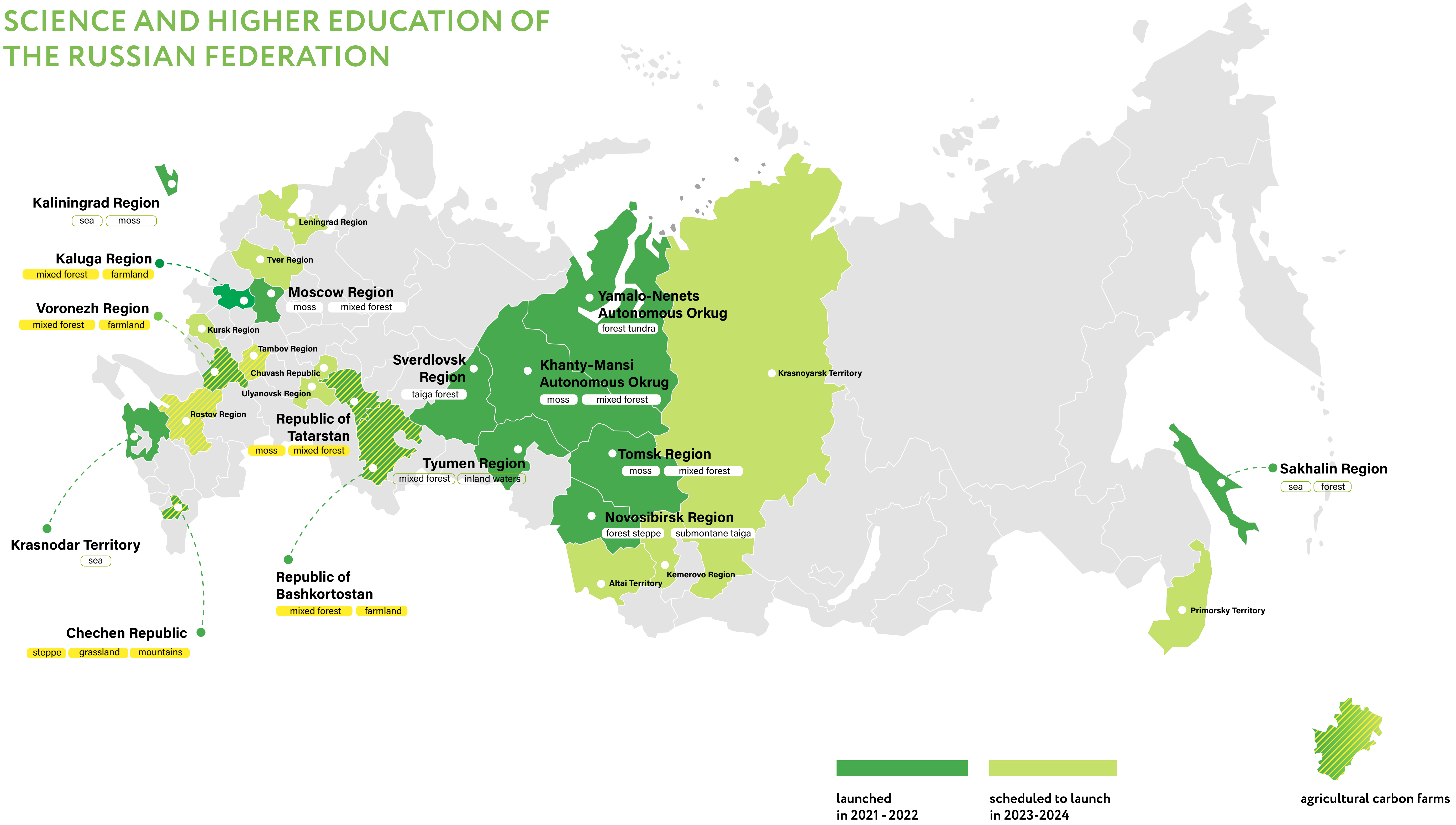
Subsequently, matrix data on various ecosystem parameters were subjected to a clustering procedure based on the K-means method. This algorithm identifies clusters or centroids (defining cluster centers), referring each data point to the nearest cluster, while maintaining the characteristics of centroids. This problem is solved iteratively with optimization for various statistical parameters. Each cluster has a minimum variance of values for the selected variables and, therefore, can be considered as a unique physical and geographical region for our purpose. Clusters in our study are types of representative landscapes to justify the location of stations in the network of carbon measurement supersites. Each cluster is characterized by a homogeneous (regarding the formation of fluxes of climate active gases) landscape.

The conducted zoning allows us to conclude that the existing 15 measurement supersites are representative of landscapes covering an area of 392,800,000 ha. This is approximately 23.1% of the Russian territory (~17,000,000 km2). The total area of the 15 supersites themselves is about 40,000 ha, which is 0.002% of Russia, i.e. conducting research on 0.002% of the country, we get estimates that are representative of 23.1% of the country. Also, if we exclude the permanent snow/glacier regions which occupy 6,400,000 ha, and water bodies (without swamps), occupying 63,000,000 ha for which assessments must be carried out separately, then the adjusted estimate shows that the current 15 measurement supersites are representative of 24.4% of the Russian territories.

Data	Original resolution	Source
Topography data		
Absolute height, m Slope steepness	0,00083° или 3" (~ 90 m on the equator)	MERIT DEM http://hydro.iis.u-tokyo.ac.jp/
Climate data		
Average monthly solar radiation, MJ	0,0083° or 30" (~900 m)	WorldClim 2.1 https://worldclim.org
Average monthly temperature, °C Average monthly precipitation, mm		CHELSA Bioclim V2.1 https://chelsa-climate.org/bioclim
Vegetation and landscape data		
Spectral vegetation indices NDVI (2017-2021): 10 periods for the growing season (April 23 – September 14) 2 periods for the winter season (January 17 and February 2)	250 m	MODIS https://lpdaac.usgs.gov/
Vegetation map (landscape cover) for Russian territories	250 m	Space Research Institute RAS http://pro-vega.ru/
Soil data		
Carbon reserves in the upper 30 cm per m^2 Volume weight of soil kg/m^3	250 m	ISRIC SoilGrids https://soilgrids.org

MAP OF EXISTING AND PLANNED CARBON POLYGONS AT ORGANIZATIONS OF THE MINISTRY OF SCIENCE AND HIGHER EDUCATION OF THE RUSSIAN FEDERATION

Carbon Supersites
RUSSIAN FEDERATION



KEY RESULTS OF CARBON POLYGONS

Carbon Supersites
RUSSIAN FEDERATION

WAY CARBON POLYGON

Chechen Republic
Kadyrov Chechen State University

The carbon measurement supersite of ChSU is unique in conducting scientific research for the development of regenerative animal husbandry technologies in mountainous and foothill areas. Regenerative grazing management, in particular adaptive grazing with multiple pastures reduces soil degradation compared to continuous grazing, and thus, has the potential to reduce carbon emissions from the soil. The combination of crop rotation and maintenance of perennial cover crops with controlled grazing also contribute to the accumulation of organic carbon in soils.

This task is being solved under the scope of the project to create a pasture management instrument. In order to effectively achieve its goals, the University actively collaborates with climate and carbon scientists from the Peoples' Friendship University of Russia, the Voronezh State Forestry University, the National Research University of the Higher School of Economics, the Institute of Geography RAS, the Yu.A. Israel Institute of Global climate and ecology.

The project aims to identify the most effective methods of regenerative animal husbandry to increase carbon sequestration by pastures and to study the impact of climate on ecosystems of mountain and foothill landscapes. The prospective service will be based on a digital model of a pasture site, allowing to analyze the state of pastures and their possible degradation, to quantify the volume of the produced forage, to detect damage to soil and grass cover, wind and water erosion and traces of salinization. At each site (reference site, intensive grazing site, average grazing site), aboveground herbaceous vegetation is sampled to assess the volume and quality of biomass. The dominant plant species for each ecosystem are defined. In total, 62 species of vascular plants belonging to 31 families have been identified on the southern slope of the Makazhoy basin.

As part of the project, a mathematical model has been utilized that takes into account the mechanisms of physical stabilization of soil organic matter. The parameter identification of this model is currently taking place at test sites with regenerative animal husbandry.

This project should result in the restoration of soil quality and an increase in soil carbon content, an increase in the profitability of production by increasing the density of livestock on the same areas and a reduction in the cost of production due to the natural restoration of pastures.

Field research on the diversity of plant communities, soils, hydrological, geological and weather conditions on the compact territory of the Makazhoy basin of the ChSU carbon measurement supersite

WAY CARBON POLYGON

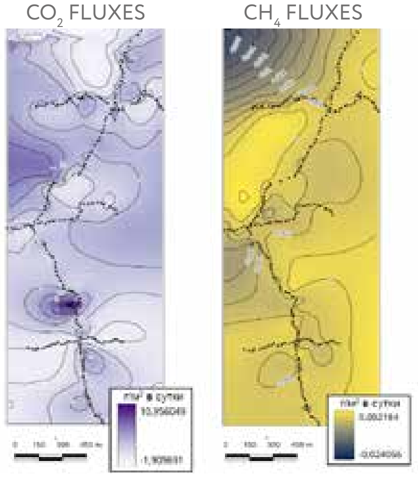
Chechen Republic
Grozny State Oil Technical University

Since May 2022, regular observations of the fluxes of climate active gases using covariance methods and chamber measurements have been conducted at the test plots. Also, a portable photosynthetic system LI-6800 is used for measuring photosynthesis and respiration of vegetation, as well as a mobile system with a closed-type analyzer G4301 (Picarro - USA). Simultaneously, multispectral surveys using unmanned aerial vehicles take place.

The obtained data allowed us to create long-term (5 months) series of fluxes of carbon dioxide, methane and nitrous oxide and establish the characteristics of their seasonal and short-period variability. Thus, seasonal changes in CO_2 amounted to 4 g/m^2 per day and exceed the short-term variability in magnitude. Meanwhile, the methane fluxes showed quite strong variations in the short-term (up to 0.1 g/m^2 per day) with practically no pronounced longer fluctuations associated with the seasonal course. Integral estimates obtained for one of the plots («Farm») showed magnitudes of inter-monthly variability associated with seasonal changes up to 300 mmol/m^2 per day. Soil respiration studies were carried out at the Roshni-Chu site using a mobile system based on a G4301 closed-type analyzer. The constructed maps of CO_2 and CH4 fluxes from the soil surface reveal a sufficiently strong spatial variability of fluxes of carbon dioxide and methane, well exceeding the average values for the site.

Photosynthesis parameters of the main edifiers and subedifiers of foothill broadleaf forests have also been studied at the supersite using a portable photosynthetic system for measuring photosynthesis and respiration of vegetation elements LI-6800 (complete with a light source, a 3x3 cm working camera and accessories) (LI-COR, USA). The conducted experiments showed significant interspecific differences in photosynthesis parameters of five deciduous tree species (oak, beech, hornbeam, hazel, walnut) growing under the canopy of mature stands among the broad-leaved forests of the foothills of the North Caucasus. The obtained results allow to quantify estimates of how various tree species differ in CO_2/H_2O-gas exchange at various vegetation stages, under different geographic conditions, in trees of various ages.

CO_2 FLUXES CH_4 FLUXES



Maps of CO_2 (left) and CH_4 (right) fluxes based on soil respiration data measured with a mobile system at the Roshni-Chu site

EURASIAN CARBON MEASUREMENTS TEST AREA

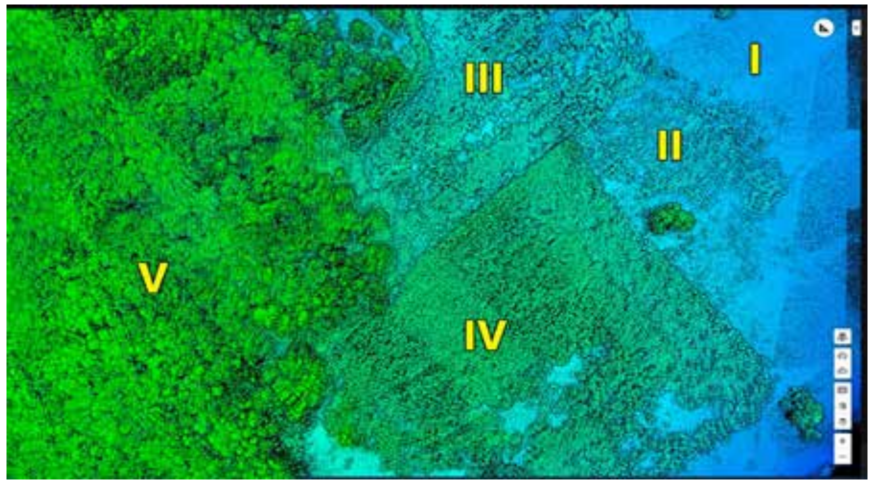
Republic of Bashkortostan
Ufa State Petroleum Technological University

Afforestation of long-fallow lands is one of the most effective ways to deposit carbon. In Bashkortostan, from 1990 to 2020, the acreage of cultivated land in forest and forest-steppe zones decreased by almost 35%. The Mishkino site is laid on disused lands within the broad-leaved forest zone of the Republic, where a fast-growing hanging birch (Betula pendula) dominates and the predominant age of the stand is 10-22 years.

