Bank of Russia

CLIMATE PHYSICAL RISKS: APPROACHES TO ANALYSIS AND RECOGNITION IN FINANCIAL SECTOR

Consultation paper

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CONTENTS

This report was prepared by the Financial Stability Department.

Please send your responses to the questions, comments and suggestions before 17 October 2025 to: mmm1@cbr.ru, sidorovskiymo@cbr.ru, musaelyanda@cbr.ru.

The reference to the Bank of Russia is mandatory if you intend to use this consultation paper.

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ABSTRACT

Climate change is causing natural hazards, such as heatwaves, floods, droughts and storm winds, to become more frequent, persistent and intense. Rosgidromet data suggests that the territory of Russia since the 1970s has been heating up 2.5 times faster than the global average.[1] These changes are already affecting the main regions of the country, posing a threat to ecosystems, infrastructure and public health. This in turn hinders the achievement of Russia's national development goals, including improved quality of life, stable economic growth and the creation of a safe living environment. To analyse the effects of climate change, the notion of climate physical risk is used, understood as a combination of hazard, exposure and vulnerability components.

The realisation of climate physical risks may cause both direct damage (infrastructure destruction, lower crop yields and land degradation) and indirect effects (disruptions in logistics, growing prices, deterioration in business conditions and lower economic activity). Aggregate damage may be significant relative to GDP. This is particularly evident in low-income countries, tropical regions, island states and coastal lowlands. Macroeconomic damage is quantified using integrated assessment models (IAM) and econometric approaches, but each method has its limitations. For Russia, the estimates range from moderate damage[2] to potential benefits[3] provided that a large-scale adaptation programme is delivered; in this case, the regions located in permafrost areas and the southern agricultural regions remain especially vulnerable.[4]

Financial institutions around the world are already experiencing the impact of climate risks as they are confronted with higher insurance payments, lower collateral quality and declining solvency of borrowers.[5] Banks register an increase in credit risk in vulnerable sectors and regions[6]; insurance companies come under pressure, having to raise their provisions and address the rising costs of reinsurance.[7] However, it is not feasible to directly extend the climate risk assessment approaches for the real sector to financial sector companies due to the nature of their operations. A hazard-exposure-vulnerability model is needed to quantify risks for the entire portfolio of financial institutions and convert them into financial indicators used in risk management systems.

Given that underestimated climate-related threats can translate into systemic risk, tools are also needed to assess, monitor and disclose physical climate risks across the financial sector. International organisations and regulators have extensive experience of stress testing, integrating climate-related metrics into supervisory reporting and developing digital vulnerability assessment platforms. However, the still limited access to high-quality data, models and analysis infrastructure requires that regulators, the academic community and market participants joint efforts.

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1 Rosgidromet's 2024 Report on Climate in the Russian Federation. 2025 [in Russian].

2 Porfiryev B.N., Kolpakov A.Yu. and Lazeeva E.A. Assessing the impact of climate change on the Russian economy using integrated assessment (IAM) models. 2025 [in Russian].

3 Economic effects of climate change in Russia. Analysing risks and opportunities for the country's sustainable development. 2024 [in Russian].

4 Makarov I.A. and Chernokulsky A.V. Climate Risks in Russia: Ranking of Regions by Adaptation Needs. Izvestiya, Atmospheric and Oceanic Physics. 2024.

5 Financial Stability Board. Assessment of Climate-related Vulnerabilities. 2025.

6 Bank for International Settlements. Stress-testing banks for climate change – a comparison of practices. 2021.

7 Financial Stability Board. The Implications of Climate Change for Financial Stability. 2020.

Questions for consultations and promising areas of focus for the Bank of Russia, federal executive bodies, academic communities, financial and non-financial companies, and other stakeholders

1. Physical risks cause direct damage to infrastructure and agriculture, leading to indirect losses through disruptions in logistics and declines in business activity.[8] Global damage assessments vary depending on the models, scenarios and approaches. Regional studies highlight the high vulnerability of developing and tropical countries, as well as sectors such as agriculture and tourism. Current models are far from perfect given their limited verification of damage functions, failure to fully account for irreversible changes in the climate system and adaptation mechanisms, which creates significant forecast uncertainty.

It is feasible to promote international cooperation to enable progress in the following areas:
- Development of global and regional economic models to assess climate physical risks
- Efforts to improve the monitoring and climate data collection system to enhance the accuracy of risk forecasts.

Do you agree with the suggested areas of activity?

2. The uneven distribution of damage caused by climate change, the lack of data and other limitations are formidable challenges for researchers. Few macroeconomic studies, including domestic research, make the case for moderate or even positive effects of climate change. Regional and sectoral works on this subject confirm the existence of serious physical risks for a number of Russia's territories and economic sectors. Thus, the effects of chronic countrywide risks and acute regional risks are uneven.

Going forward, we believe it is feasible to:
- continue research into the impact of climate change on the Russian economy, individual sectors and regions
- further define the effects of climate change and a number of natural hazards on the economy, including by means of econometric methods, and compare the results with sectoral and regional assessments
- assess the potential indirect effects (including on the financial sector) of more frequent major natural hazards.

Do you agree with the suggested areas of activity?

3. Considering the potential consequences of climate-related events, including rising credit and market risks, a methodology should be developed to assess the largest, in terms of size and importance, climate-sensitive portfolios. Such a methodology may be aimed at identifying risks in highly vulnerable regions, industries or client groups.

To formulate an approach to creating the methodology, the following areas should be clarified:
- Which direct and indirect climate physical risks do you consider to be most material?
- How do you factor in these risks in your portfolio assessments?
- What sources and formats of information do you use to identify, monitor and assess information?
- How do you manage these risks? Which adaptation measures do you use to reduce your operational risk?

Furthermore, it is advisable to create a public service, which in turn:
- is intended to consolidate existing data on hazard-exposure-vulnerability components
- will involve a model-based approach, enabling data conversion into indicators that can be easily integrated into credit or insurance processes

[8] IPCC. Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the IPCC Sixth Assessment Report. 2022.

- will be easily accessible to financial companies (e.g. via APIs) and have a reliable infrastructure to prevent customer data breaches.

The Risk Office of Russian National Reinsurance Company (RNRC) has extensive experience of flood modelling and flood scaling to other types of climate threats.

Limited information remains the key barrier to assessing physical climate risks at the financial sector level. For all the methodological approaches in existence, including those adjusted to regulator needs, quantitative assessments are limited in terms of both coverage and quality of source data.

The first stage may involve targeted assessments of exposure to specific climate risks of certain asset classes and activity types (e.g. by surveying credit institutions and insurance companies), as well as analysis of existing internal methods.

The next step may be a stress test with a shift in focus away from making an accurate estimate of damage to identifying vulnerable segments and indicators reflecting sensitivity to physical risks. This approach makes it possible to use stress testing as a tool to identify gaps in data and generate a relevant request.

In the long term, the key focus of efforts will remain on improving the volume and granularity of available information, including global experience.

To create a map of the financial system's exposure to climate risks and subsequently develop risk management tools, a database is needed to enable the Bank of Russia to gauge financial institutions' exposure to physical risks. In particular, the quantitative metrics of exposure to climate physical risks can be based on the following information:

- the geographical location of borrowers or insured assets (e.g. according to the Russian Classification of Territories of Municipal Formations (OKTMO)[9]
- additional conditions or limitations in corporate borrowing or insurance, which are related to natural and climate conditions (e.g. operational limitations, shorter timelines, exclusion of some risks from coverage, additional protection requirements, etc.).
- more detailed breakdowns of insurance benefits:
  - information related to the realisation of natural hazards by their type (floods, storm winds, droughts, permafrost thawing)
  - identification of fires caused by wildfires.

Do you agree with the suggested areas of activity? What kinds of support (including methodological, digital and legal) are needed from the Bank of Russia and federal executive bodies to enable progress in these areas of activity?

Please send your responses to the questions, comments and suggestions before 17 October 2025 to: mmm1@cbr.ru, sidorovskiymo@cbr.ru, musaelyanda@cbr.ru.

[9] Specifically, data may be collected as part of a pilot project to assess the possible formats of submission.

1. CLIMATE CHANGE AND CLIMATE RISKS

Climate change increases the frequency, duration and intensity of natural hazards, including heatwaves, floods, droughts and storm winds. These changes are already affecting the main regions of the country. They are a threat to public health, ecosystems and infrastructure, and thus create significant obstacles to achieving Russia's national development goals, including improved quality of life, stable economic growth and a safe living environment. The implications are analysed using the concept of climate physical risk as a set of hazard, exposure and vulnerability components.

Climate: current state and future changes

The Earth's climate is now changing faster than at any point of time in the history of civilisation. This is chiefly attributed to human activities, mainly related to greenhouse gas emissions. Climate change is marked by long-term changes in temperature and precipitation patterns, as well an increased frequency of natural hazards. Specifically, in 2024, the global average surface temperature was 1.55°C higher than the average of 1850–1900, making 2024 the warmest year on record. The last decade (2015–2024) was one of the warmest periods on record.

The sea surface temperature is also on the rise. The increase of 0.27°C per decade between 2019 and 2023 led to ocean warming 4.5-times faster than in the 1980s. In 2024, the area of sea ice in Antarctica was the second lowest on record, with glaciers continuing to melt rapidly and thus contributing to additional greenhouse gas emissions and increasing climate change.

In addition, current climate change has driven up the frequency, intensity and duration of heatwaves; it has also driven down the number of extreme cold days and nights in most regions of the world.

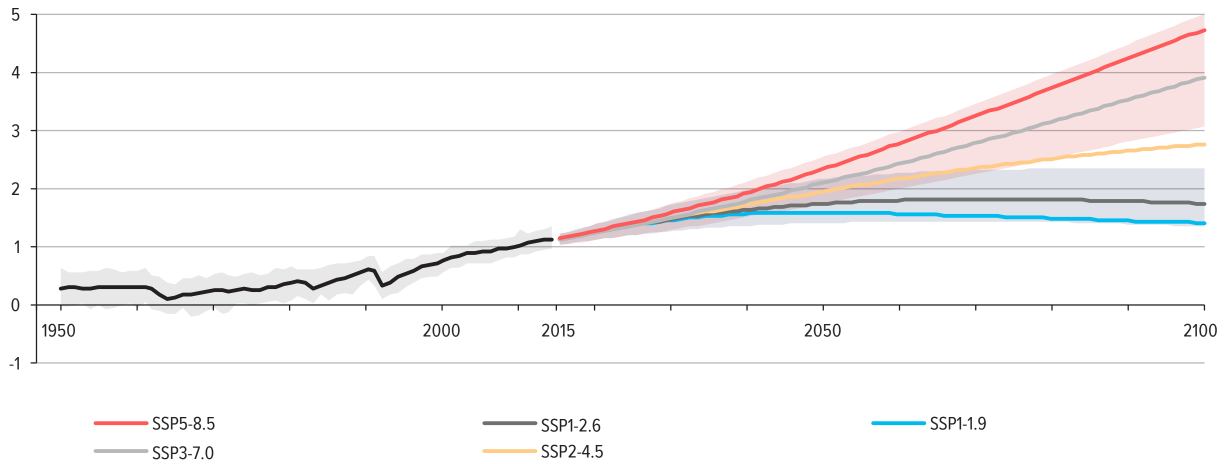
To address this problem, the Paris Agreement was signed in 2015 as part of the UN Framework Convention on Climate Change. This international treaty is aimed at keeping the increase in global average temperature much below 2°C and limiting temperature growth to 1.5°C relative to pre-industrial levels. The signatory countries voluntarily pledged to reduce greenhouse gas emissions, enhance adaptation to climate change effects and support less developed countries in these efforts.

Climate model projections show that the global average temperature is on course to increase by almost 5°C by the end of the 21st century unless anthropogenic greenhouse gas emissions are significantly reduced (scenario SSP5–8.5). Significantly lower emissions will limit warming to 2°C (scenarios SSP1–1.9 and SSP1–2.6, Figure 1). See Appendix 2 for more details on climate scenarios.

