Study of climatically active gas flows on carbonic polygons

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Abstract. The study of climatically active gas flows on carbonic polygons is a topic of growing significance in the field of environmental science and climate research. Carbonic polygons, also known as ice-wedge polygons, are distinctive geomorphological features found in permafrost regions. These polygonal patterns play a critical role in the dynamics of greenhouse gas emissions, particularly methane and carbon dioxide, which are potent contributors to global warming. As our planet experiences the effects of climate change, understanding the mechanisms and factors influencing gas emissions from these carbonic polygons becomes essential. This study delves into the complex interactions between permafrost, vegetation, and gas fluxes, shedding light on how these interactions can impact our climate. Investigating climatically active gas flows on carbonic polygons is not only a scientific endeavor but also a proactive step toward addressing the challenges posed by climate change.

1 Introduction

The climate changes observed today on Earth are unprecedented in terms of the intensity and rate of changes in key climatic parameters, primarily surface temperature. This conclusion is based on the conclusions of all assessment reports of the Intergovernmental Panel on Climate Change (IPCC), including the latest, sixth assessment report, released in 2021. The last decade (2011–2020) was the warmest in the history of instrumental observations. Moreover, since the 1980s, each subsequent decade has been warmer than any previous one since 1850. Global surface temperature in 2011–2020 was 1.1°C higher than in 1850–1900, while the warming over land (1.59°C) was much stronger than over the oceans (0.88°C). Average rate of global warming during 1976-2020 amounted to 0.18°C/10 years on a global scale, and during this period alone, the global temperature increased by 0.8°C. It is important that the temperature increased especially rapidly in the Northern Polar Region, where, according to Roshydromet estimates, the linear increase in the average annual temperature over 30 years (1991–2020) was about 2.64°C with trends reaching more than 0.7°C per decade. (Fig. 1).

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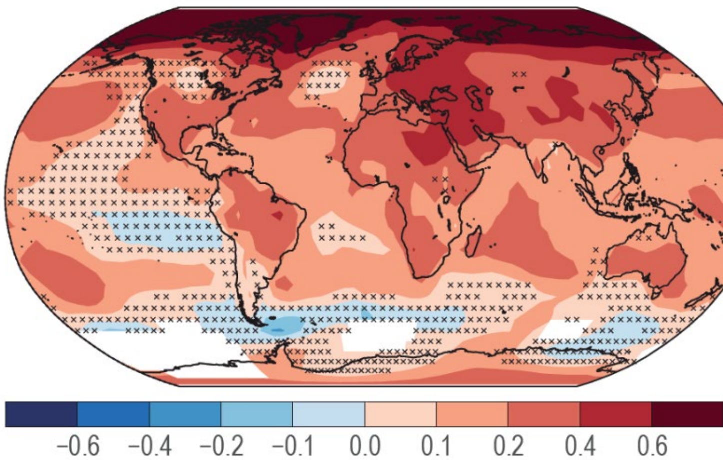

Fig. 1. Map of linear trends in surface air temperature for the period from 1981 to 2020. (°C per decade) presented in the IPCC 6th Assessment Report

The significant variation in global warming trends holds profound implications for Russia's vast territory, which experiences a considerably higher increase in surface temperature compared to the global average. According to the 3rd Assessment Report on climate change and its specific repercussions for the Russian Federation, published by Roshydromet in 2022, Russia is witnessing a warming rate that is nearly double the global land average, measuring at 0.51°C per decade. Remarkably, each passing decade since the 1980s has been progressively warmer than the previous one. Furthermore, out of the ten warmest years on record, nine have occurred in the 21st century, underlining the urgency of addressing climate change in Russia.

The main reason for the observed climate changes over the past 170 years is the emission of climatically active gases into the atmosphere, the main of which are carbon dioxide (CO2), methane (CH4) and nitrous oxide (N2O). The effect of these gases, which are called well-mixed long-lived gases, is due to the fact that they prevent the escape of long-wave solar radiation from the climate system. An additional effect is also created by halogen gases (CFCs, HCFCs, HFCs, PFCs, SF6), whose climate impact is somewhat less. The sources of emission of climatically active gases into the atmosphere are, firstly, human anthropogenic activity, and secondly, natural sources associated with biogeochemical processes in the Earth's climate system [2]. Anthropogenic influence on the emission of climatically active gases is provided by energy production, transport, agriculture, and various industries, the relative role of which in emission may vary from country to country, although the main source of emission in most countries is energy production. Another way of anthropogenic influence on the emission of climatically active gases is the change in landscapes and land use practices. Atmospheric concentrations of three major greenhouse gases have risen since the pre-industrial era: CO2 by 46%, CH4 by 157% and N2O by 22%.