To study the amounts of carbon deposition by vegetation and soil, 36 test plots were laid, differing in age and completeness of the stand. 1300 vegetation and soil samples were taken to analyze the dynamics of carbon deposition during the afforestation succession. The analysis of plant biodiversity was carried out, a floristic classification of the succession stages was developed in accordance with the Brown-Blanke approach. To analyze the productivity, we used the mowing method on 1x1m plots for herbaceous vegetation, and for woody vegetation we employed a set of forest taxational characteristics (height and age of the stand, trunk diameter) as well as the method of model trees involving measuring the mass of stem wood, branches and leaves. To analyze the phytomass of root systems, soil monoliths were collected to the depth of the greatest penetration of root systems (up to 50-60 cm).

Preliminary estimates show that carbon deposition on the entire Mishkino site, 10 x10 km in size, can range from 20,000 to 35,000 tonnes per year with the expected economic effect in 2021 prices ranging from 1,000,000 to 1,750,000 euros. To measure the productivity of the stand, a set of ground-based methods was used, as well as UAV surveys with multispectral and lidar cameras. The latter provided data on the height of trees with an accuracy of 2-5 cm.

The ongoing research at the Mishkino site will allow, in the near future, to proceed with the creation of the first carbon farm in the Republic of Bashkortostan. There will be developed methods to increase the sequestration potential of vegetation using agrochemical and forestry measures, which over time will let carbon farms to create profit.



Stages of birch growth on long-fallow land, obtained by lidar surveys from UAVs: stage I – age 2-5 years, stage II – age 7-10 years, stage III – age 12-15 years, stage IV – 18-22 years, stage V – 25-30 years.

Departure of a Matrice 300 RTK drone with a lidar camera to scan a section of a carbon landfill

CARBON POLYGON GELENDZHIK

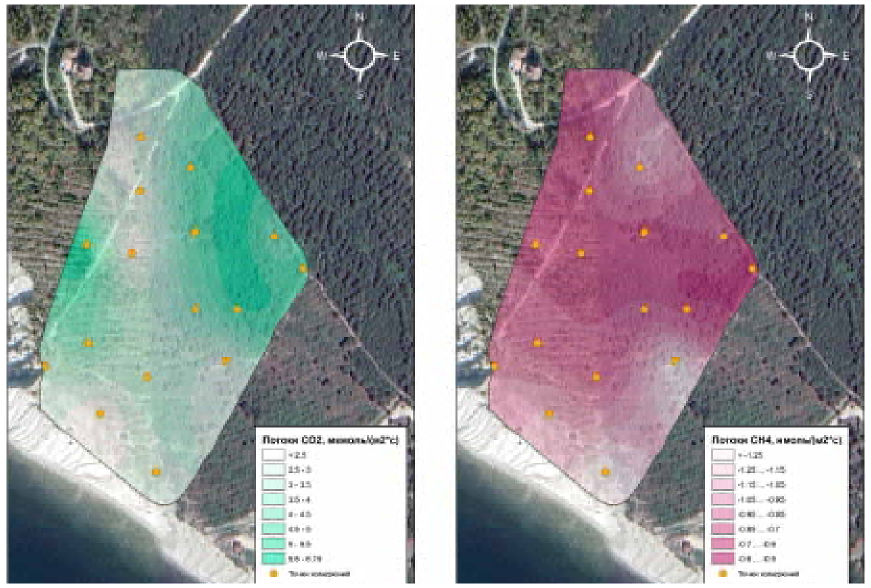
Krasnodar Region
Shirshov Institute of Oceanology
of Russian Academy of Sciences

Studies of CO_2 and CH_4 fluxes from the soil surface at the coastal site of the Gelendzhik carbon measurement superset were carried out in the summer of 2022. To conduct measurements, the site was divided into 16 plots with homogeneous vegetation and soil cover, the plots beingevenly distributed within the supersite. Measurements were taken both in daytime and at dusk under various weather conditions.

Analysis of the results of measuring CO_2 and CH_4 fluxes from the soil surface at the supersite showed high spatial and temporal variability determined by a combination of abiotic and biotic factors, including air and soil temperature, soil moisture, granulometric composition and carbon stock in the soil, species composition and structure of vegetation, its functional state, type, etc. CO_2 emissions from the soil surface varied from 2 to 6.15 mmol/m²s. The maximum emissions were detected in the northeastern and western parts of the supersite, associated with a significant contribution of autotrophic respiration of woody vegetation roots. The minimum CO_2 emissions (< 2.5 mmol/m²c) were observed in areas with herbaceous and shrubby vegetation in the southern part of the supersite where soil moisture was low.

The analysis of spatial variability of methane fluxes also showed significant heterogeneity of fluxes determined by weather conditions, aeration and microbial processes, reserves of organic matter in soils, vegetation structure, temperature and soil humidity. Throughout the entire studied area of the carbon measurement supersite CH_4 absorption from the atmosphere was observed. The values of the CH_4 flux varied on average from 0.5 to 1.25 nmol/m²c. The minimum methane absorption rates were observed in the northeastern and northwestern parts of the supersite. In the southern part of the site, the absorption of methane by the soil cover was the highest and reached the average of 1.25 nmol/m²c.

The daily variability of CO_2 and CH_4 showed the maximum CO_2 emission in the afternoon, and the maximum rates of absorption (oxidation) of methane in the soil – in the morning. There is a statistically significant increase in CO_2 emissions from the soil surface with the rise in temperature (up to 30°C), which fades as the temperature increases further. A steady increase in CO_2 emissions with an increase in soil moisture and carbon reserves was revealed. The rate of absorption of CH_4 from the atmosphere increased with a decrease in humidity and an increase in soil temperature.



Maps of the spatial distribution of the CO_2 flux (left) and CH_4 (right) on the coastal site of the Gelendzhik carbon supersite.

The carbon budget of coastal waters and the role of phytoplankton communities in it were studied at the offshore site of the supersite. In total, 4 sea expeditions were carried out in 2022. In addition to measuring CO_2 fluxes above the sea surface, phytoplankton was sampled with increased frequency in 2022. In the dynamics of phytoplankton, the main adaptation strategies have been identified that determine the change of morphotypes with the light regime changes. In particular, the influence of the structural and functional organization of phytoplankton on the functioning of the marine carbon pump was investigated, and it was shown that the natural carbon pump consists of 2 components: organic and carbonate pumps, with diatoms mainly responsible for the former, and coccolithophorides - for the latter. The structure of the phytoplankton community and, above all, the coccolithophorid-diatom system determine the operation of the biological pump. The organic pump removes carbon from the cycle for a short time, and the second (carbonate) pump – for long periods, which is extremely promising for the development of sequestration technologies. These studies have discovered a brand new mechanism of carbon absorption in water. Microalgae adapted to light of low intensity (for example, in the area of seasonal thermocline) are subject to fluctuating illumination with spans of very high (for them) intensity. Damage by excessive light can lead to a decrease in the rate of photosynthesis and even cell death, followed by replacement with other, more adapted, species. This discovery has opened the way to the Mesocosm experiment aimed at assessing the prospects of carbon sequestration by phytoplankton in the coastal area of the sea. A submersible platform has been designed and built, on which aquariums with experimental biological media are at the levels with different illumination. Such a system will become a prototype of a potentially effective sequestration technology. During 2022, test experiments have been conducted with several descending aquariums. November 2022 will see the active phase of experimentation.

CARBON-SAKHALIN

Sakhalin region
Sakhalin State University

At the Sakhalin carbon measurement supersite, work is underway to assess the possibilities of carbon sequestration in near-shore biomorpholithosystems in the coastal waters of the Aniva Bay. For reliable quantitative assessment of fluxes and understanding of the variability factors of greenhouse gas fluxes in coastal marine ecosystems, studies of areas with active sedimentation of organic matter are necessary. This study aims to define the geomorphological position and dynamics of marches and silty drains of the Sakhalin carbon supersite and to assess the content of organic carbon in these, climate affecting, components of biomorpholithosystems. The research area is located in the Salmon Cove, the northern part of the Aniva Bay, in the estuaries of the Tsunai and Susuya Rivers. The marches formed in this delta system consist of oligohaline wetlands due to fresh water discharges through the delta channel network. Analyses of bottom sediments from columns and sections have been performed. This made it possible to obtain numerical values of the organic carbon content and link them to the dynamics of silty drains and marches in the estuary zone of the Bay. It was shown that autochthonous organic carbon is practically absent in the delta sediments of silty drainage located directly in the river estuary, in contrast to the bottom sediments of lagoons. This makes it possible to determine the volume of suspended sediments that are deposited in the estuary zone and to estimate the amount of organic carbon that remains in the sediments of the estuary. A preliminarily estimate of average annual volume of organic carbon is about 2000 tonnes.

The volumes of carbon deposited annually in the bottom sediments of the closed Ainskoye lagoon and Nyyskaya lagoon have also been estimated and turned out to be an order of magnitude higher than the volumes of organic carbon deposited in the marshes, and 150% higher compared with the Chaivo Lagoon and Salmon Bay. Thus, the overall conservative estimate for carbon sequestration by lagoon biomorpholithosystems alone in terms of CO_2 equivalent is at least 500,000 tonnes/year. Although the proposed concept of the organic matter deposition in the marshes of lagoons in the region is based on relatively rough estimates of the parameters of the sedimentation system and requires development and refinement, in particular in the context of the biogydrogeochemical cycles in wetlands of estuaries and lagoons, the obtained estimates seem encouraging. Subsequent studies of the sequestration capacity of near-shore marine biomorpholithosystems involves the creation of a system for obtaining data on levels of greenhouse gases in the atmosphere, water and soil gas exchange. We envision the creation of ground-based experimental industrial sites within the terrestrial, supralittoral site of the Sakhalin State University carbon measurement supersite, where technologies will be tested for accelerated silt-pelite and organogenic sedimentation in purpose-built zones.

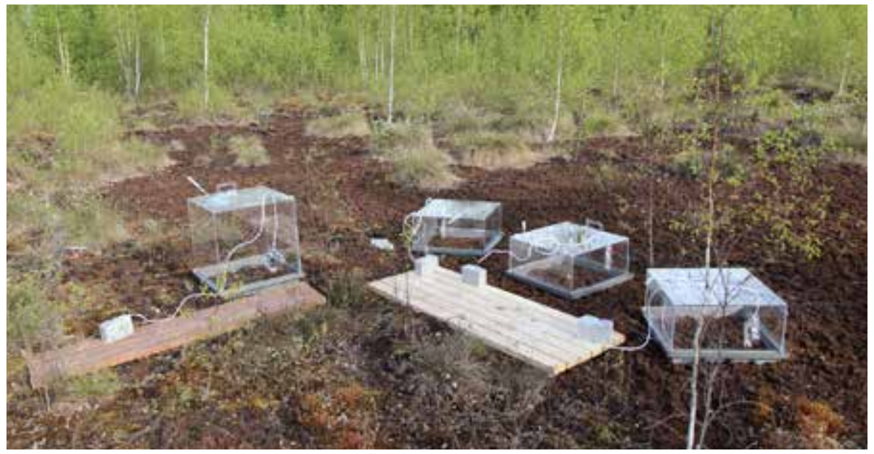
General view of a silty drain (top) and a sampled column of its deposits (bottom)

CARBON POLYGON ROSYANKA

Kaliningrad region
Immanuel Kant Baltic Federal University

An inventory of plant communities has been carried out at the Rosyanka carbon measurement supersite, operated by the Immanuel Kant Baltic Federal University. A detailed digital vegetation map of the carbon supersite has been created based on the remote sensing data and field surveys. It includes over 100 objects belonging to 28 classification units: 6 types of vegetation and 22 categories of plant communities. On representative sites showing the key elements of the vegetation cover of the carbon supersite (disturbed peatland), regular measurements of CH_4 and CO_2 fluxes by the chamber method are carried out, as well as accompanying measurements of environmental parameters in order to determine sites with greenhouse gas fluxes of different intensity and the possibility of mapping them.Thus, we pioneered the methods of linking greenhouse gas fluxes to areas of land, in the Baltic region, which could be mapped and standardized on a regional and interregional scale. The obtained results make it possible to monitor integrated fluxes under sequestration projects (such as restoration of swamp ecosystems), and also perform modeling based on tying in additional parameters (geochemical, soil, hydrological, etc).