Changes in the climate system are responsible for the uneven distribution of precipitation. Northern Europe, South Asia and the east of the US are seeing an increase in annual precipitation and, most importantly, in the number of extreme precipitation days. Forecasts suggest that each degree of change in global temperatures will increase the amount of extreme daily precipitation by as much as 7% and further strengthen the upward trend (Figure 2).

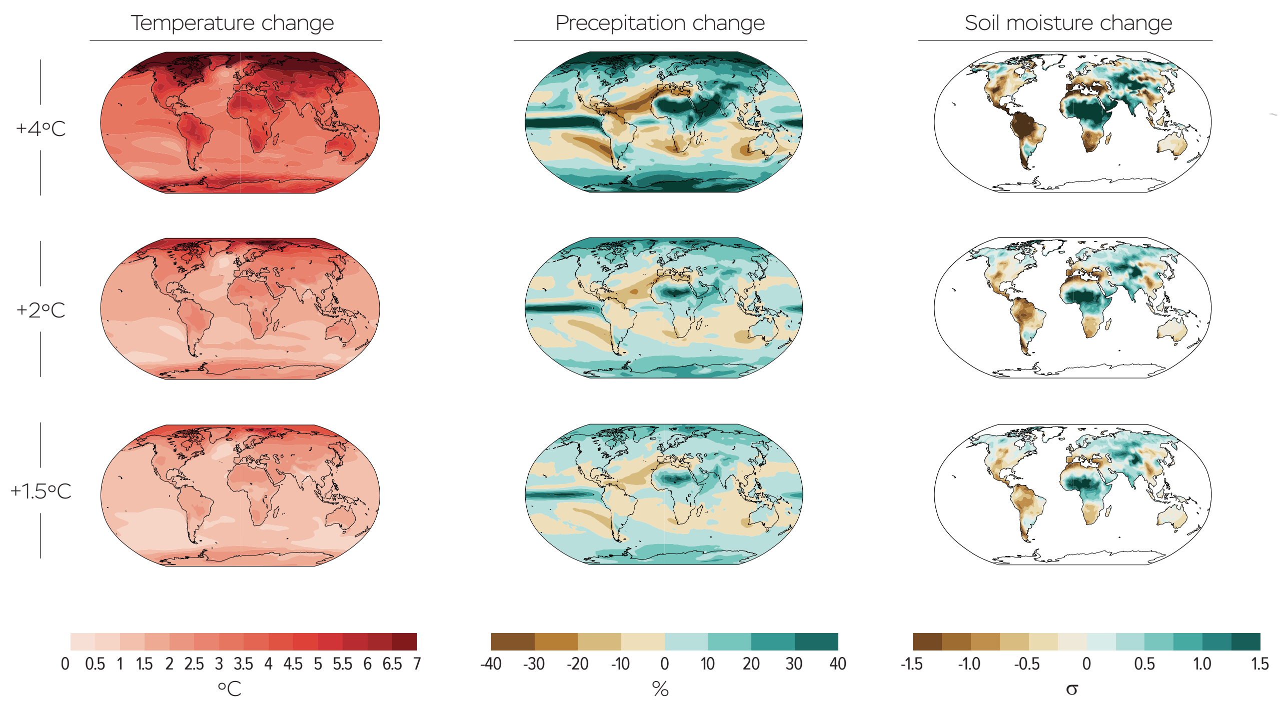
Climate change is expected to increase a number of other natural hazards. According to the UN, droughts around the world have in recent years become much more frequent and more intense. Since 2000, their number is up about 30%, especially in the Mediterranean, Western Asia, many parts of South America, most of Africa and Northeast Asia. Climate change is expected to increase the risk of droughts in regions marked by rapid population growth and food security problems. Megadroughts, that is prolonged drought events lasting for a decade or more, are also becoming more frequent, causing serious damage, as was the case of southwestern North America and Chile.

CHANGE IN GLOBAL SURFACE TEMPERATURE RELATIVE TO 1850–1900 *Figure 1*



Source: IPCC. Summary for Policymakers. Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. 2021.

CHANGE IN SURFACE TEMPERATURE, PRECIPITATION AND SOIL MOISTURE RELATIVE TO 1850–1900 *Figure 2*



Source: IPCC. Summary for Policymakers. Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. 2021.

Climate risk and its components

Climate change affects both ecosystems and humans, their economic activities and health. The concept of climate risk was introduced to analyse and assess this impact. In its Sixth Assessment Report, the Intergovernmental Panel on Climate Change (IPCC) determine that climate risk results from dynamic interactions between the hazard associated with climate change, the exposure of affected societies and ecosystems and their vulnerability. Damage from climate change should be determined as the difference between actual damage from climate change alongside the associated natural hazards and damage in a counterfactual baseline scenario, that is damage from natural hazards in a world that is identical to ours but has stable climate conditions. However, the quality and quantity of data today do not allow for the detailed calculation of damage in a counterfactual baseline scenario.

The Sixth Assessment Report of the IPCC identified 127 key climate risks relevant for the whole world. They are divided into eight groups depending on what is exposed. Each group is described in Table 1.

IPCC CLIMATE RISK GROUPS *Table 1*

Risk group	Examples
1. Risk to integrity of low-lying coastal social and environmental systems	Risk to ecosystem services, people, livelihoods and key infrastructure in low-lying coastal areas associated with a wide range of hazards: sea level changes, ocean warming and acidification, natural hazards (storms, cyclones), loss of sea ice, etc.
2. Risk to terrestrial and marine ecosystems	Transformation of terrestrial and oceanic/coastal ecosystems, including changes in their structure and/or functioning, and loss of biodiversity
3. Risk to critical infrastructure and services	Systemic risks due to natural hazards causing destruction of infrastructure providing critical goods and services
4. Risk to living standards	Economic impacts on various scales, including impact on GDP, poverty and livelihoods, and exacerbating socio-economic inequality between and within countries
5. Risk to human health	Mortality and morbidity caused by heat and heatwaves, and by infectious and parasitic diseases and water-borne diseases
6. Food security risks	Food insecurity and destruction of food systems due to the impact of climate change on land or ocean resources
7. Water security risks	Flood and drought risks and deteriorating water quality
8. Risks to peace and human mobility	Risks of armed conflict and the inability to leave affected territories

Source: IPCC. Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the IPCC Sixth Assessment Report. 2022.

Overall, many industries (construction, agriculture, finance) have traditionally approached climate risk assessment by relying on historical data. For example, building regulations are based on climate regulations without considering current climate change. Credit institutions assess the probability of default based on past years' statistics; insurance companies assess the probability of insurance risk realisation based on, among other things, the frequency and impact of previous losses.

However, climate change has resulted in the frequency and intensity of such hazards deviating significantly from their long-term historical trends. This creates a gap between traditional risk assessments and the actual hazards that emerge in new climate conditions. Building rules, elaborated decades ago, may factor out the increased frequency of extreme precipitation or permafrost thawing, and financial models may underestimate the increase in credit risks in regions more heavily exposed to climate change.

All this requires a separate assessment and consideration of climate physical risks. Traditional – historical data-based analysis – should be supplemented with forecast models that take the pace of climate change into account. This is the only way to ensure that infrastructure, the financial system and the economy are resilient to new challenges.

2. PHYSICAL RISKS AND GLOBAL ECONOMY

Aggregate damage from climate physical risks over a horizon of 2050–2100 may total a significant share of GDP, especially in low-income or tropical countries. Integrated assessment models (IAMs) and econometric approaches used to quantify macroeconomic damage are limited in effectiveness due to the long horizon and high uncertainty of the course of natural hazards and adaptation to climate change.

Global estimates of damage from climate physical risks

According to the IPCC Sixth Assessment Report, global warming of about 4°C by 2100 will cause a 10–23% loss in global GDP, unadjusted for adaptation.[10] This is based on findings by Burke M. et al. (2015), Kahn M.E. et al. (2019) and Kalkuhl M. and Wenz L. (2020). At the same time, the IPCC expects regional losses to be uneven. For example, developing countries, especially in Africa and South Asia, will suffer greater economic losses of up to 15% of GDP by 2050 (Baarsch F. et al. (2020)) and up to 80% by 2100 in worst-case scenarios (Burke M. et al. (2015). Swiss Re Institute expects that Southeast Asian countries, Africa and the Middle East will suffer the most from climate change.[11] In 2014–2023, an average of 20–30 million cases of displacement annually due to disasters were recorded in the world, of which more than 80–90% were linked to climate hazards, mainly floods and storms. The bulk of such migration was registered in developing countries whose limited adaptation and recovery capabilities exacerbate long-term socio-economic impacts.

GDP remains the basic indicator for damage from climate change. However, in modelling climate change damage, economists look beyond GDP as they seek to convert losses, including non-economic ones, into monetary values.[12] For this reason, GDP – an indicator that includes only market operations – may in effect be confused with climate damage assessment methods relying on GDP as a basis but supplementing it with non-economic components through special models.[13]

Physical risks are an increasingly meaningful source of risks for the financial system. The flood in Pakistan in 2022 is an example of contagion effects of a major natural emergency on the financial system. The flood killed or injured tens of thousands of people, forcing millions to leave their homes; 13,000km of roads, 2 million houses, 500 bridges and 5 million acres of crops were destroyed. A third of the country was under water. The flood caused $30.1 billion in damage ($14.9 billion worth of infrastructure, buildings and other tangible assets destructed, and $15.2 billion of loss of income and other economic opportunities), which totals more than 4% of the country's GDP. Financial sector losses totalled $417 million, as a result of physical destruction of infrastructure (e.g. bank branches and ATMs), loan losses and additional insurance payouts. At the same time, some Pakistanis were confronted with financing constraints. The Pakistani government needed $16.3 billion for the recovery programme. The damage was uninsured, which required a request to the IMF for urgent financial support. Ultimately, the country's external debt rose 32% to $77 billion in 2023, with liabilities to the IMF rising 45% to $7 billion .

10 IPCC. Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the IPCC Sixth Assessment Report. 2022.

11 Swiss Re Institute. The economics of climate change: no action not an option. 2021.

12 Non-economic losses caused by climate change are difficult to quantify in monetary terms (loss of life, health, cultural heritage or ecosystem services). They are different from economic losses, which imply measurable losses of property, assets or income. Understanding and accounting for non-economic losses is critical to an integrated approach to assessing and responding to climate change impacts.

13 Nordhaus William D. and Andrew Moffat A. Survey of global impacts of climate change: replication, survey methods, and a statistical analysis. 2017.

According to the IMF[14], the rapid increase in public spending in advanced economies offsets negative effects, which sustains steady GDP growth and foreign trade stability (unlike in developing countries). In developing countries, limited fiscal space and weak institutional mechanisms are responsible for a significant decline in economic activity in the course of a disaster year, and a subsequent recovery fails to offset the losses. Small island states, relying on tourism and foreign trade, are particularly exposed. Damage to their key facilities (e.g. ports) and reduced export flows exacerbate economic consequences of natural disasters.

An active policy of reducing global greenhouse gas emissions can help avoid some damage. Developing countries are potentially much more interested in a rapid reduction in greenhouse gas emissions than developed countries. Developing economies in Africa and Asia incur the highest losses (relative to GDP) due to climate change. Direct losses of African countries already total 2–5% of GDP and counting,[15] while in Asia, annual damage from meteorological hazards is set to grow from 2.9% to 3.1% of regional GDP if 2°C warming is registered by mid-century.[16] According to the IPCC, the key risks for Africa include an increased duration of droughts and a rise in average temperatures, which destroy natural ecosystems and reduce biodiversity.[17] The main threat to the population is increased morbidity and mortality rates driven by high temperatures and the spread of infectious diseases, as well as a decline in agricultural output. Climate change in Asia leads to an increase in the frequency, duration and intensity of droughts; as monsoon circulations weaken, the distribution of precipitation in the region[18] changes. South and Southeast Asia is at risk of more devastating floods and hurricanes.