2 Research Methodology

The decisive influence of emissions of climatically active gases on the change in the average global temperature makes it possible to predict climate changes for the coming decades and a century. Such forecasts are based on experiments with climate models that take into account various climate change factors, including the concentrations of climatically active gases, which determine the so called radiative equivalents (effective radiative forcing) [1-2]. To improve the reliability of climate forecasts, more than 100 Earth system models are currently used within the framework of the IPCC, which differ in configurations, parameterizations used, and spatiotemporal resolution [3]. As a rule, several experiments (up to 10) are performed with each model in order to obtain predictive characteristics of the climate, which differ in the initial conditions of initialization. This approach is called the ensemble approach, which makes it possible to form several rather close to each other solutions, the scatter of which also makes it possible to estimate the uncertainties of forecasts associated with model configurations. In addition to modeling uncertainties, significant uncertainties in the climate outlook are associated with emissions scenarios that are developed based on economic models that take into account the development of the world economy and projected socio-economic processes. The scenarios, which are defined as "Shared Socioeconomic Pathways" (SSPs), include not only forecasts of emissions of climate-active gases, but also forecasts of changes in land use practices and a number of other factors (Fig. 2). Thus, forecast estimates show that anthropogenic factors associated with greenhouse gas emissions can lead to critical changes in both the global climate and climatic conditions in Russia, which will significantly affect all aspects of the life and economy of the country, including agriculture, energy, quality of life of the population.

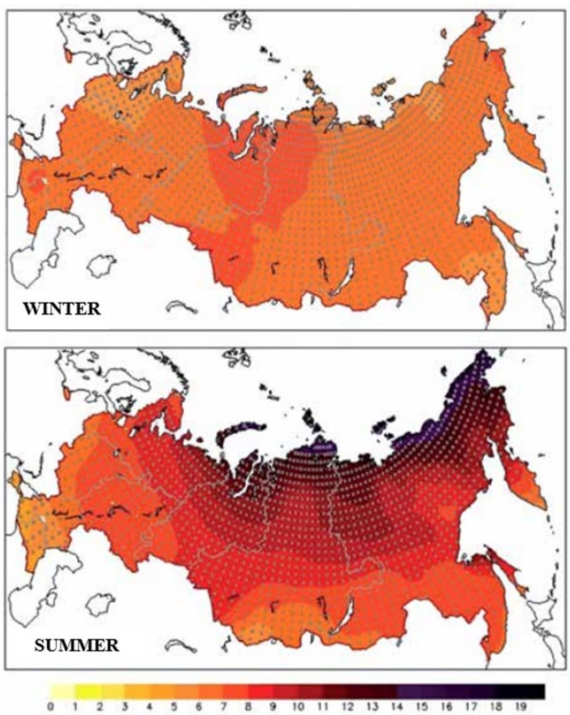

Fig. 2. Projected growth of surface air temperature in Russia in the period 2081–2100. in degrees Celsius under the most unfavorable scenario SSP5 8.5 for winter (above) and for summer (below) according to the 3rd Assessment Report of Roshydromet on climate change and its consequences on the territory of the Russian Federation.

The Kyoto Protocol, a pivotal international treaty, emerged as an extension of the United Nations Framework Convention on Climate Change. It was ratified with the intention of curbing the growing threat of climate change, primarily driven by greenhouse gas emissions. The Protocol placed binding commitments on industrialized nations, as well as countries in transition, to curtail their emissions of greenhouse gases. These obligations included specific targets for each participating country, reflecting their historical responsibility for emissions and economic capacities. By signing the treaty, nations committed to substantial reductions in emissions within the given timeframes. The protocol provided flexibility in how countries could achieve their targets, allowing them to explore different strategies such as emissions trading and Clean Development Mechanism projects. Countries that exceeded their emission reduction targets were permitted to trade excess emissions credits to others. The Kyoto Protocol's first commitment period ran from 2008 to 2012, and it achieved varying degrees of success in meeting reduction targets. While it marked significant progress in international cooperation to address climate change, the Protocol also faced challenges, including non-participation from major emitters. The treaty laid the foundation for later climate agreements, such as the Paris Agreement, as nations continued to work collectively towards a more sustainable and climate-resilient future.