In 2022, comprehensive studies of the marine environment continued at the offshore site of Rosyanka. An assessment of the vertical distribution of primary productivity parameters and the ratio between the main components of plankton (phyto-, zoo- and bacterial) by biomass and functionality for all seasons of the year have been obtained. This is fundamentally important for assessing the ability of the ocean to bind CO2, which is determined by the intensity of the «biological pump» (i.e. immersion of photosynthetically produced organic matter into the depths of the ocean before the re-mineralization (decomposition) of this organic matter occurs). Analysis of the data obtained in 2021 has shown that the bulk of primary production was concentrated in the upper 10-meter layer of the water. Photosynthetic activity, reflecting the use of absorbed light energy in the synthesis of organic matter, increased in June and October. The depth-integral values of chlorophyll-a, bacterial and phytoplankton biomass peaked in October. The maximum values of zooplankton biomass were recorded in June, and they were 5-14 times higher than in other seasons. The functional characteristics of the biological components of the ecosystem relating to the budget of suspended organic carbon in the marine environment (primary phytoplankton production, zooplankton feeding intensity and bacterial destruction) integrated for the 0-25 m layer differed significantly during the year. In summer, suspended organic carbon synthesized by phytoplankton practically does not form a downward flow, but remains within the active upper layer in the form of biomass and metabolites of bacterial plankton and zooplankton. Also, at the off-shore site, methane fluxes from bottom sediments have been calculated for the first time on the basis of measurements.



Chamber measurements of greenhouse gas fluxes at the Rosyanka supersite

URALS–CARBON

Sverdlovsk Region
Ural Federal University

At the Ural-carbon superstore (Sverdlovsk region), a preliminary assessment of the volume of carbon absorbed by ecosystems from the atmosphere (tCO_2/ha) during the April-September vegetative period has been performed, and comparisons with the data from previous years have been made. The volume of CO_2 absorbed from the atmosphere by taiga landscapes in Kourovka, in tonnes per hectare, varies depending on the year from 1.4 t/ha to 2.35 t/ha: 2013 – 1.41 t/ha, 2014 – 1.43 t/ha, 2015 – 2.35 t/ha, 2020 - 2.32 t/ha and 2021 – 1.52 t/ha.

To obtain integral estimates, an original neural network model was created for estimating carbon fluxes (GPP – gross primary production, NEE – net primary production, TER – ecosystem respiration) in boreal forest ecosystems. The model was trained using a data set from the FLEXNET service for the Ru-Fyo weather station located in the boreal coniferous forest in the Tver region. After training, the model was tested at the UrFU carbon supersite. Data from the MODIS/Aqua and MODIS/Terra spectroradiometers for 2002-2022 and 2000-2022 respectively were fed to the model input as well as the data of the retrospective climate analysis ERA5 for 2000-2022 for a plot at the Ural-Carbon supersite of the Kourov Observatory, UrFU.

The graph shows the obtained estimates of GPP carbon fluxes (gross primary production) for taiga landscapes of the Ural-Carbon carbon supersite in Kourovka in 2021-2022 and demonstrates a pronounced seasonal variability with a magnitude of up to 10 g/cm² per day. These estimates will be validated by the ground measurements, already taken.

The results of the GPP (gross primary production) assessment of taiga landscapes of the Ural-Carbon measurement supersite in Kourovka in 2021-2022, obtained using an original neural network model

GPP. Neural network model

CARBON POLYGON CHASHNIKOVO

Moscow region
Lomonosov Moscow State University

Researchers of the M.V. Lomonosov Moscow State University (operator of the Chashnikovo supersite) conducted a study of the vegetation cover and determined the quantitative parameters of vegetation, taking into account seasonality and using data from digital aerial photography (DAP). The Chashnikovo supersite is unique in having in a wide range of landscapes. Here, coniferous-deciduous forests on sod-podzolic soils are interspersed with meadows, swamps and arable lands, which makes it possible to simultaneously develop low-carbon environmental management strategies, reforestation and agronomic technologies aimed at long-term deposition of atmospheric carbon in forest, floodplain and agricultural landscapes.

A set of data was obtained as the result the study, and subsequently analyzed using specialized software products. This led to the creation of a GIS product currently located on the cartographic server of the MSU Carbon Supersite project (http://qgis.carbon.msu.ru/qwc). Eventually, a comprehensive solution was found for analyzing, storing, and visualizing DAP data from UAVs and, potentially, remote sensing satellites, while differentiating between the areas of decreasing and increasing NDVI index when monitoring the vegetation cover, including wild plants and agricultural crops.

The regularities revealed by the analysis of the created database in the «soil - plant - NDVI index» system allow to optimize the monitoring of phytomass dynamics and to obtain reliable input data for parametrization of mathematical models of the budget of climate active gases. Phenological observations in the first half of the growing season and UAV data have revealed that, in winter, a significant part of the carbon supersite is covered with evergreen coniferous vegetation, and in the warm season the vegetation cover significantly expands. A detailed map of the phytomass distribution based on the results of the NDVI index analysis can be found on the geoserver of the MSU carbon supersite. This cartogram enables the calculation of areas with different activity in relation to the emission or absorption of climate active gases.

These developments will make it possible, in the near future, to develop low-carbon strategies for nature management, forest restoration and agronomic technologies aimed at long-term deposition of atmospheric carbon at the Chashnikovo supersite.

Shrub-forest landscape of the Chashnikovo supersite

CARBON POLYGON KALUGA

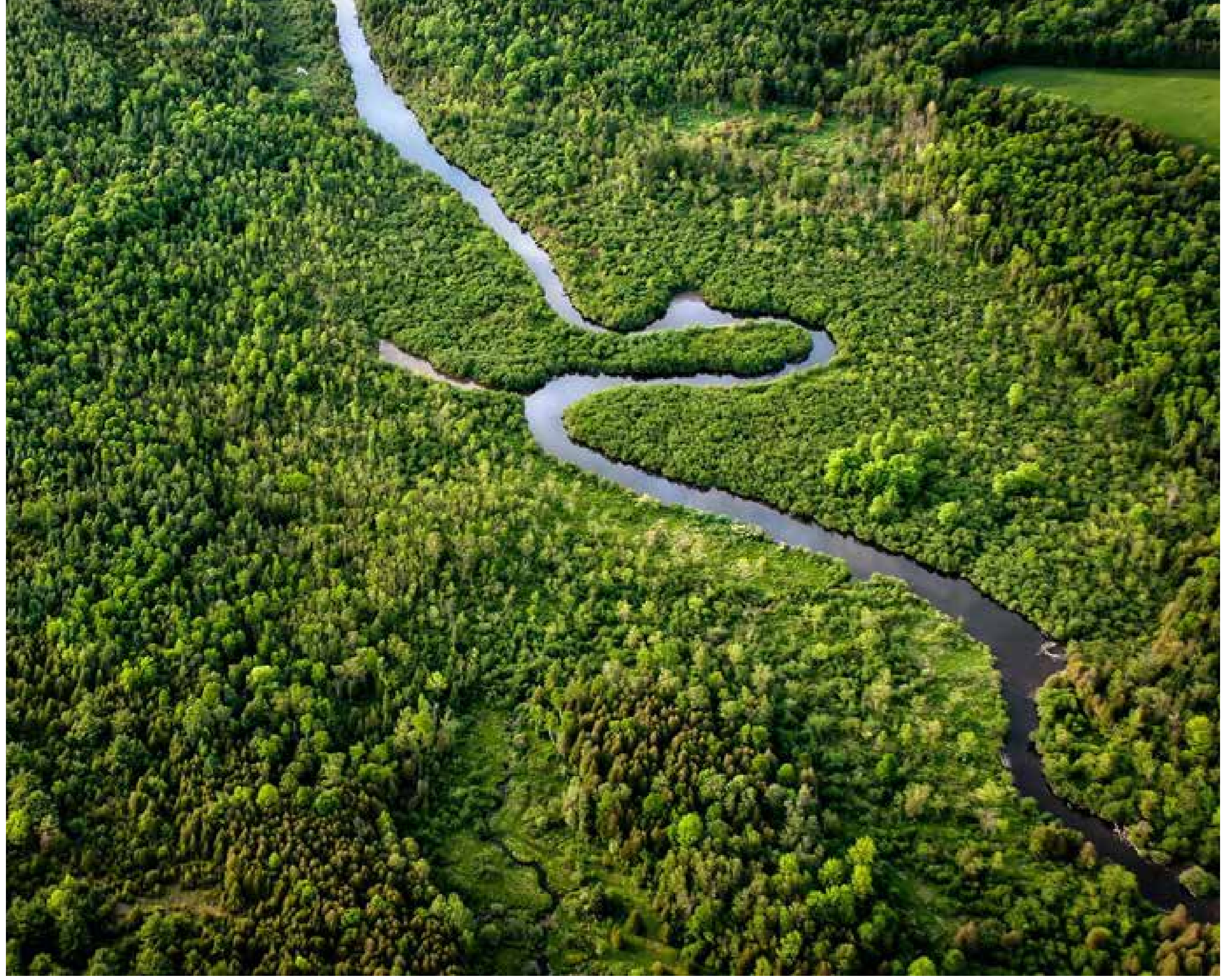
Kaluga region
Ctrl2GO Ltd

The development of technologies for increasing the sequestration of greenhouse gases by forest plantations through the application of complex mineral fertilizers has been carried out at the supersite. The methodology of the experiment was developed by the Federal Budgetary Institution "All-Russian Scientific Research Institute of Forestry and Forestry Mechanization" (FBI VNIILM). The methodology complies with the requirements of regulatory and legal acts, regulatory technical documents in force in the Russian Federation and can be used when conducting similar experiments in other regions of the country. In 2021-2022, 2 experimental sites were laid, complex fertilizers were applied, and appropriate measurements were carried out at the beginning and at the end of the season.

A complete ground vegetation taxation (all-over recount) and calculation of carbon reserves in biomass were also carried out on experimental sites. Data from the first year of the experiment and scientific calculations show the possibility of increasing sequestration by up to 30% with a single application of selected combinations of mineral fertilizers for the duration of 7-10 years.

Also at the supersite, technologies have been developed to increase the sequestration of greenhouse gases by optimizing density and species composition of forest plantations. The methodology of the experiment was developed by the Federal Budgetary Institution "All-Russian Scientific Research Institute of Forestry and Forestry Mechanization" (FBU VNIILM). The methodology complies with the requirements of regulatory and legal acts, regulatory technical documents in force in the Russian Federation and can be used when conducting similar experiments in other regions of the country. In 2021, 2 experimental sites were laid, thinning works were performed, and appropriate measurements were carried out at the beginning and end of the season. A complete ground vegetation taxation (all-over recount recalculation) and calculation of carbon reserves in biomass were also carried out on experimental sites. Data from the first year of the experiment and scientific calculations show the possibility of increasing sequestration by up to 25% with a single application of the technology for the duration of 15-20 years.

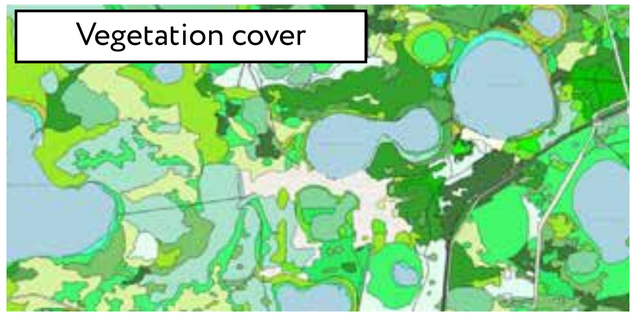
Location of the experiment sites



TYUMEN CARBON POLYGON

Tyumen region
Tyumen State University

An interactive digital database of the region has been created at the Kuchak carbon measurement superset of Tyumen State University, able to analyze the main surface parameters, including hypsometric characteristics, topography, vegetation types and land use, as well as vegetation indices (for example, NDVI) obtained from satellite data. An Internet portal has been created based on this set of data https://kuchakutmn.nextgis.com/resource/9/display?panel=layers, which allows for integrated analyses of different layers of characteristics.



VOLGA—CARBON

Republic of Tatarstan
Kazan Federal University

A basic assessment of the carbon stock in the dendro-biomass has been carried out at the Volga-Carbon supersite of the Republic of Tatarstan. It ranges from 0.043 t to 2.404 t per tree, and overall amounts are 40.77 t for the entire observation site or 163 t/ha, which significantly exceeds estimates for the similar regions of the North Caucasus, Crimean mountains (111.1 t/ha) and coniferous-deciduous forests. Based on the assessment of the carbon reserves in the dendro-biomass and soils as well as on data from dendrochronological studies, the sequestration potential of the ecosystem of the hairy-leaved linden with spruce and oak on sod-podzolic soils, located on alluvial-delluvial quaternary deposits of the third terrace of large rivers, has been estimated. This site is being designed to serve as a monitoring site for gas exchange between the ecosystem and the atmosphere using the Eddy Covariance system. The site is located in a phytocenosis widely spread in the European part of Russia, which is a broad-leaved forest under anthropogenic pressure of medium intensity with a long history of development. Subsequently, the data were veryfied using UAVs, which made it possible, for the first time, to perform estimates of carbon losses with emissions from forest soils in the forest ecosystems of the Middle Volga region.