While underfunding for the adaptation programmes remains a systemic problem worldwide (according to UNEP, the lack of funding is $187–359 billion per year through 2030 vs $25 billion of actual funding), the adaptation issue is most acute in the least developed countries, most of which are in Africa and Asia.[19] Given the chronic underfunding, each dollar invested in the adaptation of regional economies is economically more effective, compared to advanced economies,[20] inasmuch as it helps prevent losses. In developed countries, a reduction in potential damage will not be as great as in developing countries in Africa and Asia. Swiss Re also shows that preventable losses are higher in developing countries than in advanced economies (Figure 3). If the Paris Agreement's goal of keeping global average temperature growth well below 2°C is achieved, up to 10% of expected global GDP losses by mid-century will be prevented compared with 2.6°C global warming.

To meet the goals of the Paris Agreement, mitigation measures were developed, aiming to slow the pace of climate change by reducing or absorbing greenhouse gases. Among these measures are renewable energy and energy efficiency programmes, forest protection and the green transition.

Insurance of climate risk is an important tool to protect investment in projects of mitigation and climate change adaptation, and a way to minimise financial losses in natural hazards. A number of countries are increasingly using parametric (or index-based) insurance whereby automatic payments are made when preset climate limits are reached.[21] This reduces uncertainty for investors and speeds up disaster recovery actions, which is especially relevant for countries with limited public resources.

14 Nguyen Ha, Alan Feng, and Mercedes Garcia-Escribano. Understanding the Macroeconomic Effects of Natural Disasters. 2025.

15 WMO. State of the Climate in Africa 2023.

16 ESCAP. Asia-Pacific Disaster Report 2023.

17 IPCC. Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the IPCC Sixth Assessment Report. 2022.

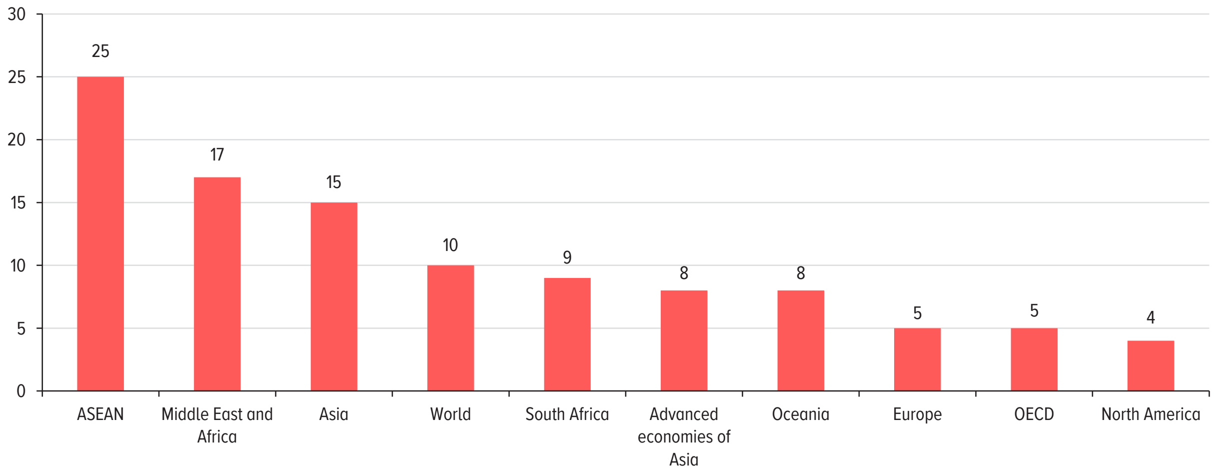
18 IPCC. Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the IPCC Sixth Assessment Report. 2022.

19 UNEP (2024). Adaptation Gap Report 2024.

20 Global Commission on Adaptation. 2019. Adapt Now: A Global Call for Leadership on Climate Resilience.

21 Financial Stability Institute. Turning up the heat – climate risk assessment in the insurance sector. 2019.

POTENTIALLY PREVENTABLE LOSSES IN ACHIEVING PARIS AGREEMENT GOALS. MOODY'S HYBRID MODEL (% OF 2.6°C WARMING SCENARIO) *Figure 3*



Source: Swiss Re Institute. The economics of climate change: no action not an option. 2021.

Also, globally accepted financial instruments include catastrophe bonds and their variety – resilience bonds. Catastrophe bonds are financial instruments that allow states, insurers and other economic agents to raise funds to cover losses from natural disasters. Payments on such bonds depend on whether a certain catastrophic event has occurred or not. The emergence of serious insurance risk (e.g. a strong earthquake) may entail the loss of all investments in such financial instruments. For investors, this is a risky but normally highly profitable instrument with little correlation with financial markets.

The main difference between resilience bonds and traditional catastrophe bonds is in investors agreeing in advance to discount the coupons due to them if the bond issuer has implemented resilience projects that reduce disaster risks. The resulting savings are also allocated to resilience projects, such as dam construction or flood control. This benefits both society and investors.

Macroeconomic assessment of damage

The wide range of estimates of possible losses from climate change is a sign of how challenging the subject is for science. It involves many uncertainties, especially in quantifying the indirect effects of climate-related natural hazards. There are multiple approaches to quantify damage caused by climate physical risks and climate change impacts on GDP over a medium and long-term horizon (Figure 4). The scientific community has adopted structural economic modelling and econometric tools as dominant macroapproaches.

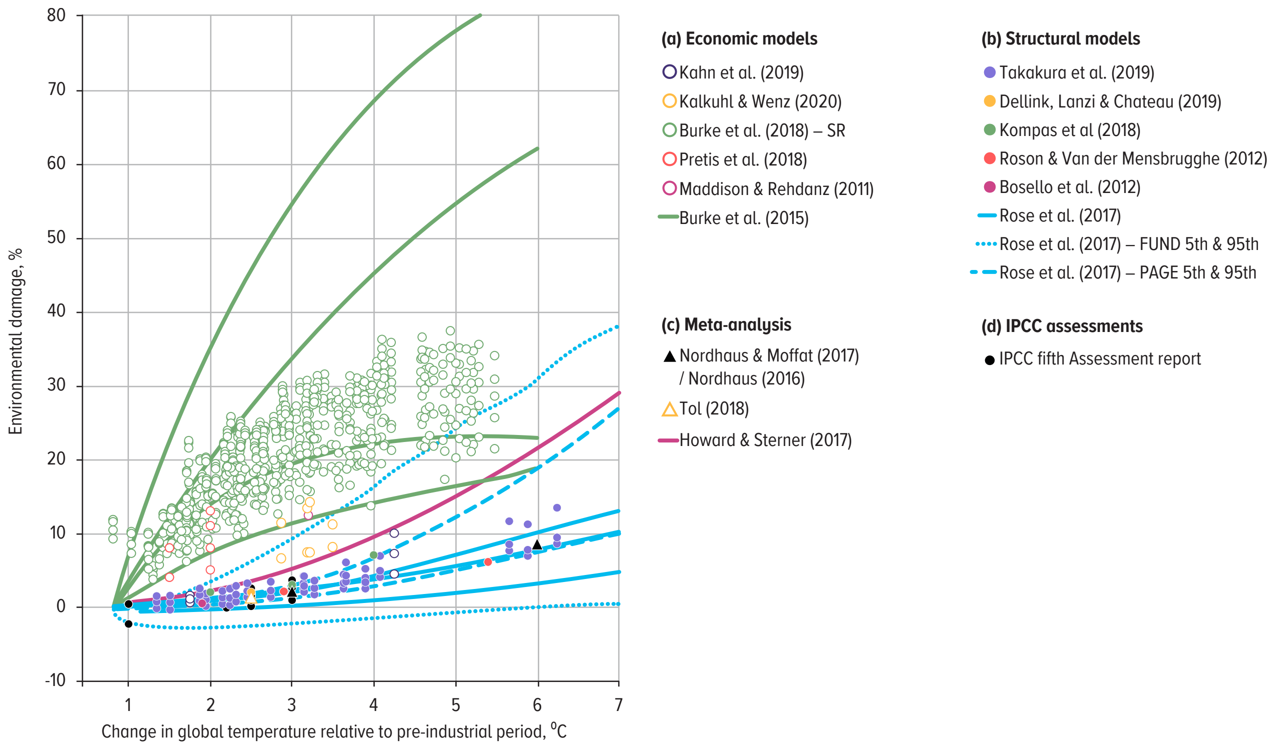
Structural economic modelling is used to analyse climate change effects on production factors, output, household consumption, aggregate investments and sectoral and regional markets (Reilly J. et al. (2007), Roson R., and van der Mensbrugghe D. (2012), Dellink R. et al. (2019), Takakura J. et al. (2019)), often using computable general equilibrium (CGE) models. Structural models make it possible to assess how market and non-market forces can feed through into the economy, as well as adaptation responses in the markets for production and output factors, in consumer and investment decisions and in interregional trade, e.g. Dellink R. et al. (2019), Takakura J. et al. (2019).

Integrated assessment models (IAMs) link climate forecasts to economic indicators through loss functions, which reflect the relationship between temperature and capital losses.[22] Among these

[22] McKinsey Global Institute. Climate risk and response. Physical hazards and socioeconomic impacts. 2020.

ESTIMATED DAMAGE TO GLOBAL ECONOMY FROM CLIMATE CHANGE
(ANNUAL GLOBAL GDP LOSSES, % VS SCENARIO WITHOUT CLIMATE CHANGE)

Figure 4



Source: *IPCC. Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the IPCC Sixth Assessment Report. 2022.*

models are DICE, PAGE, GCAM and REMIND–MAgPIE. Most IAMs consider damage only as a loss of current output without due consideration of long-term endogenous factors (such as investment or technological change). Finally, many models of this type fail to fully capture the mechanisms of financial shocks and other potential sources of systemic consequences, including population migration, increased mortality and armed conflict, which may lead to the underestimation of climate risks. At the same time, many IAMs are updated through regular revisions of input data, code and model architecture updates. IAMs have their own areas of application and can be used not only to assess the effects of climate change, but also to analyse climate and energy policies, model relationships between the economy, the environment and technology – at global and regional levels.

Under another macroapproach, the impact of historical climate changes (usually temperature and precipitation) on economic performance is subject to econometric assessment, and its future effects are subsequently investigated. Such models can be built without assumptions about people, companies and governments adapting to climate change; instead, they use observed data that already include actual adaptation measures. For example, Burke M. et al. (2015) rely on econometric methods to show that overall economic activity is a non-linear function of temperature for all countries: productivity peaks at the average annual temperature of 13°C and then declines at higher temperatures. This trend has proved universal worldwide. It has remained unchanged since the 1960s, observed in both agricultural and non-agricultural sectors of rich and poor countries. This approach does not however consider the possibility of a radical climate transformation beyond past records, which limits its predictive power. It fails to explicitly model structural shifts in the economy and institutional development or technological adaptation, which can mitigate climate change effects. Furthermore, the aggregate nature of estimates may conceal important regional and sectoral differences in vulnerability. Beyond the scope of such models are non-linear effects and climate-economy relations.

There remains a gap between assessments based on different approaches. For example, structural models predict losses of up to 20% of GDP in 4°C warming relative to the pre-industrial period, whereas econometric models project losses of up to 70%.[23] On the one hand, the difference in the estimates can be explained by the fact that structural models are better at capturing adaptation to climate change. On the other hand, for a temperature rise of 6°C, structural models put damage at only 0–30%, whereas in practice such warming makes many parts of India, the Middle East, Southeast Asia and Africa physically uninhabitable. At 31°C and 100% humidity or at 40°C and 50% humidity, thermoregulation is impossible even in young and healthy people (Vecellio D.J. et al. (2022), and these regions are already registering even tougher conditions (Raymond C. et al. (2020).

The uncertainty of damage functions remains the key methodological problem. Most models fail to fully capture the tipping points that lead to major, accelerating and often irreversible changes in the climate system (tipping points). Such a tipping point can be the destruction of Greenland glaciers or the collapse of sea currents. Unlikely if warming is moderate, such events become real at 3–4°C warming and can result in catastrophic GDP losses.[24] A further challenge is adaptation simulation. While some studies suggest that technology is set to mitigate the damage, others point to the limitations in poor countries, whose vulnerability is exacerbated by underinvestment.