3 Results and Discussions

A pilot project of the Ministry of Science and Higher Education of the Russian Federation was aimed at solving the problems of assessing the balance of greenhouse gas flows for various ecosystems in Russia and developing technologies aimed at sequestering greenhouse gases [3]. The main indicator in assessing the role of individual countries in gas emissions will be net emissions (that is, the difference between emissions and absorption). As such, the assessment (inventory) of climatically active gases by each country has to be done in order to find out the net emission from all countries. It is also important to understand how reliable quantitative accounting of anthropogenic and natural sources of this gas on the one hand; and natural (or man-made) absorbers of these gases. However, in modern conditions, this is the problem not only purely scientific and environmentally significant but also political and economic. The inventory of both emissions as well as sequestration from greenhouse gases will be subject to international community's trust in national monitoring systems for climate-active gases has been made into an issue that is non-only scientific and environmentally significant, but also global and economic, since the data on emission and sequestration of greenhouse gases are considered the subject of international community’s trust in national monitoring systems for climate-active gases can be monitored by all countries with interest. In absence (at least for the time being) of well-defined standards for measuring and calculating emissions, sequestration and emission, it is possible to speculate on the possibility of an area of economic speculation. Among other things, the lack of internationally-recognized gas monitoring and analysis technology for gas inventory and monitoring in the country will lead to the need to take “for granted” data on existing monitored systems that are not completely accurate or difficult. In addition, the lack of international standards for gas inventory and monitoring in the country will lead to the need to take "for granted" estimates based on existing satellite monitoring technologies, the verification of which will be extremely difficult or impossible, as well as models that are not entirely accurate. In addition, not always justified approaches to large areas are also possible, but with no reasonable approximation to large areas. For example, it is possible to conclude that the position of Russia in terms of financial and economic issues concerning global trade flows will be unstable. This will lead to the fact that its position on discussing problems with the development of international relations and an attempted introduction of cross-border carbon control for trade flows will be poorly funded, as well as risking large losses for Russians (according to various data, from 4 to 24 billion dollars a year). On the territory of Russia, in 2021, the project was initiated to create an effective monitoring system for gases that are volatile and provide it with effective methods. The development process will be carried out on the basis of the concept "Building an effective monitoring system" by providing them with scientific and pedagogical tests as well as experiments into how to measure emission and sequestration potentials by different ecosystems. A pilot project is designed to assess the potential of Russian ecosystems in terms of ensuring the sequestration of climatically active gases [5]. The strategic goal of the pilot project is to assess the potential of Russian ecosystems in terms of ensuring the sequestration of climatic active gases [5]. However, in this case, the project will solve several problems. This is a first step in obtaining reliable integral and completely correct information about the fluxes of the main greenhouse gases over the Russian Federation, as well as some types of landscapes, which is fundamental for international reporting. In addition to this, it is an assessment of the potential in terms density and greenhouse gas retention. Secondly, it was assessed the potential of different types of landscapes in terms of greenhouse gas absorption.