Work is also underway at the supersite to monitor the dynamics of the exchange of climate active gases over the Kuibyshev reservoir. The dynamics of phytoplankton in the reservoir was studied using spectral data and vegetation indices. It has been shown that the data of the OLI sensor from the Landsat 8 satellite are suitable for remote monitoring of the algal bloom in the surface waters of the Kuibyshev reservoir. To highlight the bloom areas, the color index "Blue/Green" was used. The analysis of the images for the water area of 7 out of the 8 stream pools of the Kuibyshev reservoir shows that the algae bloom is observed every year. The peak occurs at the end of July – in mid-August (the average value for July is 65.7%, for August – 90.9%). The area of bloom varies from 31.5% to 99.8%, while the intensity of bloom in the latter case is extremely high, probably due to the biomass of blue-green algae.

Studying dendro-chronology characteristics

CARBON POLYGON FOR&ST CARBON

Voronezh Region
Voronezh State Forestry Engineering University named after G.F. Morozov

In the course of the lengthy economic development of the Voronezh Region, its original ecosystems have been almost completely transformed by man. Current climate changes tend to dry out forest ecosystems, increase their vulnerability to natural disturbances and even cast doubts on the possibility of sustainable development of agriculture in the south of the European part of Russia.

FOR&ST CARBON measurement supersite (FOR – «forest» and ST – «steppe») represent ecosystems of the Voronezh region and, also, the entire Central Forest-steppe Area of the Russian plain, including forests and agricultural land. Forest ecosystems include pure and mixed stands of different ages, represented by oak, pine, soft-leaved species growing in various geographic conditions. A number of forested areas were struck by fires in 2010: some have growth over them and some remain barren. The plot within the «Kamennaya Steppe» nature reserve is an agroforestry complex consisting of arable land and forest strips and is considered a model of an optimally organized agricultural landscape.

Research work at the supersite includes systematic monitoring of emission, sequestration and assessment of carbon stocks in soils, plant biomass and mortmass of various types of forest-steppe ecosystems. In 2021-2022, methods of accounting for carbon pools and fluxes in ecosystems have been tested on permanent test plots: the total reserves of phytomass and mortmass and by fractions; carbon stocks in soils, carbon content and vertical distribution; the photosynthesis activity was measured in plants using a portable gas exchange measurement system. The research also covers young pine-birch plantations, for which the dynamics of carbon accumulation up to 10 years has not been studied, and this information is not available in the tables of biological productivity.

A software and hardware Russian made complex for meteorological monitoring of the atmosphere and soils installed at the forest plot of the carbon supersite registers a set of meteorological parameters. Using UAVs produced by the Russian company «Geoscan» equipped with a lidar and multispectral camera, aerial photography of the territory of the supersite has been carried out, and a digital model of topography and vegetation of forested land totalling 39 ha has been created.

The research and development performed at the carbon supersite aim to obtain reliable estimates of the carbon budget of ecosystems, find ways to increase the natural capacity of greenhouse gas sinks, and to increase the sustainability of natural and man-made ecosystems. The system studies at the FOR&ST CARBON supersite should reduce the uncertainties of the initial data and increase the reliability of the assessment of the integral values of the carbon budget of the ecosystems of the Voronezh Region and the Central Forest–steppe as a whole. Importantly, they would tap a huge and yet untouched potential to reduce the carbon footprint of the region and, hopefully, help to mitigate local consequences of climate change.

Fragments of a digital map of the Voronezh supersite with growth over the 2010 burnt forest areas

PROTOTYPES OF NATURAL-CLIMATIC PROJECTS

Carbon Supersites
RUSSIAN FEDERATION

CLIMATIC PROJECT CARBON SEQUESTRATION PLANTATIONS IN THE BURNED AREAS

G.F. Morozov Voronezh State Forestry University

MAIN GOALS

a) transformation of unforested landscapes into the forest-covered landscapes capable for vegetation
b) reduction of the risk of forest fires by changing the composition of tree species
c) increasing the ecological potential vegetation capacity of forests in the sparsely forested Voronezh region
d) increasing the carbon sink in the forest areas and the reduction of industrial greenhouse gas emissions of the JSC "Voronezhsintezkauchuk"

BASE SCENARIO

Natural regeneration of the vegetation in the regions affected by fires is difficult due to unfavorable environmental conditions (poor sandy and sandy loamy soils, insufficient moisture and competition with grassy vegetation). Burnt areas are therefore transformed into wastelands covered with grassy vegetation

PROJECTED SCENARIO

Creation of carbon sequestration plantations in the forest areas, where natural reforestation is difficult and artificial reforestation by creating predominantly coniferous monocultures is ineffective. The project scenario provides an increase (compared to the baseline scenario) of carbon stocks in the phytomass and soil pool

PROJECT PROFITABILITY

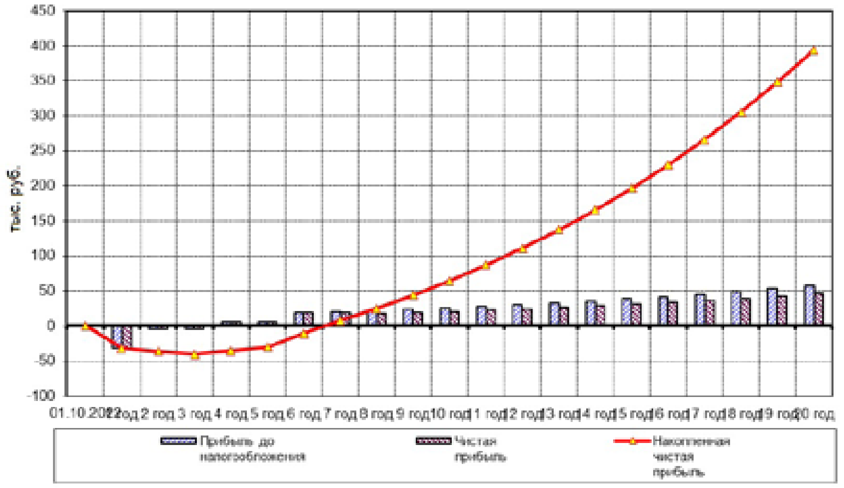
With a baseline rate of CO_2 absorption of 2.54 tons of CO_2/ha, a design baseline of 15 tons of CO_2/ha and at a cost of deposition of 1000 rubles per ton of CO_2, the income for the entire life cycle of the project (20 years) will be 595 thousand rubles. The accumulated net profit for the twenty-year period of the implementation of the project will amount to 394 thousand rubles per 1 ha

PROJECT SCOPE

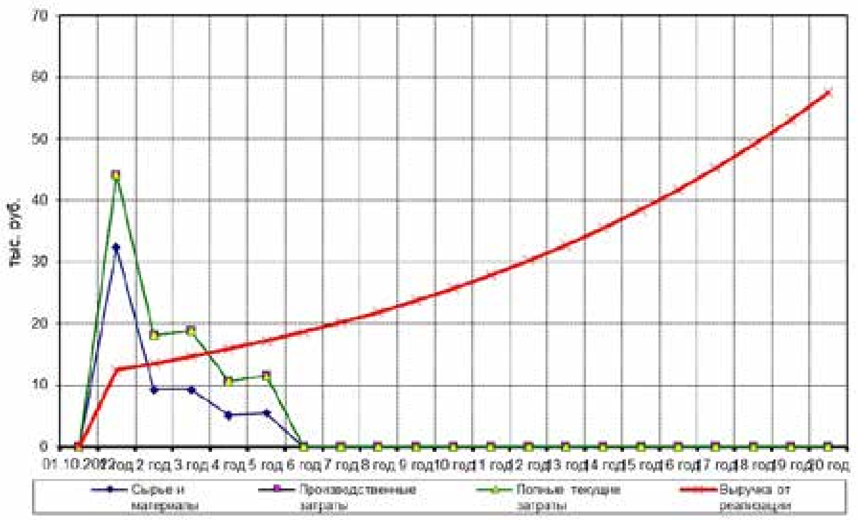
Domain of the educational and experimental VGLTU supersite with a total area of 750.8 hectares

ESTIMATED CARBON SEQUESTRATION (TCO_2/YR/HA)

Estimated plantation crop uptake with high cultivation practices is 12.4 tCO_2 ha/yr



Profit from the implementation of the project, thousands rubles



Estimated income of the reforestation project implemented in the Voronezh region, thousand rubles

BRIEF DESCRIPTION OF THE WORK PERFORMED

During the forest seeding campaigns of 2022-2024 we will carry out the creation of mixed forest crops with a planting density of 4000-5000 pcs/ha adjacent to the soil and plant conditions

Removing logging residues, dead wood and litter without burning. All wood residues must be buried in soils

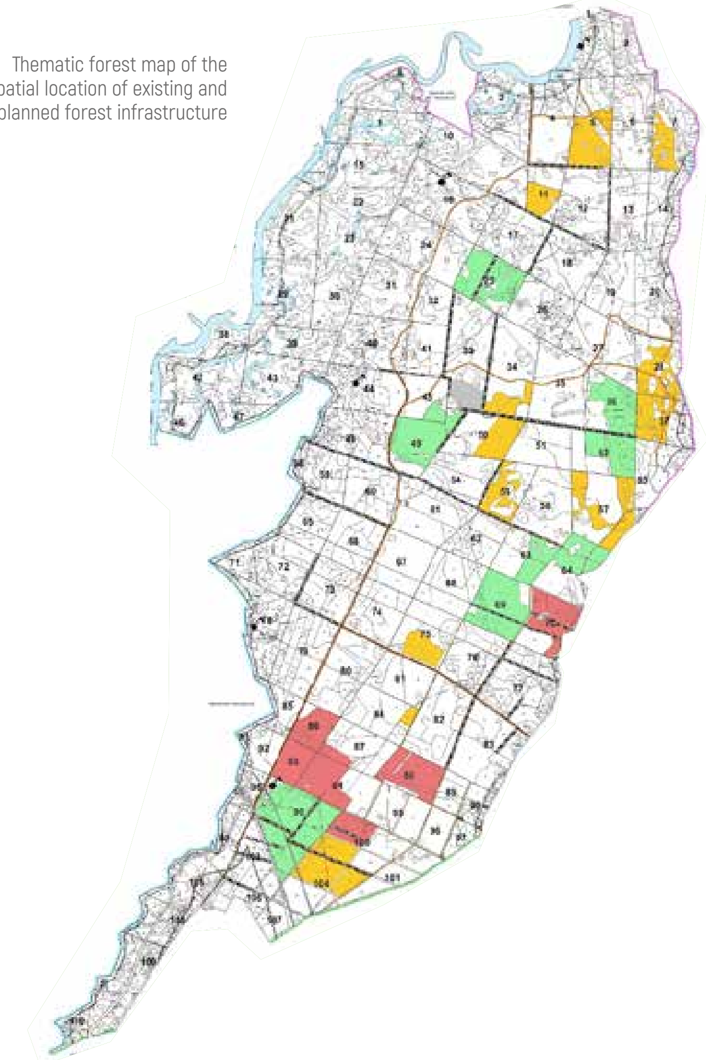
Soil preparation is carried out by disking

The choice of the composition of species – using native tree species with high biological productivity (Scots pine, breeding varieties of silver birch and poplar)

Manual planting seedlings and seedlings with a closed root system

Implementation of a set of measures of agricultural care including manual care and watering as well as protection against pests and fires

Thematic forest map of the spatial location of existing and planned forest infrastructure



CLIMATIC PROJECT THE CARBON FARM OF GROZNY STATE OIL TECHNICAL UNIVERSITY

MAIN GOALS

Cultivation of highly productive tree plantations, afforestation and land rehabilitation in reclaimed polluted areas in order to develop greenhouse gas sequestration technologies

BASE SCENARIO

Carbon Farm is located on the left bank of the Sunzha River, northeast of the city of Grozny, and is currently an authorized city dump for construction and household waste. It is assumed that construction and household waste over 100-200 years will emit progressively greenhouse gases. This area is a source of significant emissions of carbon dioxide, nitrous oxide, F-gases (halogens) and methane. Expert assessment of the total emission of various gases is from 2 to 10 tons of CO_2 equivalent per ha