The Network for Greening the Financial System (NGFS),[25] a community of central banks and supervisors, develops climate risk assessment scenarios, including for climate physical risks. NGFS scenarios help financial regulators, central banks and insurers estimate the potential economic impact of climate change. In its climate stress testing,[26] the Bank of Russia relies on these scenarios.

The NGFS uses a comprehensive multimodel approach to analyse climate risks, allowing both chronic and acute risks to be considered. The methodology integrates the results of various models, each performing its unique function in assessing economic implications of climate change (Table 2).

MODELLING TOOLS USED BY NGFS *Table 2*

Model	Model type	Application
Structural economic modelling	CGE (computable general equilibrium) models	Assessment of long-term effects with priority for detailed sectoral and regional breakdowns
Integrated Assessment Models (IAMs)	DSGE (dynamic stochastic general equilibrium models) models	Models of acute (stochastic) climate shocks and assessment of short-term macroeconomic responses
NiGEM	Macroeconomic model	Integrating IAM and CGE output and modelling macroeconomic consequences of physical and transition risks
Special disaster models	Natural disaster models	Modelling acute climate events (floods, hurricanes, natural hazards) and their rapid economic impact
REMIND–MAgPIE, MESSAGE-GLOBIOM, GCAM	Various IAMs with a focus on transition risks, i.e. changes in regulation, policy, technology, and market preferences in the transition to a low-carbon economy	Assessment of scenarios for the transition to a low-carbon economy, including the analysis of the energy balance, demand and supply changes, as well climate policy impact

Source: Authors' conclusions based on NGFS publications.

[23] IPCC. Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the IPCC Sixth Assessment Report. 2022.

[24] IPCC. Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the IPCC Sixth Assessment Report. 2022.

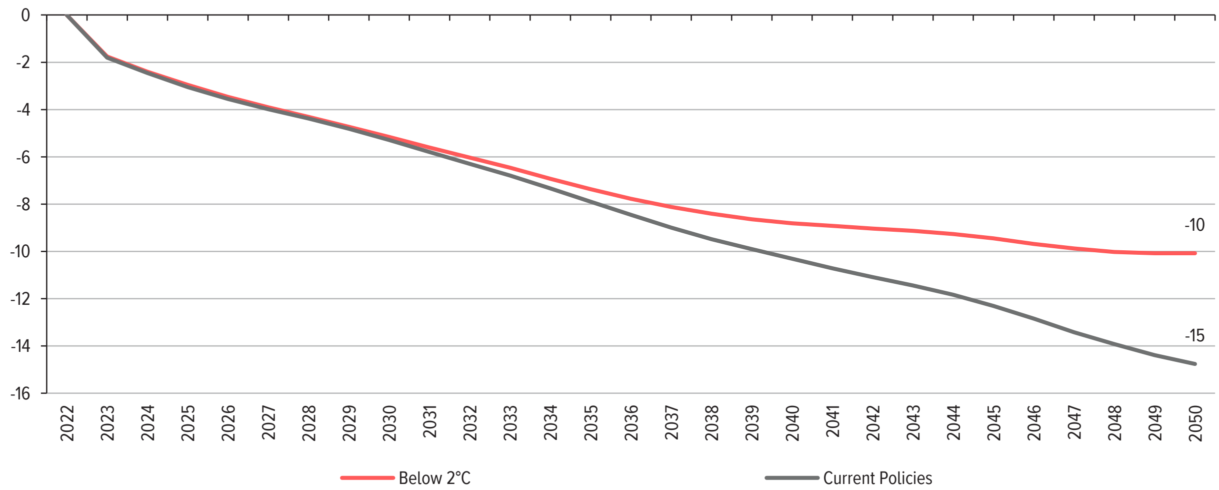
[25] Central Banks and Supervisors Network for Greening the Financial System, NGFS.

[26] Bank of Russia. Stress testing of climate transition risks: provisional valuation. 2024.

Such integrated assessment models serve as a source of climate and economic variables, while the macroeconomic NiGEM model processes these data to determine economic effects.[27] Special models of natural disasters are used to assess the impact of acute physical risks, which makes it possible to take sudden and natural hazards into account.

NGFS scenarios were updated in 2024, together with the damage function – the link between climate models and macroeconomic analysis (according to Kotz M. et al. (2024). This is what is basis for the NGFS estimate of a 5–15% reduction[28] in global GDP by 2050 (Figure 5). There is so-called committed warming caused by accumulated greenhouse gas emissions and climate system inertia, so the damage curves over the horizon of 10 and 15 years are almost identical.

IMPACT OF PHYSICAL RISKS ON GLOBAL GDP BY 2050 VS THE BASELINE SCENARIO FOR THE BELOW 2°C AND CURRENT POLICIES SCENARIOS, NIGEM NGFS V1.24.2[REMIND-MAGPIE 3.3-4.8] *Figure 5*
(%)



Source: Network for Greening the Financial System (NGFS). NGFS Climate Scenarios for Central Banks and Supervisors – Phase V. 2024.

Questions for consultations and promising areas of focus for the Bank of Russia, federal executive bodies, academic communities, financial and non-financial companies, and other stakeholders

Physical risks directly damage infrastructure and agriculture, causing indirect losses through logistics failures and a decrease in business activity.[29] Global damage assessments vary depending on the models, scenarios and approaches. Regional studies highlight the high vulnerability of developing and tropical countries, as well as sectors such as agriculture and tourism. Current models are far from perfect given their limited verification of damage functions, failure to fully capture irreversible changes in the climate system and adaptation mechanisms, which leads to significant forecast uncertainty. It is advisable to promote international cooperation in the following areas:

- development of global and regional economic models for assessing climate physical risks
- improvements in rapid climate data monitoring and collection systems to improve the accuracy of risk forecasts.

Do you agree with the suggested areas of activity?

[27] Network for Greening the Financial System. NGFS Climate Scenarios Technical Documentation, Version 5.0. 2024.

[28] The baseline scenario reflects a hypothetical path assuming that the climate is unchanged and no climate transition and physical risks realise.

[29] IPCC. Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the IPCC Sixth Assessment Report. 2022.

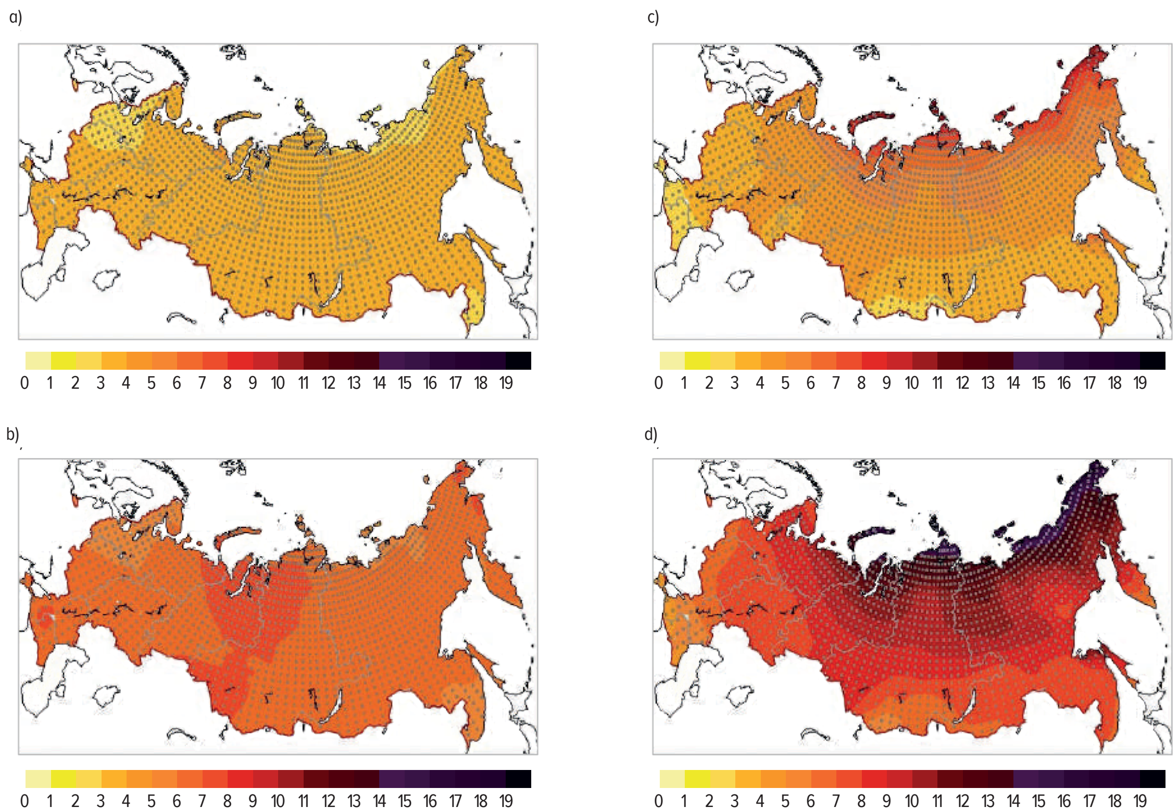
3. ECONOMIC IMPLICATIONS OF PHYSICAL RISKS FOR RUSSIA

The process of climate change in Russia is much faster than the global average, especially in the Arctic and Siberian regions, where temperatures are rising 3–3.5 times faster than global temperatures.[30] *This increases the frequency and intensity of natural hazards such as floods, heatwaves, wildfires, storms and permafrost thawing. The economic implications range from moderate damage (about 1–2% of GDP annually) to potential benefits from a comprehensive adaptation programme that could offset negative effects and create new opportunities for regional development. The most exposed regions are those located in permafrost areas, where significant infrastructure destruction is expected by the middle of the century, and agricultural regions in the south of the country, where water stress and droughts will significantly reduce crop yields.*

In Russia, the average air temperature rises about 2.5 times faster than the global average. Recent decades have seen growth rates of about 0.45–0.50°C over a decade, which is above the global indicator (0.18°C). This warming is ahead of its global pace due to the country's position in high latitudes and continental climate.

In the Arctic part of Russia, the pace of warming is 3–3.5 times the global average. While in the European part of Russia temperatures over the past 100–150 years were up by about 1.5–2°C, in Siberia and the Arctic they added 2.5–4°C in some places. In the unfavourable scenario (SSP5–8.5), temperatures in the 2050s may be 3.9°C higher than in late 20th century, while in the sustainable development scenario (SSP1–2.6) this increase will approximate 2.6°C (Figure 6).