A final, thirdly, this is the acceptance of sequestration techniques, most effective in different climatic conditions. And, finally, it is the development and construction of an road map for the implementation of climate projects in the natural ecosystems of Russia. [6]. As part of the pilot project, the construction and installation of measuring sites in various natural systems that are both emitters or absorbers of gases has begun [6]. So-called such areas are different forests, swamps, permafrost and coastal waters, as well as active land production. In the polygon, precision measurements of gases that are mainly climatically active, as well as heat and moisture flows are provided on the basis of pulsation and Chamber methods, as well as direct emission from the soil surface. A network of ground sensors, as well as remote observations are provided by unmanned aerial cars equipped with the required set of sensor equipment- multi- and hyperspectral cameras, radars, lidars, etc. This is possible to obtain such measurements through an electronic network of sensors, as well as remote observations using unmanned aerial vehicles equipped with the necessary set of sensor equipment - multi- and hyperspectral cameras, radars, lidars, etc. It is important to understand that the composition and configuration of measuring tools depends on the characteristics of the test site itself. As the polygons occupy relatively small territories in terms of area, totaling about 100 percent to Russia and representing different kinds of land that make up tens or tenths of the Russian Federation, but as an example for such regions, it will be possible to solve problems above. The polygons will form an effective observational network that will help you solve all the problems mentioned above. In addition to this, observations carried out at the sites will be included in international scientific and research programs including: EU-Copernicus CO2 Human Emissions project (CHE), FLUXnet, Accelerator Global Atmospheric Gases Experiment (AGAGE), WMO World Atmosphere Observing System (GCOS) or other. The polygons will be not only monitoring sites, but also experimental landscape modifications in order to assess the effectiveness of ecosystems' absorption potential. The work of such experiments can be based on the use of highly sequestering plant materials, changeing soils and studying mariculture's potential for assessing its destruction. It is possible to include: planting highly sequestering crops, changing soil types, studying the potential of mariculture to assess its sequestration potential, and other technologies. The most successful of them will later be climate projects developed by industrial partners of the landfills, which are intended to develop by industrial partners of the landfills. In a year, many key assessments will be possible to assess the results of the monitoring system by polygons. The full assessment of the results of the monitoring system using polygons will be possible in a decade, although many key assessments will appear and be used in 3-4 years. Among scientific and educational systems, polygons also serve to create a new level of human resources for the development and maintenance of an environmental monitoring system. At the moment, the task of monitoring climatically active gases is an interdisciplinary one and demands specialized knowledge from specialist in many different disciplines: climatiology, meteorological oceanography numerical modeling. The technique of measuring temperature-active gases is complex and requires the involvement of specialists in various scientific field: climatology, meteorology and oceanography, numerical modeling, measurement technology, machine learning etc. This demanded the joint work of research and university institutions to create new formats that are specifically for the test sites, adapt existing ones. It was also required by this group's involvement in creating new educational formats related to the test sites itself, to adapt existing ones, and to develop new master's and postgraduate programs consolidating knowledge from different fields [8].

The Kadyrov Chechen State University Carbon landfill is the only one where scientific research is carried out on the development of technologies for regenerative animal husbandry 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 soil carbon emissions. The combination of crop rotation and the maintenance of managed grazing perennial cover crops also contributes to the accumulation of organic carbon in the soil. This task is being solved within the framework of the project on creating a pasture management tool. In order to effectively achieve its goals, the university actively interacts with teams that are competent in climate and carbon topics – Peoples' Friendship University of Russia, Voronezh State Forest Engineering University named after G.F. Morozov, National Research University Higher School of Economics, Institute of Geography RAS, Academician Yu.A. Israel. The project is aimed at identifying the most effective methods of regenerative animal husbandry to increase carbon sequestration by pastures, and studying the impact of climate on the ecosystems of mountainous and foothill landscapes. The service being developed is based on the creation of a digital model of a pasture area, which will allow analyzing the state of pastures in terms of their possible degradation and quantifying the volume of the produced forage base, disturbances in the soil and grass cover, the presence of areas of wind and water erosion and salinity zones. At each site (reference site, intensive grazing, grazing), aboveground herbaceous vegetation is sampled to assess the volume and quality of biomass. The dominant plant species for each ecosystem are summarized [9]. In total, 62 species of vascular plants belonging to 31 families were found on the southern slope of the Makazhoy depression (Fig.3). As part of the project implementation, a mathematical model was implemented in software that takes into account the mechanisms of physical stabilization of soil organic matter. At present, parametric identification of this model is being carried out on test sites of regenerative animal husbandry. The project will result in restoration of soil quality and an increase in soil carbon content, increase in profitability of production by increasing the density of livestock in the same area, and a reduction in production costs due to the natural restoration of pastures.

Fig. 3. The Kadyrov Chechen State University Carbon landfill

Obtaining the spatial distribution of greenhouse gas fluxes and, ultimately, integral estimates of the fluxes and components of the carbon balance in Russia is impossible without a detailed account of the landscape heterogeneity of the country's territory [10]. To obtain integral estimates of fluxes using point measurement data, it is necessary to develop a methodology for spatial interpolation of data based on a set of factors that take into account regional climatic conditions, the structure and species composition of vegetation, the structure of the soil cover, the topography of the area, and many other factors. The modern network of stations for monitoring greenhouse gas fluxes in Russia is still quite rare, which does not allow the use of conventional statistical methods for interpolation of point observational data.