PROJECTED SCENARIO

To sequester greenhouse gases released by the soil of the carbon farm, 10000 seedlings of tree species that are dominant in this climatic zone and landscape area and have high sequestration potential (poplar, oak, linden, pine, birch, aspen) will be planted. According to preliminary estimates, this will make it possible to sequester the emitted gases in the amount of more than 100 tons of CO_2 during one growing season. It is also planned to develop technologies for bio-rehabilitation of lands contaminated with oil, oil products and thermal waters. In the future, it is planned to plant tree plantations with high sequestration capabilities in the reclaimed territories

BRIEF DESCRIPTION OF THE WORK PERFORMED

Inventory of the landscape types and biodiversity, sampling and geochemical analysis of soils
Targeted study of soil profiles and meteorological observations
Eddy-covariance measurements of greenhouse gas fluxes and chamber measurements of soil respiration
Cultivation of highly productive tree plantations.
Afforestation in semi-desert areas
Rehabilitation of lands contaminated with oil, oil products and thermal waters

PROJECT SCOPE

23.5 ha

ESTIMATED CARBON SEQUESTRATION (TCO_2/YR/HA)

Forecasted sequestrated carbon in 10 years – from 0.5 to 2.0 tC/year per ha or 1.85-7.3 – CO_2 equivalent per ha

CLIMATIC PROJECT MICROALGAE OF THE BLACK SEA

Shirshov Institute of Oceanology, RAS

MAIN GOALS

Controlling the rate of long-term carbon sequestration at the seabed by regulating the effectiveness of the so-called marine "carbon pump". The carbon pump ensures the deposition of microalgae cells on the seabed from the surface layer, and its efficiency largely depends on the species composition of the microalgae used. Regulation of the species composition is carried out by forming a specific local marine environment by changing its initial characteristics and activating environmental factors that are optimal for the intensive growth of the required species (in our case the coccolithophores Emiliania huxleyi, a class of unicellular marine plankton haptophyte algae), which actively uses carbonate calcium, and is characterized by high sedimentation rates

BASE SCENARIO

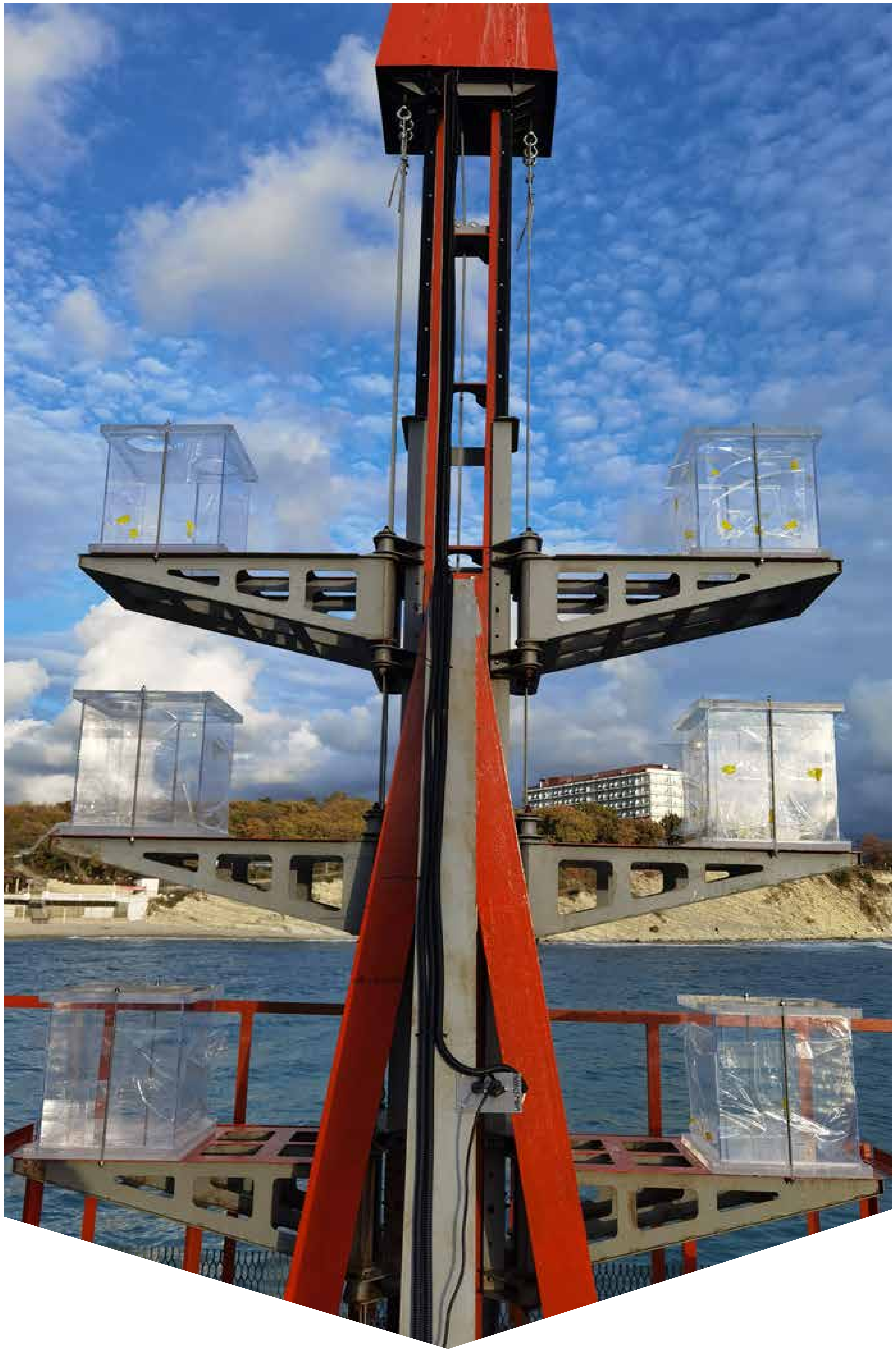
Under natural conditions, mass development of coccolithophorids occurs once over few years, and the dominant microalgae species most often die during settling before reaching the bottom, thus returning CO_2 to the natural carbon cycle of the marine ecosystem

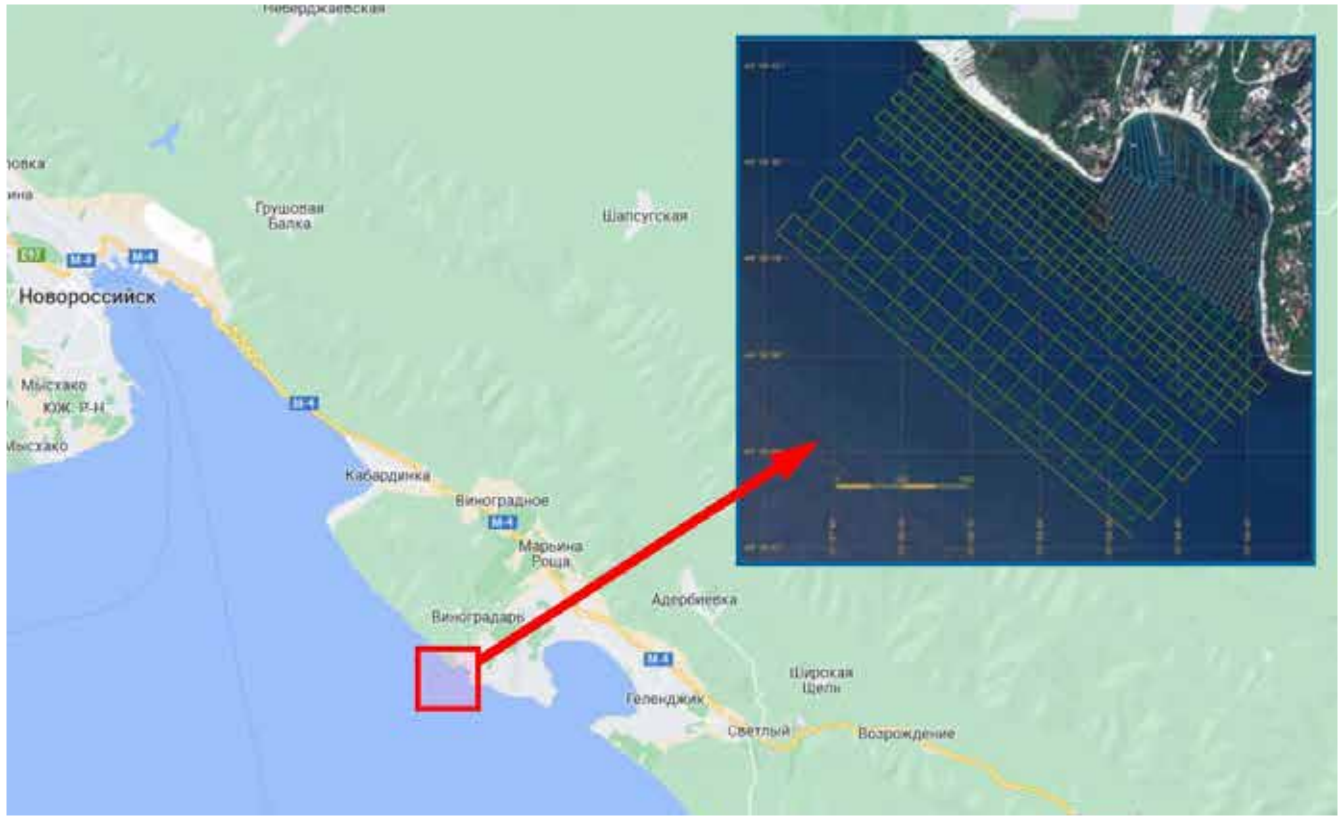
PROJECT SCOPE

40 hectares with initial testing over several tens of meters of the coastal shelf

PROJECTED SCENARIO

The scenario assumes an increase in the extent and duration of the "bloom" of coccolithophorids in the coastal areas of the Black Sea and the creation of conditions for the increasing mass of coccolithophorids through local changes in the parameters of the marine environment, which allows for explosive growth of the population and a significant increase in carbon dioxide sequestration by the marine environment





BRIEF DESCRIPTION OF THE WORK PERFORMED

The process of developing, testing and adapting technology includes several stages:

- Study of the annual dynamics of phytoplankton and environmental parameters, including the incoming solar radiation in different spectral ranges (started, 2022-2023)
- Experimental study of the influence of abiotic environmental factors on the ratio of microalgae species and their productivity in the laboratory experiments (ongoing, until mid-2023)
- Development and verification of a model of the growth of a multispecies phytoplankton population, including the coccolithophores Emiliania huxleyi, on the basis of the results of experiments (will be completed in 2023)
- Assessment of the amount of deposited carbon on the basis on the results of experiments
- Experimentation in the natural conditions in mesocosms, and assessment of the potential of scaling the technology
- Practical implementation of the design technology

ESTIMATED CARBON SEQUESTRATION (TCO_2/YR/HA)

is from 0.2 to 2.0 t C/year per ha

CLIMATIC PROJECT
MARINE CARBON FARM OF ANIVA BAY

Sakhalin State University

MAIN GOALS

Assessment of the sequestration potential of the marine ecosystem of the Aniva Bay under the joint cultivation of bivalve mollusks and seaweed. It is planned development and testing of technologies for long-term carbon fixation by processing products of carbon farms (algae, shellfish, etc.), assessment of the technological and economical cycle of cultivation and processing of seaweed. Also planned is the development of a business model for an aquaculture marine carbon farm

BASE SCENARIO

Absorption of carbon dioxide dissolved in water by aquatic organisms during their life cycle is stable. However, during the life cycle of the marine ecosystem, the carbon accumulated by organisms is mainly returned to the environment in the course of their vital activity or through the decomposition of dead organic matter. Only a small part enters deeper water layer for further disposal