CHANGE IN AVERAGE SEASONAL SURFACE AIR TEMPERATURE (°C) IN 2081–2100 VS 1995–2014 IN SUMMER (A, B) AND WINTER (C, D) FOR SCENARIOS SSP2–4.5 (A, C) AND SSP5–8.5 (B, D) *Figure 6*



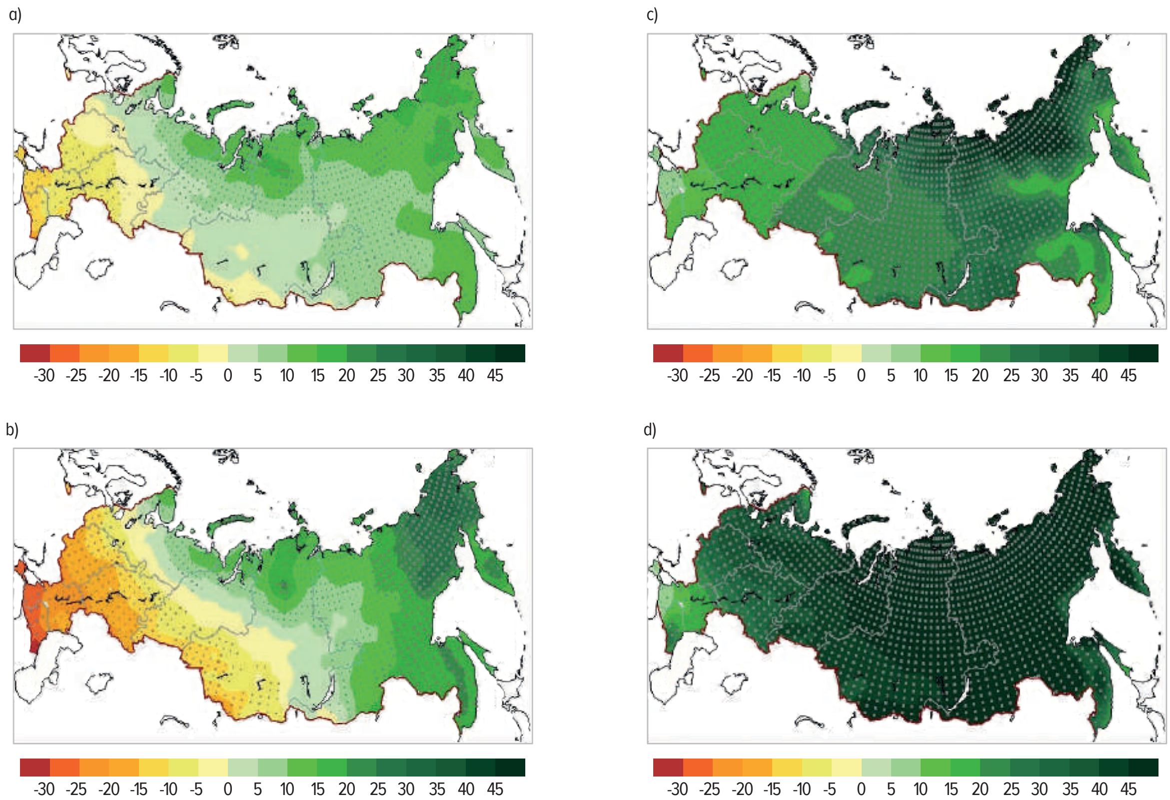
Source: Rosgidromet. Third Assessment Report on Climate Change and Its Effects in the territory of the Russian Federation. Summary 2022. [in Russian].

30 Rosgidromet. 2024 Report on Climate in the Russian Federation. 2025.

Russia has predominantly seen an upward trend in annual precipitation. The average rise in precipitation is 1.8% over a decade, but the rise in some regions of Siberia and the Far East is above 5%. Nevertheless, the southern and south eastern regions of Russia[31] – the key agricultural regions – may see a 25% drop in precipitation by the end of this century compared to the beginning of the century.

Climate change drives up the frequency of heavy rains and other natural hazards, as exemplified by the catastrophic floods on the Amur in 2013 and the more frequent destructive typhoons in Primorye. On the other hand, rainless periods and droughts are becoming increasingly more frequent in the European part and southern regions of Russia, and such periods are forecast to last longer (Figure 7).

CHANGE IN AVERAGE SEASONAL PRECIPITATION (%) IN 2081–2100 VS 1995–2014 IN SUMMER (A, B) AND WINTER (C, D) FOR SSP2–4.5 (A, C) AND SSP5–8.5 (B, D) SCENARIOS *Figure 7*



Source: Rosgidromet. Third Assessment Report on Climate Change and Its Effects in the territory of the Russian Federation. Summary. 2022 [in Russian].

In assessing damage from physical risks, a list of key natural hazards in the area under study should be determined. For all the importance of regional characteristics in Russia, the following hazards are commonplace:

- **Floods.** Increased rainfall leads to flash floods, which are especially dangerous in mountain and foothill areas of the south of Russia and in cities with undeveloped drainage systems. Large floods cause huge damage and require effective adaptation measures to mitigate the consequences. Recent examples include the flood in the Amur River basin in 2013, when the river level went up by more than one meter, setting a new high, and the 2021 flood in Kuban, when the region received six months' worth of rain in several days.

- **Water stress.** The National Research Institute of Agricultural Meteorology forecasts that Russia's total crops may fall 10% over a short-term (ten-year) horizon because of droughts. In the second half

[31] The Rostov, Volgograd and Astrakhan Regions, the Krasnodar and Stavropol Territories, the Central Black Earth and Volga regions.

of the 21st century, the country's southern regions such as the Krasnodar Territory, the Volgograd and Rostov Regions may become irrelevant as agricultural centres for the lack of water.

- **Heatwaves**. Abnormally high air temperatures are becoming increasingly more frequent and intense.[32] In particular, Russian regions saw the number of year-average days marked by extremely high day and night temperatures increase by 5–10 between 1960 and 2012, and their intensity by 1–2.5°C.[33] According to Rosgidromet, the duration of heatwaves is likely to increase significantly by the middle of the century, which will in turn drive up the number of days with a high fire hazard class. For example, heatwaves in the North-Western Federal District are expected to last 8–9 days longer, and the number of high fire hazard days to increase to 6–11.

- **Wildfires.** Heatwaves, especially in arid southern regions and boreal forests, occur with growing frequency. For example, large-scale fires were observed in 2010 in Central Russia, causing the destruction of ecosystems and crops.

- **Growing intensity of wind and storm events.** According to Rosgidromet, the frequency of strong winds and the intensity of storms on the Black, Azov and Far Eastern seas are expected to increase.[34] The North Caucasian Federal District is the most exposed area to strong winds, thunderstorms and ice loading. Moreover, they have grown in frequency over the past 30 years.

- With **permafrost** occupying more than 60% of the country's territory, its thawing threatens infrastructure, especially in Eastern Siberia and a number of northern cities, where cases of structural deformation are already recorded. By the middle of the 21st century, the permafrost areas may decline 22–28%. Climate zone shifts affect ecosystems and threaten Arctic species. They also enable the spread of new species including pests.

In the foreseeable future, climate factors are set to have an increasingly stronger impact on the **labour market and employment rates** in Russia through worktime losses caused by an increased frequency and intensity of natural hazards and decreased labour productivity (mainly for outdoor work), caused by extreme weather conditions (heat, intense precipitation including tropical and ice rains, hail, squally winds, tornadoes, forest fire smoke, storm surges, etc.). According to Rosgidromet, provided that the optimistic climate scenario materialises and the adaptation is successful, worktime losses in Russia in 2030 will be negligibly low at 0.01%. However, they grow in pessimistic scenarios. Sector-wise, the greatest losses in worktime are forecast in agriculture and construction – the industries that involve long outdoor work.[35]

Climate change affects **public health** through rising average temperatures and humidity, more frequent natural disasters and the spread of infectious diseases. The increased frequency of periods of abnormally high temperature pushes up excess mortality linked to cardiovascular and respiratory diseases in summer. On the positive side, this is offset by a decrease in excess mortality from cardiovascular and respiratory diseases associated with cold.[36] Rising temperatures also increase the habitats of disease vectors, such as encephalitis, malaria and West Nile fever.[37] Although there

[32] Rosgidromet. Third Assessment Report on Climate Change and Its Effects in the Territory of the Russian Federation. Summary. 2022 [in Russian].

[33] Wang J., Chen Y., Tett S.F.B. et al. (2020). Anthropogenically-driven increases in the risks of summertime compound hot extremes. Nature Communications, 11.

[34] Rosgidromet. Third Assessment Report on Climate Change and Its Effects in the Territory of the Russian Federation. Summary. 2022 [in Russian].

[35] Rosgidromet. Third Assessment Report on Climate Change and Its Effects in the Territory of the Russian Federation. Summary. 2022 [in Russian].

[36] Economic effects of climate change in Russia. Analysing risks and opportunities for sustainable development. 2024 [in Russian].

[37] Rosgidromet. Third Assessment Report on Climate Change and Its Effects in the Territory of the Russian Federation. Summary. 2022 [in Russian].

has been no upward trend in the incidence of the above diseases in Russia, climate conditions are becoming more favourable to the spread of disease vectors (mosquitoes and ticks).[38, 39, 40]

Domestic estimates of climate change impact on the Russian economy vary greatly depending on the preferred approach and as a result of the uneven regional distribution of damage. Sectoral studies note mostly negative effects: droughts and declining crops are set to occur in southern regions, while northern regions will face infrastructure damage due to permafrost thawing. At the same time, macroeconomic assessments project a positive impact on the broader economy given the opportunities climate change offers. These conflicting sectoral and macroeconomic perspectives suggest imperfect methodologies and the need for their convergence.

In studies based on the extrapolation of past events, the macroeconomic damage to Russia is projected to be lower than to advanced economies and significantly lower than to emerging economies. Porfiryev B.N., Danilov-Danilyan V.I. (2022) put the average annual direct damage from natural disasters in Russia at 0.50–0.55% of GDP and 1.0–1.5% of GDP inclusive of indirect effects. In their earlier work, Katsov V.M. and Porfiryev B.N. (2011) make similar estimates: 1–2% of annual GDP.

Structural model-based studies even allow for a positive effect. The Institute of Economic Forecasting of the Russian Academy of Sciences (IEF RAS) calculates that the economic effects through 2060 are likely to vary from tangible damage to minor benefits: from ₽-3 trillion to ₽+300 billion.[41] In their later study, Porfiryev B.N. et al. (2025) find that the average annual temperature change of 1°C – in a scenario assuming the absence of adaptation measures – will result in ₽3.1 trillion of climate change damage (in 2022 prices). This amount of losses is driven by a decline in output, caused by disposal of production assets because of permafrost thawing and floods. If implemented, the adaptation programme fundamentally changes the economic result: the change in annual GDP is positive at about ₽300 billion.[42] The recent report by IEF RAS experts (Centre for Climate Policy and the Economy of Russia) says that the overall positive effect of climate change on Russia's annual GDP given an appropriate adaptation policy could amount to about ₽1 trillion in 20 years with 1°C warming. This high estimate may be linked to, among other things, failure to consider cumulative effects of natural hazards. At the same time, the publication, focusing on the details of calculations, emphasises that climate change can cause significant damage in a number of sectors.[43]

There are estimates of damage made by a number of organisations and institutions, but they do not disclose information about the methods and details of their studies. According to the Ministry of Economic Development, each degree rise in temperature wipes out ₽3 trillion from annual Russian GDP. Other estimates show that damage from climate change for Russia may amount up to ₽580 billion annually between 2023 and 2027. The most vulnerable regions are estimated to incur 5–6% losses of gross regional product annually (the estimates are preliminary and the study details remain undisclosed).

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38 Andaev E.I., Nikitin A.Ya., Tolmacheva M.I., Zarva I.D., Sidorova E.A., Bondaryuk A.N. and Balakhonov S.V. Epidemiological situation of tick-borne viral encephalitis in the Russian Federation in 2015–2024 and a short-term incidence forecast for 2025 [in Russian].

39 Mazurina E.O., Arakelyan R.S., Maslyaninova A.E., Arakelyants O.A., Asadova S.E., Idiatulina E.D. and Vasilyeva A.S. Influence of climatic features on malaria incidence. International Research Journal. 2024 [in Russian].

40 Zelikhina S.V., Shartova N.V., Mironova V.A., Varentsov M.I. The role of climate change in expanding West Nile fever nosoarea in Russia: spatial-temporal trends. Arid ecosystems. 2021 [in Russian].