4 Conclusions

The measured fluxes are representative for the most part only for an extremely small area near the measuring tower, which poses the most difficult task of scaling the data to larger areas and their further interpolation using nonlinear models with a set of parameters describing climatic and geomorphological conditions, soil structure. and vegetation cover. Complex models with a large number of input variables usually accumulate errors in determining the parameters and initial data, which leads to the fact that the accumulated error can significantly exceed the effect of taking into account the features of the simulated nonlinear processes. Simplification of the problems of interpolating spatial data, calculating the parameters of ecosystem functioning, and, as a result, calculating carbon fluxes can be achieved by constructing regional linear models. In this case, the operating unit of modeling can be an ecoregion that unites a territory with the same climatic conditions, similar relief parameters, soil characteristics, and vegetation cover properties. Statistical modeling methods were used to formalize the process of identifying ecoregions in the study. The set of variables characterizing the relief, climate, structure, soil and vegetation conditions, and vegetation parameters are given in the table. Next, the matrix data on various ecosystem parameters were subjected to a clustering procedure based on the K-means method. This algorithm makes it possible to identify clusters or centroids (characterizing the centers of clusters), assigning each data point to the nearest cluster, while maintaining the characteristics of centroids. This problem is solved iteratively with optimization with respect to various statistical parameters. Each cluster is characterized by a minimum dispersion of values for the selected variables and, in our case, can thus be considered as a unique physical and geographical region. The clusters in our study represent types of representative landscapes to substantiate the location of stations in the carboniferous polygon network. Each distinguished class is characterized by a homogeneous (in relation to the formation of flows of climatically active gases) landscape. The zoning carried out allows us to conclude that the existing 15 polygons are representative of landscapes occupying an area of 392,800,000 hectare. This is approximately 23.1% of the territory of Russia (~17,000,000 km2). The total area of the 15 polygons themselves is about 40,000 ha, which is 0.002% of the territory of Russia; i.e., conducting research on 0.002% of the territory, we obtain estimates that are representative of 23.1% of the territory. Some refinement estimates can also be made. Thus, permanent snows/glaciers in Russia occupy 6,400,000 ha, water bodies (without swamps), for which assessments should be carried out separately, amount to 63,000,000 hectare. Then the corrected estimate shows that the current 15 polygons are representative of 24.4% of the territory of Russia.

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References

1. G. V. Vorontsova, G. V. Chepurko, R. M. Ligidov, T. A. Nalchadzhi, I. M. Podkolzina, Problems and perspectives of development of the world financial system in the conditions of globalization, **57**, 862-870 (2019)
2. Y. E. Klishina, I. I. Glotova, O. N. Uglitskikh, E. P. Tomilina, I. M. Podkolzina, Peculiarities of the financial policy of non-profit organizations in the macroeconomic unstable environment. Espacios, **38(34)**, 34 (2017)
3. A. Lawler, End Game for Oil? OPEC Prepares for an Age of Dwindling Demand. Reuters (2021)
4. I. V. Taranova, I. M. Podkolzina, F. M. Uzdenova, O. S. Dubskaya, A. V. Temirkanova, Methodology for assessing bankruptcy risks and financial sustainability management in regional agricultural organizations, **206**, 239–245 (2021)
5. A. S. Salamova, O. Dzhioeva, Green transformation of the global economy in the context of sustainable development, 152-159 (2023)
6. A. S. Salamova, Global networked economy as a factor for sustainable development, 03053 (2020)
7. V. Sebestyén, E. Domokos, J. Abonyi, Focal Points for Sustainable Development Strategies: Text Mining-Based Comparative Analysis of Voluntary National Reviews. Journal of Environmental Management, **263** (2020)
8. S. G. Shmatko, L. V. Agarkova, T. G. Gurnovich, I. M. Podkolzina, Problems of increasing the quality of raw material for wine in the stavropol region, **7(2)**, 725-730 (2016)
9. R. A. Gakaev, I. A. Bayrakov, M. I. Bagasheva, Ecological foundations of the optimal structure of forest landscapes in the Chechen Republic, 50-52 (2006)
10. R. Gakaev, Carbon sequestration in landscapes of the Chechen Republic. Reliability: Theory & Applications, **3(66)**, 193-196 (2022)
11. G. Kerse, A. B. Çakıcı, V. Deniz, The Manager, **13(5)**, 49-66 (2022)