PROJECT SCOPE

Marine domain is 5 ha, land infrastructure (Taranai) 1.8 ha

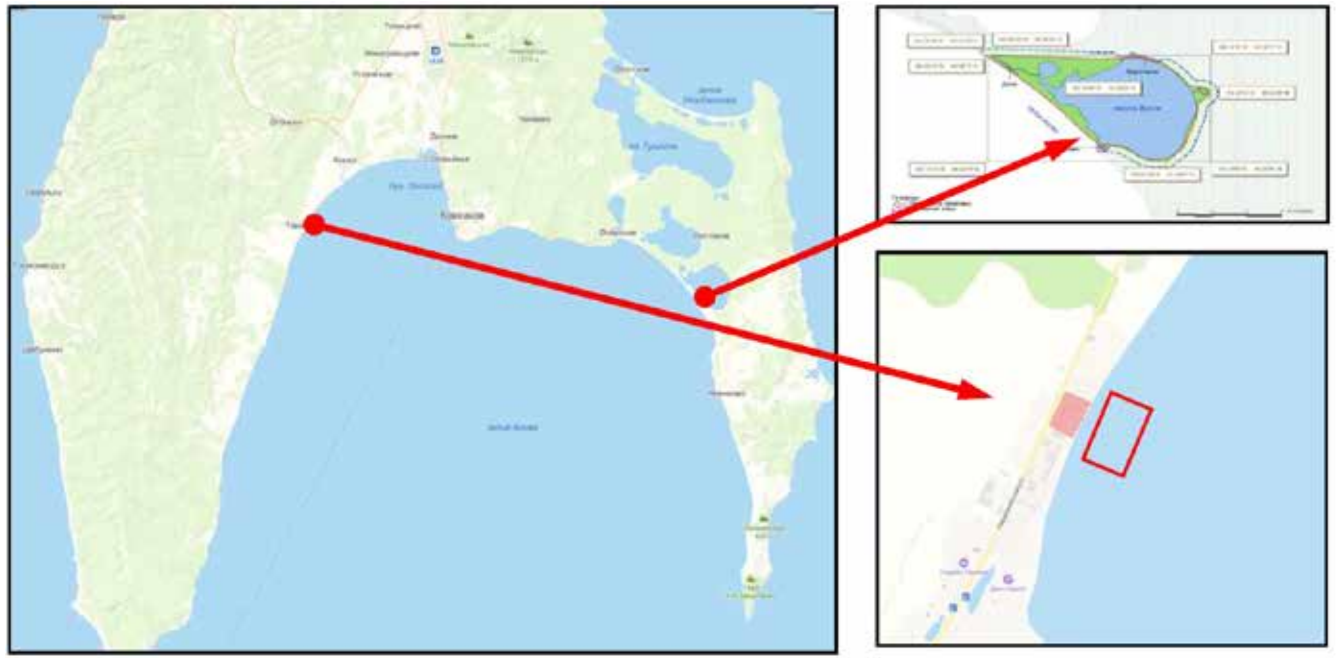
PROJECTED SCENARIO

An effect of the absorption of carbon dioxide by marine ecosystems can be obtained through the development of aquaculture carbon farms for the production of "BlueCarbon". Water areas suitable for intensive aquaculture off the coast of Sakhalin occupy more than one million hectares. Planned avenues of the development are the following:

1 Development of a methodology for assessing the baseline of a climate project (measurements of carbon absorption in the phytomass of seaweeds and bivalves within experimental work followed by the modeling of the natural carbon cycle in Aniva Bay)

2 Testing of technologies for achieving an additional effect of greenhouse gas absorption (installation of a re-circulating water supply system to measure carbon dioxide absorption under different modes of growth of the aquatic organisms, including accelerated accumulation of biomass in wastewater discharge areas

3 Production of biochar from algae, shellfish powder, etc



BRIEF DESCRIPTION OF THE WORK PERFORMED

Development of digital maps of the marine area of carbon farm with the characteristics of the bottom topography, coastline, surface and subsurface temperatures and salinities, as well as biochemical characteristics, including parameters of the carbon cycle

Purchase and installation of a re-circulating water supply unit on the coast (Taranai), planting of hydrobionts, development of technology for accelerated accumulation of biomass

Development and creation of a marine plantation of algae and shellfish.

Regular measurements of the content of dissolved gases and other parameters in sea water in the plantation area and without it.

Measurements of absorption and accumulation of carbon in the phytomass of seaweeds and bivalves

Experiments for the processing of algae into biochar and shellfish into powder for additives in building materials

ESTIMATED CARBON SEQUESTRATION (TCO_2/YR/HA)

Preliminary estimates indicate that culturing seaweed (e.g. Japanese kelp) with bivalve mollusks can provide an additional sequestration in the Aniva Bay, the volume of which is under evaluation

CLIMATIC PROJECT ECOLOGICAL REHABILITATION OF THE WITTGIRREN PEAT BOG

Immanuel Kant Baltic Federal University

MAIN GOALS

The main goal of the project is to restore previously destroyed peat bogs and their ecological functions by raising the level of groundwater, that will prevent fires, significantly reduce greenhouse gas emissions, and create conditions for the repatriation of the lost flora and fauna species. In the restored bogs, their conventional use will be also possible; in particular, the cultivation of the biomass of bog plants (such as reed, sedge, sphagnum, cranberries, etc.)

BASE SCENARIO

In the absence of measures for the ecological rehabilitation of the swamp, the threat of fires will increase. In addition, the drained swamp besides not capturing CO_2 from the atmosphere will continue to emit greenhouse gases into the environment. Greenhouse gas emissions from the drained peat lands are as high as one-fifth of the industrial emissions. Moreover, the territories adjacent to drained swamps often also tend to dry up. There will be a drastic increase of fire danger in the drained area and over the adjacent territories

PROJECTED SCENARIO

1 Restoration of the hydrological regime by establishment of cascading drainage ditches using dams, dikes, peat barriers and lock installations;

2 Re-vegetation through the local expansion of refugia, artificial repatriation and removal of alien species

BRIEF DESCRIPTION OF THE WORK PERFORMED

Project design and delivery of estimates of recourses for the watering of the Wittgirren peat bog
Development of a predictive model for the restoration of the peat deposit ecosystem, taking into account the peculiarities of the geological structure of the peat deposit and changes in the hydrological regime
Coordination of the project with the local authorities and regional Government.
Implementation of the watering project
Long-term multi-year climate monitoring

PROJECT SCOPE

Peat land with an area of about 112.4 ha (managed system), secondary watering is planned for 57 ha

ESTIMATED CARBON SEQUESTRATION (TCO_2/YR/HA)

4.8 tCO_2/year/ha

CLIMATIC PROJECT CHASHNIKOVO – FOREST

Lomonosov Moscow State University

MAIN GOALS

Development and testing of a methodology for the quantitative assessment and monitoring of the carbon budget of natural and anthropogenically-changed landscapes and to assess the spatial and seasonal dynamics of the carbon sequestration potential

PROJECT SCOPE

The project area is 1 ha for reforestation and 1 ha for control, as well as 1 acre in the nursery for breeding seedlings

BASE SCENARIO

Currently, this is a spruce forest site that lost its structure after the invasion of the bark beetle-typographer, resulting in drying of the trees. In subsequent years, a series of windblows took place. Secondary succession is currently underway

ESTIMATED CARBON SEQUESTRATION (TCO_2/YR/HA)

up to 2 tCO_2/year/ha

PROJECTED SCENARIO

Reforestation (spruce). The domain is located in the southern taiga zone, which is characterized by presence of common spruce

BRIEF DESCRIPTION OF THE WORK PERFORMED

Selection of a test domain of 1 ha in the forest for reforestation and another domain nearby for control experiments, both on the terrace of the Klyazma River. Both sites should be occupied mainly by common spruce
Geobotanical description, analysis of the main soil and climatic indicators
Purchasing the planting material (2 thousands pieces of Norway Spruce), sowing, care, single transshipment allowing for obtaining a P9 container with plants of 10-15 cm high, ready for planting in the fall of 2023
Building a greenhouse for forest seedlings for reproduction
Sowing process seeding two thousands pieces (duration 2 years)
Development of a new soil structure, which is used at the stage of the first transfer to the P9 container (water-retaining material, fertilizers)
Preparation of 1 hectare of degraded forest area for reforestation for planting next autumn (late August – early September)
Landing and care (weeding from DKR next autumn)

CLIMATIC PROJECT RECULTIVATED GRANITE QUARRY

Ural State Forestry University

MAIN GOALS

Research the potential of carbon sequestration by components of artificial forest plantations of various species composition, development of methods for determining carbon sequestration by various components of forest plantations, selection of an assortment of trees and shrubs for biological reclamation of depleted granite quarries with maximum carbon deposition from atmospheric air

BASE SCENARIO

In the absence of project, vegetation will be slowly formed on the main part of the depleted quarry over the next decades. The reason for the slow formation of vegetation (at first lichen, then herbaceous, and only after many years tree-shrub) is the lack of soil. The territory of the quarry (granite base) is prevents developments of a fertile soil layer. Thus, this territory will be excluded from economic use and the production of wood and the other products and will not provide carbon sequestration in the lack of vegetation that performs photosynthesis

PROJECTED SCENARIO

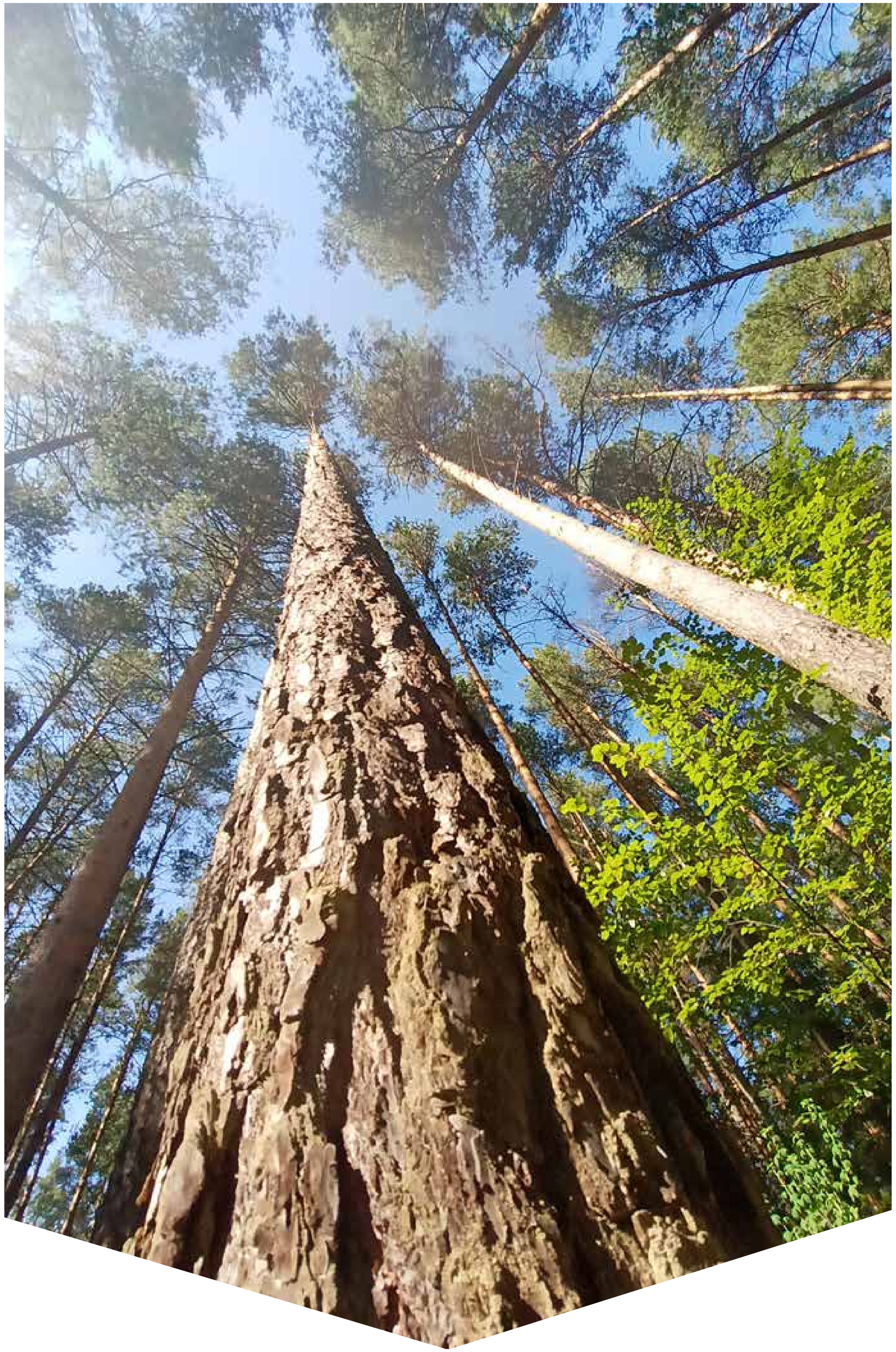
It is planned to carry out a set of activities focused on technical and biological reclamation of the quarry. During the implementation of the project, taxation indicators of plantings will be established, being formed over the part of a depleted granite quarry. Data on the natural formation of woody vegetation will form the basis for determining the amount of absorbed carbon in exhausted granite quarries in the conditions of the Middle Ural taiga forest region. The major part pf the work is planned to be carried out in that part of the exhausted granite quarry where there is no vegetation, or there are single specimens growing in granite cracks

PROJECT PROFITABILITY

With initial investments into the project (preparation of the soil, purchase of planting material, planting and caring for forest crops) in the amount of 3 million rubles, the project can become profitable in 8-10 years