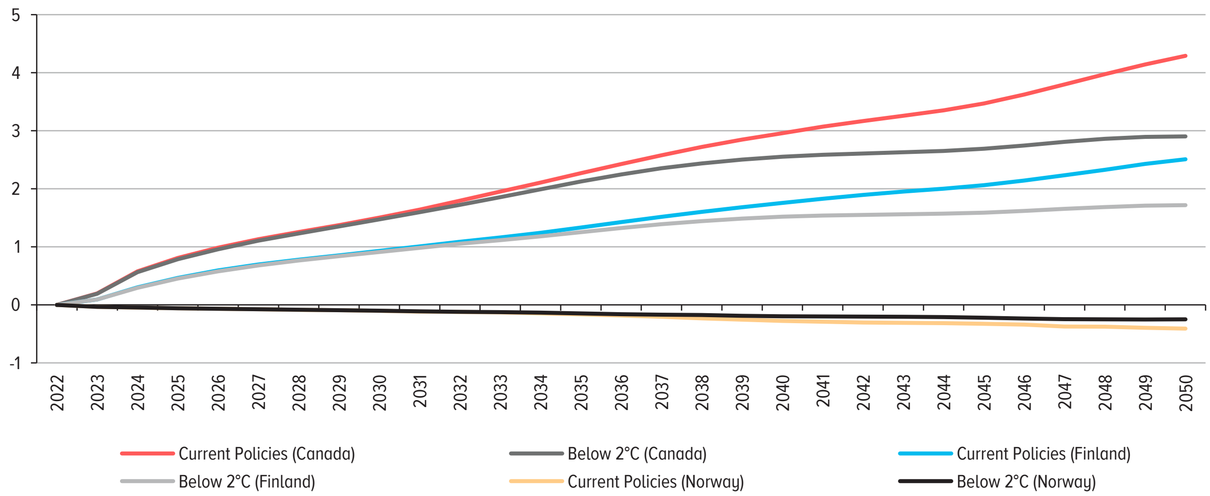
41 Porfiryev B.N., Kolpakov A.Yu. and Lazeeva E.A. Assessing the impact of climate change on the Russian economy using integrated assessment (IAM) models. Forecasting problems. 2025 [in Russian].

42 Porfiryev B.N., Kolpakov A.Yu., Eliseev, D.O., Sayenko V.V., Polzikov D.A., Lazeeva E.A. and Biryukov E.S. Economic effects of climate change in Russia. Forecasting problems. 2025 [in Russian].

43 Economic effects of climate change in Russia. Analysing risks and opportunities for sustainable development. 2024 [in Russian].

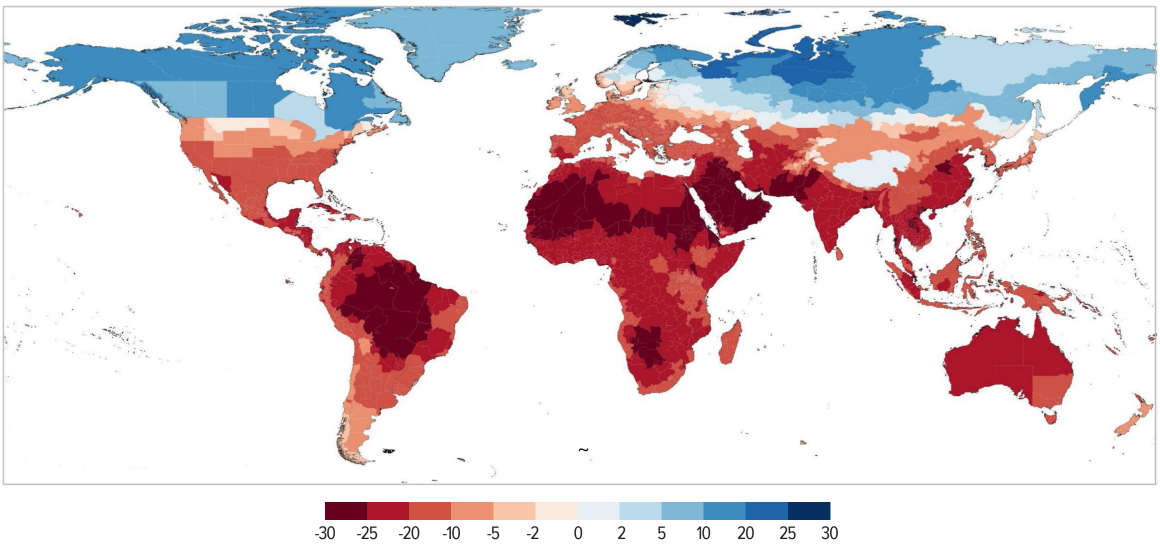
The NGFS does not present estimates of damage from the realisation of physical risks for Russia, but notes that climate change creates a positive impact on the economies of Subarctic states (Figure 8). This is a result of reduced temperature fluctuations. Daily intra-month temperatures deviate less from their monthly averages.[44] The authors measure this variability as an intramonth standard deviation of daily temperatures averaged over the months to obtain the annual value.[45] Studies show that a 1°C increase in intramonth temperature variability triggers a decline in regional growth of about 5% (Figure 9). However, the effect is mixed: in regions with mild seasonal fluctuations (common in low latitudes), the decrease can reach 10%, while in regions with pronounced seasonal changes (e.g. the northern regions of Canada or Russia), the effect is positive at about 3%.[46]

GDP IMPLICATIONS OF PHYSICAL RISK REALISATION FOR NEAR-ARCTIC COUNTRIES BY 2050, BELOW 2°C AND CURRENT POLICIES SCENARIOS *Figure 8*



Source: Compiled by authors based on NGFS data.

ECONOMIC DAMAGE CAUSED BY CLIMATE CHANGE BY REGION *Figure 9*
(% CHANGE IN PER CAPITA INCOME VS BASE LEVEL WITHOUT CLIMATE EFFECTS)



Source: Kotz M., Levermann A. & Wenz L. The economic commitment of climate change. Nature. 2024.

[44] Kotz M., Levermann A. and Wenz L. The economic commitment of climate change. Nature. 2024.

[45] Kotz M., Wenz L., Stechemesser A., Kalkuhl M., and Levermann A. Day-to-day temperature variability reduces economic growth. Nature Climate Change. 2021.

[46] Kotz M., Wenz L., Stechemesser A., Kalkuhl M., and Levermann A. Day-to-day temperature variability reduces economic growth. Nature Climate Change. 2021.

Other international macrostudies suggest that the Russian economy is exposed to limited damage from climate change. According to the European Investment Bank's global index of climate risk,[47] Russia is exposed to a moderate level of physical risk compared to most developing countries, but has specific vulnerability to chronic climate changes such as warming and degradation of infrastructure in the areas covered by permafrost. For Russia, meaningful risk sources are damage to agriculture, the costs of upgrading infrastructure to control floods and permafrost thawing, as well as loss of productivity due to heat in some regions. Despite the advanced research and technological capabilities alongside adaptation measures, the impact of potential economic losses on the budget and investment appeal may be significant given mounting climate effects, which requires systemic planning and investment in the stability of critical infrastructure.

The Economist Intelligence Unit forecasts[48] that the Russian economy may contract 3.3% by 2050 relative to the baseline scenario assuming no climate change. This estimate also accounts for potential benefits from climate change (e.g. higher crop yields), which however do not offset the damage. The methodology is the Climate Change Resilience Index, integrated with a simplified DICE model. According to Swiss Re Institute, an increase of 2.6°C in the average annual temperature relative to pre-industrial values drags Russia's GDP down 2.3% by the middle of the century.[49] However, this assessment does not factor in the tipping points and secondary effects (loss of biodiversity, migration, etc.), as well as adaptation measures. The authors write that the complete destabilisation of the climate system may send losses above 10% of GDP with secondary effects factored in. These calculations are based on the Moody's model, which combines econometric estimates and structural modelling elements.

Behind such estimates of damage from climate change in Russia are not only the implementation of adaptation measures, but also climate-related opportunities. They include, for example, a shorter heating period, easier navigation on the Northern Sea Route and others.[50] Rising average annual temperatures and an increase in the number of sunny days may over time boost the appeal of Russian resorts for domestic and foreign tourists.[51] A number of studies also indicate that rising air temperatures can increase labour productivity, contributing to GDP growth.[52]

At the same time, the distribution of climate damage at the sectoral and regional levels is uneven. Makarov I.A. and Chernokulsky A.V. (2024) rank Russian regions by the need to adapt, taking into account the cumulative impact of climate factors, the exposure of assets and the vulnerability of population and infrastructure. The authors identify four key types of negative impacts: wildfires, heatwaves, water stress and permafrost thawing. Most Russian regions will be affected by climate change, although the factors vary across constituent territories (Figure 10). In their later paper, the authors and other researchers present a relative heuristic assessment of climate risks in Russian regions.[53] They study the impacts of heatwave, wildfires, water stress, extreme precipitation, degradation of permafrost on individual sectors, population and infrastructure. According to the study, nine regions are in the top 25% in terms of the need to adapt simultaneously to three risks, and

[47] A global index of climate risk for countries. European Investment Bank. 2025.

[48] Resilience to climate change? A new index shows why developing countries will be most affected by 2050. Economist Intelligence Unit. 2019.

[49] Swiss Re Institute. The economics of climate change: no action not an option. 2021.

[50] Economic effects of climate change in Russia. Analysing risks and opportunities for sustainable development of the country. 2024 [in Russian].

[51] Choi Y.W., Khalifa M., and Eltahir E.A. North-South Disparity in Impact of Climate Change on 'Outdoor Days'. Journal of Climate. 2024.

[52] Dasgupta S., van Maanen N., Gosling S.N., Piontek F., Otto C., and Schleussner C.F. Effects of climate change on combined labour productivity and supply: an empirical, multi-model study. The Lancet Planetary Health. 2021.

[53] Chernokulsky A.V., Makarov I.A., Aniskina T.A., Chistikov M.N., Kraev G.N., Kurichev N.K., … Yudova O.A. Heuristic relative assessment of climate risks in Russian regions. Science of The Total Environment. 2025.

THE NEED FOR RUSSIAN REGIONS TO ADAPT TO CLIMATE CHANGE BY CLIMATE FACTOR (BASED ON SHARE OF VULNERABLE ASSETS, POPULATION AND INFRASTRUCTURE, IMPACT ON GRP OF CONSTITUENT ENTITY) *Figure 10*

Source: Makarov I.A., & Chernokulsky A.V. Climate Risks in Russia: Ranking of Regions by Adaptation Needs. Izvestiya, Atmospheric and Oceanic Physics. 2024.

another three (the Sverdlovsk and Irkutsk Regions and the Krasnoyarsk Territory) simultaneously to four risks.

Most sectoral and regional studies make the case for an increase in damage from climate change in Russia's northern regions. Streletskiy D.A. et al. (2019) assess the impact of climate change on the Arctic and note that permafrost thawing can destroy more than $100 billion of infrastructure assets by the middle of the 21st century. According to the G20 Risk Atlas, these processes, having already affected 30–60% of buildings and infrastructure in the Russian Arctic, may become critical: in a high-emission scenario, losses from the impact on residential buildings alone are expected to total $20.7 billion by mid-century.[54] Another study projects that average annual costs of infrastructure maintenance and reproduction may increase 27.5% by 2059 relative to the baseline scenario (Suter L., Streletskiy D., and Shiklomanov N. (2019). The study also calculates that 32% of all infrastructure (valued at $40.3 billion) will be subject to destructive impacts. The Ministry of Natural Resources and Environment of the Russian Federation also highlights the risk of permafrost thawing, and estimates that it may cost the economy about ₽5 trillion by 2050. Porfiryev B.N., Eliseev D.O., Streletsky, D.A. (2019) project the required costs of maintaining the road infrastructure in the Russian Arctic in 2020–2050 to total ₽422.68 billion to ₽864.81 billion a year. The highest costs will be needed for the Chukotka Autonomous Area, the Republic of Sakha and the Magadan Region.

Furthermore, yields in agriculture may decline in the absence of adaptation measures. Annual losses are estimated at ₽108 billion and expected to reach beyond ₽120 billion by 2050 (Safonov G. and Safonova Y. (2013). Ksenofontov M.Y., and Polzikov D.A. (2012) confirm the negative impacts of climate change for Russia's southern regions, but project an increase in gross yield of grain and

[54] G20 Climate Risk Atlas. Impacts, policy, economics. Russia. 2021.

other crops in the central and northwestern parts of European Russia. Belyaeva M. and Bokusheva R. (2018) show that an increase in temperature can make a positive impact on winter wheat, spring wheat and spring barley productivity in the northern and Siberian regions of Russia. In contrast, the country's southern regions may show a significant drop in yields of all the three crops. According to the G20 Risk Atlas, this is where the risk of water stress is.[55] Over a medium and long-term, Russia can mitigate the negative impact of climate change on grain yields by expanding the production of winter and spring grains in the north of Russia and delivering on the climate change adaptation programme in its southern regions.[56] Siptits S.O., Romanenko I.A. and Evdokimova N.E. (2021) point to a potential increase in grain and legume production in Russia in Scenario RCP4.5, which may well increase to 170 million tons by 2100 on the back of improved agricultural conditions in the Central Federal District and Central Siberia, but the researchers expect the Black Earth and Volga Region to be negative affected. The latest study by University of Illinois scientists paints a more pessimistic picture: under the scenario assuming high greenhouse gas emissions by 2100, wheat yield in Russia, as well as in Canada, the USA and China, will decrease 30–40% even with climate change adaptation measures.[57] The study is based on an econometric model combining the biophysical reactions of plants, as well as the economic behaviour of farmers in the course of climate change.

In the context of digital technology advances, it is imperative to maintain the smooth operation of relevant infrastructure including data centres. According to XDI, a specialist provider of physical risk assessments for financial institutions around the world, Russia's data centres exposed to climate physical risks are concentrated in Moscow and the Moscow Region. In the high emission scenario (RCP 8.5/SSP5–8.5), 30% of such facilities in the Moscow Region will fall into the high risk category, with total probable damage growing 152%, and in Moscow 5.33%, with total probable damage rising 49%. Among key hazards for these regions are river and surface floods that can submerse server rooms, damage equipment and cause power outage, and extreme wind that can destroy roofs and external engineering systems, as well as wildfires that threaten physical integrity of facilities and access to them.

Mounting greenhouse gas emissions and further climate change could also increase the frequency of natural hazards such as extreme precipitation and the associated floods. Regions marked by the highest risk of extreme precipitation caused by climate change are mainly the south of Eastern Siberia and the Far East of Russia,[58] with about 400,000 km^2 of Russian territory exposed to potential flooding.[59] Several studies put Russia's average annual direct losses from floods at about 0.1–0.13% of GDP.[60] The examples of such natural hazards were the large-scale flood in the Far East in 2013, one of the most devastating on record, with direct damage estimated at about 0.14% of Russia's GDP. In monetary terms, this is hundreds of billions of rubles, with the greatest damage made up by the destruction of housing, private property and transport infrastructure. Another example is the flood in the Krasnodar Territory in 2012 (Krymsk) – the most devastating flood in the region's history, which almost paralysed the municipal economy. Scientists found climate change to be behind the flood.[61]

55 G20 Climate Risk Atlas. Impacts, policy, economics. Russia. 2021.

56 Belyaeva M. and Bokusheva R. Will climate change benefit or hurt Russian grain production? A statistical evidence from a panel approach. Climatic Change. 2018.

57 Hultgren A., Carleton T., Delgado M., Gergel D.R., Greenstone M., Houser T.,… and Yuan J. Impacts of climate change on global agriculture accounting for adaptation. Nature. 2025.

58 Chernokulsky A.V., Makarov I.A., Aniskina T.A., Chistikov M.N., Kraev G.N., Kurichev N.K.,… and Yudova O.A. Heuristic relative assessment of climate risks in Russian regions. Science of The Total Environment. 2025.

59 Frolova N.L., Kireeva M.B., Magrickiy D.V., Bologov M.B., Kopylov V.N., Hall J.,… and Belyakova P.A. Hydrological hazards in Russia: origin, classification, changes and risk assessment. Natural Hazards. 2017.

60 Biryukov E.S., Terentyev N.E. Assessing economic damage from floods in Russia and potential adaptation. Theory and practice of social development. 2024 [in Russian].

61 Meredith E.P., Semenov V.A., Maraun D., Park W., and Chernokulsky A.V. Crucial role of Black Sea warming in amplifying the 2012 Krymsk precipitation extreme. Nature Geoscience. 2015.

Russia has regional plans for adaptation to climate change. These documents describe local climate risks (from thawing permafrost in Yakutia to longer droughts in the South) and set out specific measures to reduce them. For example, the Krasnoyarsk Territory's adaptation plan involves the renovation of hydraulic structures; the Stavropol Territory's plan provides for the preservation of agroforestry areas.

Also, **corporate adaptation measures** aim to mitigate climate and operational risks. For example, agricultural holdings in southern regions are switching to more drought tolerant wheat varieties; they introduce drip irrigation systems to offset rising temperatures and the lack of rainfall. The mining sector rolls out monitoring systems for buildings and structures built on permafrost. Such measures not only reduce the probability of accidents and losses, but also strengthen business resilience to long-term climate change.

Questions for consultations and promising areas of focus for the Bank of Russia, federal executive bodies, academic communities, financial and non-financial companies, and other stakeholders

The significant challenge for researchers is the uneven distribution of damage caused by climate change, lack of data and other limitations. The few macroeconomic studies including domestic ones note a moderate negative or even positive effect of climate change. Regional and sectoral surveys speak of material physical risks for a number of Russian territories and economic sectors. Thus, the effects of chronic countrywide risks and acute regional risks are uneven.

The following actions are considered feasible:

- continue research into the impact of climate change on the Russian economy, individual sectors and regions
- further define the effects of climate change and a number of natural hazards on the economy, including by means of econometric methods, and compare the results with sectoral and regional assessments
- assess the potential indirect effects (including on the financial sector) of an increased frequency of major natural hazards.

Do you agree with the suggested areas of activity?

4. PHYSICAL RISKS AND FINANCIAL INSTITUTIONS

Climate physical risks make a direct and indirect impact on the financial sector. For banks, such risks realise through deterioration of borrowers' repayment capacity and lower quality of credit portfolios, triggering the need for additional provisions and involving possible reputational loss. Confronted with a potential increase in losses from natural disasters, insurance companies may make insurance unaffordable to some vulnerable customers.

Current approaches to risk assessment are inadequate due to the high uncertainty of climate scenarios and long-term impacts of climate change. High-quality assessments involve integrating the hazard-exposure-vulnerability model and creating specialised tools to quantify climate risks across the entire portfolio and effectively integrate them into risk management processes.

International organisations and regulators have extensive experience of stress testing, integrating climate-related metrics into supervisory reporting, and developing digital vulnerability assessment platforms. However, further quality improvements are conditional on joint efforts of regulators, academia and market participants.

Transmission channels

Climate physical risks have direct and indirect influence on financial sector companies. Standard global practice has been not to assign such risks a separate category considering that financial institutions analyse them using traditional risk types.[62] The direct impact of natural hazards on financial institutions' own assets is most often analysed through operational risk, and its assessment framework is the same for all financial institutions. Having said that, the indirect impact through the corporate sector is more significant. The realisation of climate physical risks in real sector companies leads to a deterioration in their financial performance. This feeds through to financial institutions through a decrease in their borrowers' repayment capacity, a drop in collateral value (credit risk), the need to receive money after an insurance event (liquidity risk) and other channels.

This is also true for Russia: according to a Bank of Russia study,[63] only a small percentage of respondents recognise climate risk as a separate type. Most financial institutions consider it through operational and credit risks, and insurance companies, through insurance risk (Figure 11).

The direct consequences of the realisation of physical risks threaten business continuity of financial institutions and may entail both direct financial and reputational losses. At the same time, the impact of indirect consequences is often more extensive and long-lasting due to cascade effects in the economy.

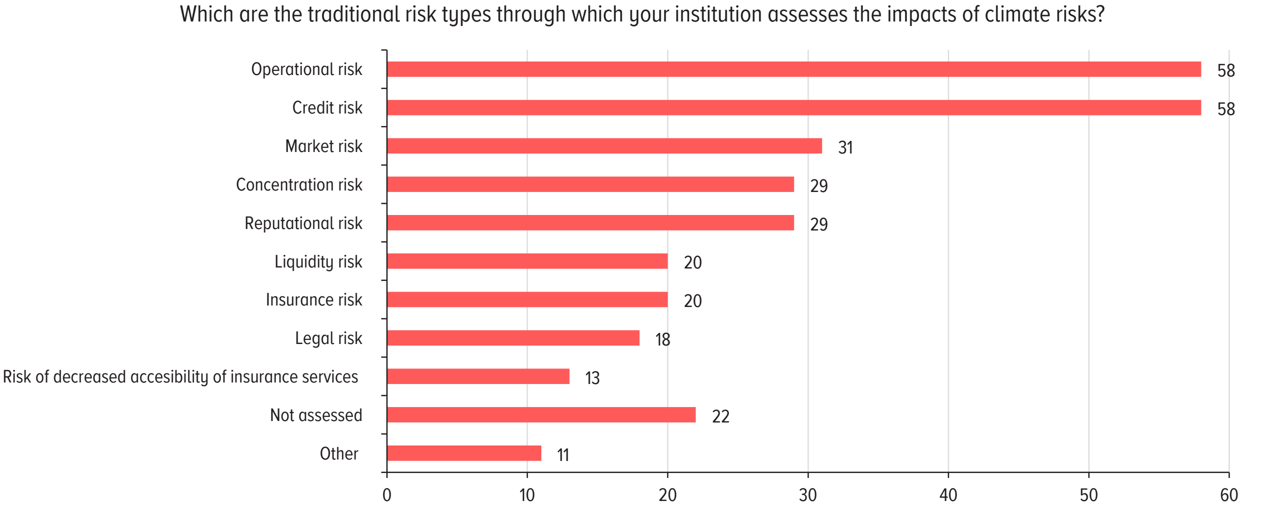
Insurance companies are more sensitive to climate issues than other financial institutions due to the nature of their operations (Figure 12). Insurers are directly exposed to climate physical risk – as a result of the impact of climate change on their insurance portfolios (insurance risk). In Russia, more frequent and serious natural disasters give rise to increased claims and insurance losses in property insurance.

[62] Financial Stability Board. Assessment of Climate-related Vulnerabilities. 2025.

[63] Bank of Russia information material 'Climate Risk Management Approaches in Financial Organisations'. 2025.

CLIMATE RISK REALISATION THROUGH TRADITIONAL RISK TYPES
(%)

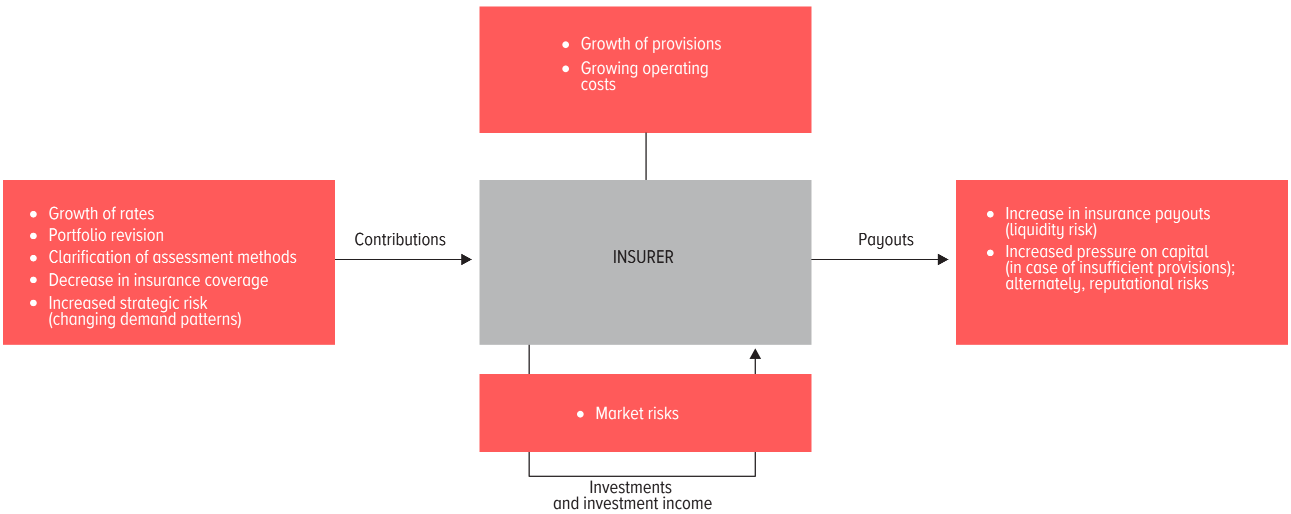
Figure 11



Note. several options may be chosen.
Source: Bank of Russia.