PROJECT SCOPE

The total area of the carbon farm is 1.2 hectares



To the left is an exterior view of the Carboniferous farm site, with poor vegetation at the farm site clearly visible. In the center - Undergrowth of pine on the excavated granite quarry. On the right - buckthorn on the depleted granite quarry (natural overgrowth)

BRIEF DESCRIPTION OF THE WORK PERFORMED

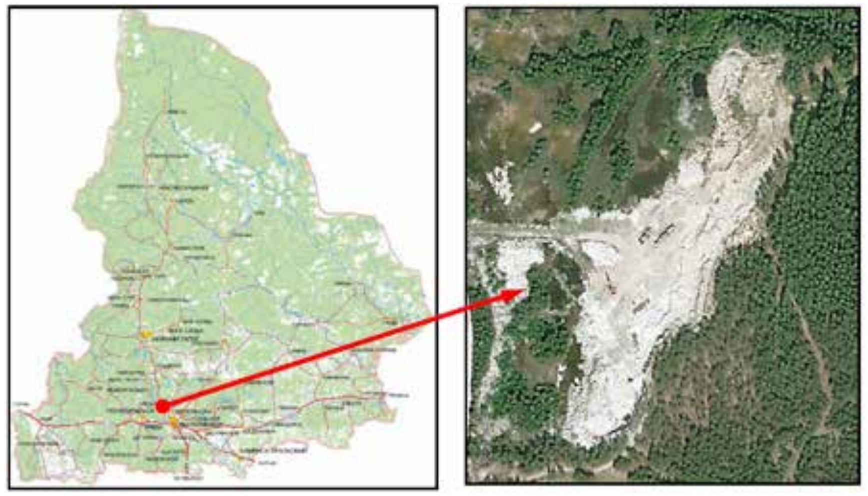
A soil layer with various thicknesses will be put over the part of the quarry and will be further allocated for the creation of a carbon farm. Previously, the territory will be leveled by a bulldozer and large stones will be removed from it. The thickness of the fill soil layer will vary from 0.3 to 1.5 m in order to guarantee favorable conditions for growing woody vegetation Scotch pine (Pinus sylvestris L.) will be used as the main tree species for cultivation on the carbon farm. The choice is justified by the fact that this breed can grow in a wide range of soils. It is known to be neutral to soil fertility and successfully grows in mountainous conditions, forming a forest upland pine forest in the Urals. When choosing pine as the main species, we took into account that it grows around the quarry, and the undergrowth was recorded directly in the quarry

In addition to Scotch pine, when creating a carbon farm on a depleted granite quarry, it is planned to use other types of trees and shrubs, in particular sea buckthorn (Hippophae rhamnoides L.), specimens of which have also been recorded in the quarry

Thus, implementation of the pilot project will create forest plantations of different composition and with different thicknesses of the bulk soil layer. In order to increase the survival rate and safety of planted seedlings, as well as to accelerate their growth, it is planned to apply fertilizers in different doses

ESTIMATED CARBON SEQUESTRATION (TCO_2/YR/HA)

Pine stands can be grown to 80 years on these plantations with a stemwood stock of 400 m^3/ha, which will provide carbon sequestration in the amount of 100 t/ha. Therefore the average rate of carbon sequestration over 80 years will be 1.25 t/year of carbon per ha or 4.58 tCO_2/year per ha. Obviously, the rate of carbon deposition will be non-linear in time. It is expected that 15 years after the implementation of the project, the maximum carbon sequestration rate will be at least 5.5 t/yr carbon/ha or 20.2 tCO_2/yr/ha



CLIMATIC PROJECT CARBONE FARM URALSKAYA

Ural State Agricultural University

MAIN GOALS

Assessment of the carbon budget and development of carbon emission monitoring technologies, as well as a methodology for assessing the carbon budget for agricultural landscapes

BRIEF DESCRIPTION OF THE WORK PERFORMED

Usage of the precise farming technologies and balanced use of chemical fertilizers
Creation of an integrated plant protection system based on innovative technologies
Application of novel agricultural methods, such as differentiated crop rotations, selection of seeds and hybrids (with a minimal carbon footprint), crop residue management, use of cover crops, application of biological PPPs, application of bacterial-fungal preparations, application of biological fertilizers, application of mycorrhiza, application of humic substances, the use of bio-stimulators, etc.
Combat soil compaction
Development of a carbon-negative system.
Assessment of the sequestration potential of the agricultural landscape
International accreditation of methods for monitoring carbon emissions
Commercial implementation of the project with a focus on the products with high sequestration potential

BASE SCENARIO

Currently conventional fallow farming is developing, traditional crops are cultivated, pesticides and agrochemicals are widely used, agriculture activities are carried out without taking into account the CO_2 budget

ESTIMATED CARBON SEQUESTRATION (TCO_2/YR/HA)

Up to 375 tons of CO_2/year under the project scenario. CO_2 sequestration will be achieved through: direct seeding (no-till), use of cover crops, effective management of nitrogen fertilizers, growing legumes instead of nitrogen fertilizers, avoiding fallows, application of bacterial-fungal preparations and agro forestry

PROJECT PROFITABILITY

With the initial investment into the project (agricultural machinery, equipment for the primary processing of plants) in the amount of 50 million rubles the project can become profitable in 5 years

PROJECTED SCENARIO

It is proposed to introduce landscape-adaptive, soil-protective and resource-saving organic farming. The main avenues are long-term zero-tillage, preservation of a permanent organic soil cover, carbon sequestration in agricultural production. This will make it possible to sequester carbon dioxide as actively as possible using the advantages of agrophytocenoses and agricultural technologies of varying intensity. Simultaneously with the cultivation of agricultural crops, long-term sequestration of atmospheric carbon into the soil will be ensured. The use of new carbon-negative plants will ensure the introduction of highly efficient technologies for sequestration of carbon by agro- and ecosystems

PROJECT SCOPE

The total area of the carbon farm is 25 hectares

RESULTS IN NUMBERS

Indicator	Total
Area of polygons, ha	39157,3
Area of carbon farms, ha	1566,2
Number of developed digital maps, pcs	35
Number of layers (or data sets) of created digital maps, pcs	170
Number of sequestration technologies under development, pcs	30
Amount of accumulated information (Gb)- meteorological data, data of pulsation and chamber observations, data of chemical analysis of water samples and bottom sediments, remote monitoring data and others	2787,43
Number of mathematical models for the analysis of greenhouse gas flows developed/under development, pcs	14
Number of researchers involved, people	333
The number of new educational programs launched since 2021, pcs	43
Graduate school	1
Bachelor's degree	8
Master's degree	11
Additional training programs	23
Number of trained specialists, people	769
Bachelor's degree	90
Master's degree	123
Additional training programs	556

769
trained specialists

43
new educational programs launched since 2021

30
sequestration technologies under development, pcs

14
mathematical models

EDUCATIONAL PROGRAMS PREPARED BY CARBON POLYGONS

THREE NEW TRAINING MODULES (EACH INCLUDES 3-5 MASTER'S PROGRAMS)

- Biological aspects of climate change (Ural Federal University)
- Global climate change, greenhouse gases and carbon cycle (Lomonosov Moscow State University)
- Carbon management in the context of climate change (Yugra State University)
- Management of climate projects and low-carbon development (University of Tyumen together with the Higher School of Economics)

NINE NEW MASTER PROGRAMS in cartography and geoinformatics, hydrometeorology and climatology, mathematical modeling, ecology and environmental management (Novosibirsk State University, Kadyrov Chechen State University, Grozny State Oil Technical University, Lomonosov Moscow State University together with Shirshov Institute of Oceanology of Russian Academy of Sciences, Immanuel Kant Baltic Federal University, University of Tyumen, Yugra State University)

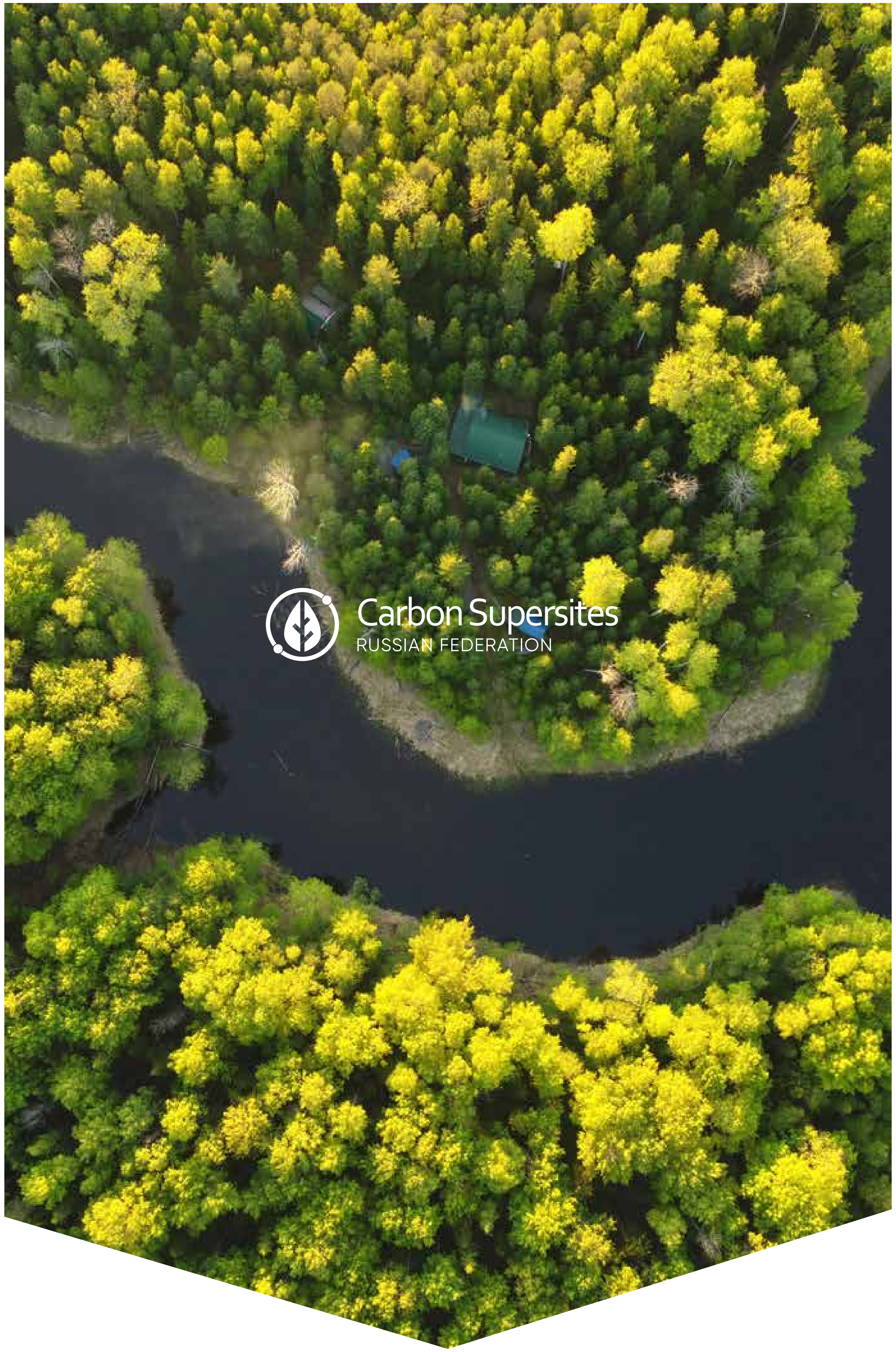
FOUR NEW UNDERGRADUATE PROGRAMS in Ecology and Nature Management and Hydrometeorology and Climatology (South Ural State University, Novosibirsk State University)

MASTER'S PROGRAM IN ENGLISH "Doing Business for Green Economy" (Novosibirsk State University)

MODULAR ADDITIONAL EDUCATION PROGRAMS "Reporting companies in low-carbon and sustainable development", "Carbon management" (Yugra State University)

PROFESSIONAL DEVELOPMENT COURSE PROGRAM "Experience in Organizing the Work and Technical Equipment of the Carbon polygon" (Yugra State University)

FIVE NEW TRAINING COURSES ON METHODS AND PRACTICES of observing greenhouse gas flows in different ecosystems (Grozny State Oil Technical University, Moscow State University together with Shirshov Institute of Oceanology of Russian Academy of Sciences, Ural Federal University, Immanuel Kant Baltic Federal University, Kazan Federal University)



DOMESTIC SAMPLES OF SCIENTIFIC EQUIPMENT FOR CARBON POLYGONS

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GEOSCAN IN THE CARBON POLYGONS PROJECT

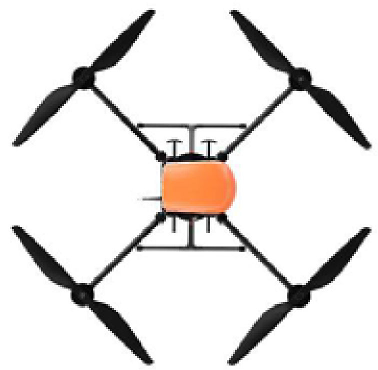
Geoscan is a leading Russian developer and manufacturer of unmanned aerial vehicles and software for photogrammetric data processing and 3D visualization. This innovative equipment is used worldwide in a variety of industries, including the field of ecology. Since 2021 Geoscan is one of the key technological and infrastructural partners of the Ministry of Science and higher Education's pilot project to create carbon test sites in Russia. The company supplies «Geoscan 401» drones with various payloads and instrumentation to scientific institutes and universities that are operators of carbon test sites.

With the help of drones scientists collect spatial data, which later allows mapping of areas, creating 3D models and GIS-maps, determining plant characteristics and monitoring the dynamics of their growth, getting DEM with relief microforms and much more. Especially important is the use of multispectral and hyperspectral cameras on drones to characterize landscapes directly related to climatically active gas flows.

«Geoscan 401» is already helping six organizations that are operators of carbon polygon with their research:

- Voronezh State Forestry University named after G.F. Morozov, the operator of the carbon polygon FOR&ST CARBON
- Novosibirsk State University, operator of the carbon polygon BioCarbon
- Shirshov Institute of Oceanology of Russian Academy of Sciences, operator of the carbon polygon Gelendzhik
- Immanuel Kant Baltic Federal University, operator of the carbon polygon Rosyanka
- Tyumen State University, operator of the Tyumen carbon polygon
- Kadyrov Chechen State University and Grozny State Oil Technical University, operators of WAY CARBON polygon

geoscan.aero



DEVELOPMENT OF DOMESTIC INSTRUMENTS FOR MEASURING THE FLUXES OF CLIMATICALLY ACTIVE GASES IN MOSCOW INSTITUTE OF PHYSICS AND TECHNOLOGY

According to the Decree of the President of the Russian Federation of 08.02.2021 N 76 "On measures for implementation of the state scientific and technical policy in the field of ecological development of the Russian Federation and climate change" and the order of the Ministry of Science and higher Education of the Russian Federation of 20.02.2021 on creation of grounds for the development and testing of technology for carbon balance monitoring MIPT offers to consider creating an experimental model of hardware-software complex for rapid monitoring of carbon sequestration by different types of landscapes and its testing in Chechen Republic, Kaluga Oblast, Yamalo-Nenets autonomous region.

In the process of approbation there will be verified the methods and conducted tests of the hardware, developed by MIPT within the projects under the Agreement with the Ministry of Natural Resources of the Russian Federation dated 22.10.2020 N DK-17-23SOD/32, state tasks and work funded by development institutions, in particular the work deployed in 2020 to create an experimental model of the system of operational monitoring of specially protected natural areas (SPNA).

The main task of the carbon polygons created at the initiative of the Ministry of Science and higher Education of the Russian Federation is the monitoring of greenhouse gas (GHG) exchange between the atmosphere and the underlying surface and assessment of the absorption capacity of different types of landscapes. Also, methods and algorithms for instrumental assessment of GHG sources and sinks based on sampling and remote sensing data for subsequent verification of calculation methods of carbon accounting based on socio-economic indicators should be worked out at polygons. The proposed methods should be based on Russian technologies and be recognized by the international expert community. Particular attention should be paid to metrological support of the implemented methods, in particular, the maximum relative error in assessing the content of the main GHGs in the atmospheric column should not exceed 0.2%. In this case, in the recommended list of equipment designed to equip the carbon dumps as the most expensive items are gas analyzers of American manufacturers Li-COR or Picarro. In particular, the declared cost of Li-COR equipment in a complete set is 28 million rubles at 2021 prices, Picarro products in Russia is currently unavailable. These instruments are based on the principles of laser spectroscopy and implement the eddy-covariance method of measuring the GHG exchange rate between the atmosphere and the underlying surface. Based on the existing achievements, MIPT plans to develop and organize serial production of devices that could successfully compete with these manufacturers both on the Russian and foreign markets.

MIPT developed a spectrometric instrument (hereinafter referred to as SC) based on a multichannel laser heterodyne spectrometer of the near-infrared range, which currently has record spectral and metrological characteristics. The SK performs measurements in the direct solar observation mode and allows to measure integral GHG concentrations with an accuracy of about 0.2%, and to reconstruct their distribution in the troposphere and lower stratosphere. SK also allows remote aerological sounding of the atmosphere, including restoration of the velocity profile of air streams, without the use of balloon probes. The cost of the SK is seven times lower than that of foreign analogues used for ground-based validation and monitoring of the GHG content in the atmosphere. The development is protected by patents and published in prestigious international journals.

Currently, a compact version of the SC for field studies has been developed, which is undergoing acceptance tests jointly with Roshydromet. The device was presented at the international forum "Army-2021" on August 22-28, 2021 as part of the complex of operational monitoring of natural areas at the MIPT stand.

Functioning experimental sample of the SK

SPECTROMETRIC COMPLEX FOR GREENHOUSE GAS MONITORING

MIPT also developed a laser gas analyzer for remote detection of methane sources, in particular, for monitoring of abnormal situations on gas pipelines and other technogenic facilities. The device can also be used to monitor natural sources of methane emissions – bogs, permafrost, water bodies containing gas hydrates. The spectrometer has competitive characteristics – the sensitivity of 50 ppm.m at a distance of 100 m and a mass of 3.5 kg, which exceeds the analogues available in Russia, in particular the developments of "Pergam Engineering" company.

As part of the M-DLS-Electronics SSR, MIPT in cooperation with IKI RAS developed and handed over to the customer the M-DLS laser spectrometer, which became part of the scientific instrumentation complex of the Russian Kazachok landing platform of the ExoMars international project. In 2020, the flight model of the spectrometer was assigned the «01» letter, and the instrument as part of the Russian scientific instrumentation complex is currently being tested at the site of the European Space Agency. The spectrometer is the first for onboard analytical instrumentation to use the method of full resonator output (ICOS), which made it possible to achieve high sensitivity and provide measurements of isotope composition of the atmosphere with the required accuracy. The development is protected by patents and published in international journals. Adaptation of the development for use on board the UAV-VT will make it possible to measure GHG concentrations and their isotopologues at different levels of the atmospheric boundary layer and lower troposphere without resorting to costly measurement techniques on special towers.

As part of the program to equip carbon test sites, MIPT is developing laser gas analyzers that implement the method of turbulent pulsations to replace, both in the Russian and international markets, the equipment of American companies Picarro and Li-COR. The volume of the Russian market is estimated at 10 billion rubles. An agreement has been reached with the Ministry of Science and higher Education of the Russian Federation on placing the MIPT instrumentation at the pilot carbon test sites for cross-calibrations and further certification of the instrumentation and measurement methods. Certification of MIPT equipment both on national and international levels will take place with the participation of RSMU.

Partners of MIPT: Ministry of Natural Resources of Russia, Roshydromet, Yu. A. Izrael Institute of Global Climate and Ecology, Space Research Institute of the Russian Academy of Sciences, company «Big Three», and MIPT AERO. In addition to instrumentation and methods for processing and interpreting measurement data, MIPT undertakes numerical modeling of transport processes of climatically active substances in the atmosphere and hydrosphere, as well as the interaction of the atmosphere with the underlying surface.

Laser gas analyzer for remote detection of methane emissions in UAV

CARBON ACTIVITIES PLANNED FOR 2023

Quarter	Activities
1st quarter	Hackathon "Decarbonization Technologies", Eurasian Carbon polygon, Bashkortostan
2nd quarter	"Forest School 2023", G.F. Morozov Voronezh State Forestry University, Voronezh carbon polygon
	Round table «Global climate changes and carbon regulation», Khanty-Mansiysk, Ugra State University, Mukhrino carbon polygon
	Advanced training course "Experience of work organization and technical equipment of the carbon polygon", June, 01-05, Khanty-Mansiysk, Yugra State University, "Mukhrino" carbon polygon
	The Youth Carbon Summer School "CO2-tech", June, 01-05th, Khanty-Mansiysk, Yugra State University, Mukhrino carbon polygon
	Round table "Role of young scientists in realization of the Carbon polygon project" within the International Scientific Conference of Students, Postgraduates and Young Scientists «Lomonosov-2023»
	Summer environmental school at the WAY CARBON polygon for students and high school students
	International Conference "Marine Carbon Disposal Sites: Monitoring and Technologies", Gelendzhik carbon polygon
	Practical Youth Scientific School «Research Methods in Estimation of Quality and Safety of Aquatic Bioresources, their Habitat and Carbon Balance of Marine Ecosystems». Shirshov Institute of Oceanology of Russian Academy of Sciences, Gelendzhik carbon polygon

Quarter	Activities
3rd quarter	International Forest Forum "Forest and Climate: Problems, Threats, Prospects" Voronezh carbon polygon
	The Second "Carbon.MSU" Soil and Environment Summer School for Schoolchildren
	International summer school "Coastal sea zone: management, research and perspectives at the carbon polygon in Kaliningrad region", «Rosyanka» carbon polygon
	Visiting field seminar for students, devoted to the research at the onshore site of the carbon test site, Vitgirrensky peat bog, Rosyanka carbon polygon
	Session of the program of additional professional education "Monitoring and control of climatically active gases", Kaliningrad, Rosyanka carbon polygon
	Symposium "Climatic changes and carbon polygons" within the 13th All-Russian scientific and technical conference "Modern problems of geology and geophysics of the Northern Caucasus", WAY CARBON polygon
	2nd All-Russian Conference of Young Scientists and Postgraduate Students (School-Intensive) "Global and Regional Climate Change. Ecological challenges" - 3rd quarter, Grozny, WAY CARBON polygon
	Summer School "Coastal Climate Carbon Studies" for undergraduate and graduate students, Gelendzhik carbon polygon
	Regional conference "Carbon cycle research and problems of decarbonization in Krasnodar region: approaches to upscaling" together with Kuban State University, KubGAU, FIC SNTS, South Russian Scientific Center, Gelendzhik carbon polygon
	VIII All-Russian field school on soil zoology and ecology for young scientists "Genetic technologies in regenerative land use" (University of Tyumen, A.N. Severtsov Institute of Ecology and Evolution, RAS). A.N. Severtsov RAS, FSTP project on the development of genetic technologies in the Russian Federation for 2019-2027)
	Youth Festival "PRO-Climate", Eurasian carbon polygon, Bashkortostan
	International scientific and practical conference "Regenerative farming in the context of climate agenda: status, problems and prospects of development" on the basis of Kadyrov Chechen State University, WAY CARBON polygon
4th quarter	VI International Caucasus Environmental Forum, Grozny. Grozny, on the base of Kadyrov Chechen State University, WAY CARBON carbon polygon
	All-Russia Climate Forum. Eurasian carbon polygon, Bashkortostan
	III Youth School-Conference "Ural-Carbon", UrFU, Yekaterinburg
	Scientific and Youth School-Conference "Sustainable Management of Coastal Island Geosystems as a Basis for Preservation of Carbon Balance and Biodiversity" at the carbon polygon of Sakhalin region

Carbon Supersites
RUSSIAN FEDERATION

FOR&ST CARBON
Voronezh Region
forest, plough lands, reclamation plantings
181.3 HA

EURASIAN CARBON MEASUREMENTS TEST AREA
Republic of Bashkortostan
Feather grass steppe, fallow lands, forests, bogs
11599.5 HA

MUKHRINO"
Khanty-Mansi Autonomous Okrug
bogs, forests, lakes
1573,4 HA

WAY CARBON
Chechen Republic
Mountains, forests, steppe, grassland
1785 HA

BIOCARBON
Novosibirsk Region
Plain forest-steppe, foothill subtaiga
1008 HA

GELENDZHIK
Krasnodar Krai
Forests, water
26 HA

VOLGA-CARBON
Republic of Tatarstan
forest, rivers, reservoirs
60 HA

CARBON-SAKHALIN
Sakhalin Region
Seashore, sea
4004 HA

ROSYANKA
Kaliningrad Region
Peatbog, agricultural land, sea
255,4 HA

URAL-CARBON
Sverdlovsk Region
Taiga forests
606 HA

CHASHNIKOVO
Moscow Region
Mixed forests, agricultural land
605,9 HA

CARBON MEASUREMENTS TEST AREA IN KALUGA REGION
Kaluga Region
agricultural land, forests
600 HA

SEVEN LARCHES
Yamalo-Nenets Autonomous Okrugr
forest-tundra
2395 HA

TOMSK CARBON POLYGON
Tomsk Region
swamp, forest and floodplain areas
450 HA

CARBON MEASUREMENTS TEST AREA IN TYUMEN` REGION
Tyumen' Region
Forests, waters
10 670 HA

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