EFFECTS OF CLIMATE PHYSICAL RISKS FOR INSURERS

Figure 12



Source: Bank of Russia.

According to the Bank of Russia's supervisory reporting, the insurance payouts following natural disasters and other natural hazards (excluding fires) totalled about ₽13 billion in 2024. All the payouts were made under voluntary property insurance programmes.[64]

The data do not reflect potential and already existing damage from natural hazards since, first, supervisory reporting does not differentiate wildfire damage and, second, Russia is marked by very low penetration of insurance against natural disasters.

Similar to other financial services companies, insurers may face the realisation of market risk following a decrease in the value and increased volatility of their investments, as well as operational risk in

[64] In this case, we show actual insurance payouts related to natural disasters and other natural hazards for 2024 since the quality and quantity of data do not allow us to make a direct estimate for the impact of climate change as the difference between potential damage from more frequent natural hazards and the baseline scenario (that is damage from natural disaster risks and natural hazards unadjusted for climate change).

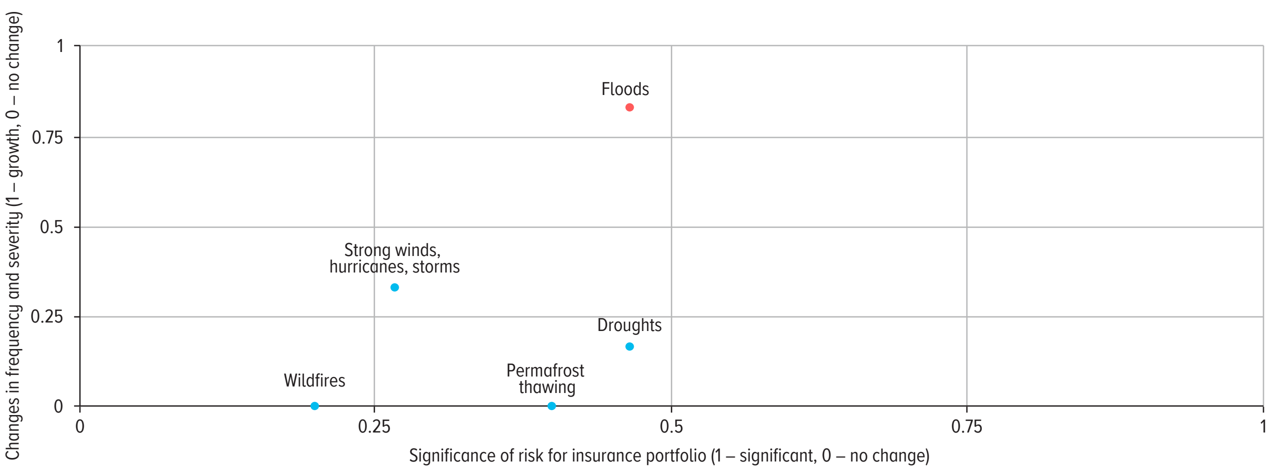
the event of natural hazards disrupting their business continuity and adversely affecting business infrastructure, systems and processes.

Natural disasters are systemic, that is, they can cause large-scale damage to tangible property of a wide range of policyholders and entail significant costs (e.g. costs of repairs), pushing up insurers' need for money (liquidity risk).

Insurers are also exposed to strategic risk since climate change may cause significant transformations in established economic relations and supply chains, which will drive a change in policyholders' needs for insurance products and thus undermine the sector's foundations.

In a Bank of Russia survey, four insurance companies were asked about the importance of climate-related environmental factors for their portfolios and current trends there (Figure 13). Floods, considered as events of utmost importance and increased severity, are critical for managing insurance risks. Droughts, strong winds, hurricanes and storms are very meaningful for the portfolio and show moderate growth. The frequency and severity of insurance events related to permafrost thawing and wildfires remain unchanged; they are classified as manageable.

EFFECTS OF PHYSICAL RISKS ON INSURANCE COMPANIES *Figure 13*



Source: Bank of Russia.

The insurance companies were further asked to assess the maximum possible loss from three unlikely but large-scale natural disasters (Table 3, see Appendix 3 for the detailed phenomenon description). The flood damage was far beyond the hurricane and drought damage.

Under the conditions described above, insurers are confronted with a further challenge – public expectations of insurance understood as one of the most obvious mechanisms for protection

MAXIMUM POSSIBLE LOSS OF INSURANCE COMPANIES FROM NATURAL DISASTERS *Table 3*

Event	Maximum possible loss, billions of rubles			
	IC 1*	IC 2	IC 3	IC 4
Flooding on Black Sea coast and Caucasus	105	333	3	<1
Typhoons and hurricanes in Primorye Territory	10	59	20	<1
Drought in European part of Russia	3	0	3	<1

** IC is an insurance company.*
Source: Bank of Russia.

against climate risks. However, more frequent natural hazards (especially very unlikely and thus most destructive events) push up losses, insurance payouts and pressure on capital of both insurance and reinsurance companies. This can weaken their stability and trigger reputational losses. Insurers may also face rising costs of reinsurance, including due to a shortage of reinsurance capacities. To minimise losses, a review of insurance portfolios may be necessary to exclude facilities most exposed to climate risks. However, this leads to an increase in uninsured losses for households, businesses and the government, threatening the entire financial system.

Given the uncertainty of future climate scenarios, the social importance of insurers is growing. Therefore, appropriate competencies need to be developed in climate and environmental due diligence of insured entities, in an effort to identify risks and advise such entities on ways to manage them. It is also imperative that the real sector is encouraged to implement procedures for climate risk mitigation, including through the use of flexible insurance rates and innovative insurance products that meet customer needs related to sustainable development.

From the standpoint of credit institutions, the key impact of physical risks reveals itself in impacts on customers and counterparties (Figure 14). As regards assets, loan portfolio quality deteriorates as borrower repayment capacity declines in vulnerable industries and regions (e.g. in the case of infrastructure destroyed as a result of thawing permafrost or crops lost as a result of droughts), which leads to an increase in overdue payments, impairment of collateral and the need for extra reserves.[65] As regards liabilities, there may be an outflow of deposits, driven by customers' disaster recovery needs.[66] Global statistics show that banks' profits are shrinking as their interest and commission income are declining (caused by, for instance, weaker demand for mortgages or acquiring services in high-risk areas), while their costs are rising for reserve creation, insurance and costlier financing.[67]

The key transmission channel is credit risk. Credit risk is on the rise due to the worsening repayment capacity of borrowers in vulnerable industries (such as agriculture and tourism) and regions (likely coastal areas, the Arctic), entailing an increase in defaults and impairment of collateral. The Basel Committee on Banking Supervision (BCBS) [68,69,70] and the Financial Stability Board (FSB)[71] stress the importance of climate stress testing loan portfolios using climate scenarios, which is also mentioned in the Bank of Russia's climate risk information letter.[72] Borrowers suffering from a federal, regional, inter-municipal or municipal emergency including floods and wildfires may request deferral of loan payments (loan repayment holidays for up to six months).[73] Alongside credit risk, the significant risks include market and reputational risks, concentration risk and liquidity risk (Table 4).

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65 Financial Stability Board. The Implications of Climate Change for Financial Stability. 2020.

66 Financial Stability Board. Assessment of Climate-related Vulnerabilities. 2025.

67 Financial Stability Board. The Implications of Climate Change for Financial Stability. 2020.

68 Bank for International Settlements. Stress-testing banks for climate change – a comparison of practices. 2021.

69 Bank for International Settlements. Principles for the effective management and supervision of climate-related financial risks. 2022.

70 Bank for International Settlements. The role of climate scenario analysis in strengthening the management and supervision of climate-related financial risks. 2024.

71 Financial Stability Board. Supervisory and Regulatory Approaches to Climate-related Risks: Final report. 2022.

72 Bank of Russia Information Letter No. IN-018-35/60, dated 4 December 2023, 'On Recommendations for Financial Institutions to Take Climate Risks into Account'.

73 Deferral of payments is open to borrowers whose loans are within the following amounts: ₽15 million – mortgage loans, ₽1.6 million – car loans, ₽150,000 –credit cards, and ₽450,000 –other loans. If the debt is above these limits, the borrower can contact the creditor about restructuring. The Bank of Russia recommended that banks restructure loans of disaster victims under their own programmes, to the point of debt forgiveness in exceptional cases.

EFFECTS OF THE REALISATION OF CLIMATE PHYSICAL RISKS FOR CREDIT INSTITUTIONS *Figure 14*

Source: Bank of Russia.

KEY TRANSMISSION CHANNELS AND EXAMPLES OF IMPACT *Table 4*

Risk channel	Example of impact
1. Credit risk	Defaults of agricultural producers as a result of a drought
2. Market risk	Volatile prices for bonds of a flood-hit company
3. Concentration risk	High share of borrowers with Arctic assets
4. Reputational risk	Negative attitude of households due to mortgage liabilities for properties in the flood zone
5. Liquidity risk	Outflow of funds from deposits of individuals whose property was damaged by wildfires or floods

Source: Bank of Russia.

Risk assessment of financial institutions

The assessment of direct and indirect physical risks involves a comprehensive approach. In Russia, there are documents laying down approaches to physical risk assessment.[74] Their main downside is concentration on the most accurate qualitative and quantitative assessment of risks for one enterprise and its core processes (operational risk).

The direct impact of physical risks shows up through effects on immovable and movable assets of financial institutions, as well as through counterparties and supply chains. The realisation of physical risks can lead to disruption of business continuity by damaging or destroying offices, equipment and IT systems, endangering staff and pushing up recovery, insurance and adaptation costs. The mechanism for assessing such risks is similar for financial and non-financial organisations. To assess physical risks, the standard approaches to operational risk assessment are adjusted in several areas. As part of a procedure for operational risk assessment (e.g. in the taxonomy of sources of operational risk),

[74] For example, Order of the Ministry of Economic Development of Russia No. 367, dated 13 May 2021, 'On Approving the Methodological Recommendations and Indicators in Adaptation to Climate Change' [in Russian].

the company classifies climate risk factors as a separate category of risk sources. This enables more precise monitoring of statistics for the realisation of physical risks; their direct consequences are additionally analysed. For example, a company finds that its sales decline in extreme heat. However, physical risks are of longer duration, which means that their estimates based solely on historical data are inaccurate. For example, if a company operates in a region with no records of thunderstorms, such a risk factor may be considered irrelevant in a risk analysis. At the same time, due to the increase in temperatures and precipitation, there is a high probability of future thunderstorms occurring in areas previously thought to have been unaffected. In such regions, buildings and infrastructure often lack sufficient protection against lightning, which may lead to the underestimation of this risk factor. To avoid this, physical risks are assessed over a long-term horizon and under several scenarios. To enable a top-level and conservative assessment, risk can be considered over the longest horizon, as well as under a scenario involving the greatest consequences of physical risk realisation. This will help assess the greatest extent of the consequences the company can prepare for in advance. In analysing climate risk drivers, it is also necessary to identify risks associated with counterparties (such as power providers) and in supply chains (e.g. delivery of goods). For banks, special focus turns to logistics chains, whose operations involve regular cash transportation between branches or ATMs and as part of cash collection.

With these risks increasing in frequency and intensity, financial institutions are forced to strengthen infrastructure protection, ensure the resilience of IT platforms and develop emergency response mechanisms, integrating climate sustainability into their business continuity strategies.

To assess indirect risks of financial institutions, current methods for assessing climate physical risks are inadequate due to their failure to capture the scale of banking and insurance business operations. They need to assess climate risks across the whole portfolio and cover multiple assets in different regions and different industries. What becomes central is not the accuracy of assessment of each particular risk, but how relevant this assessment is given the data gaps, high uncertainty and limited resources. This involves the need for risk standardisation methods so that the costs of assessment correlates with returns on the back of better risk management.

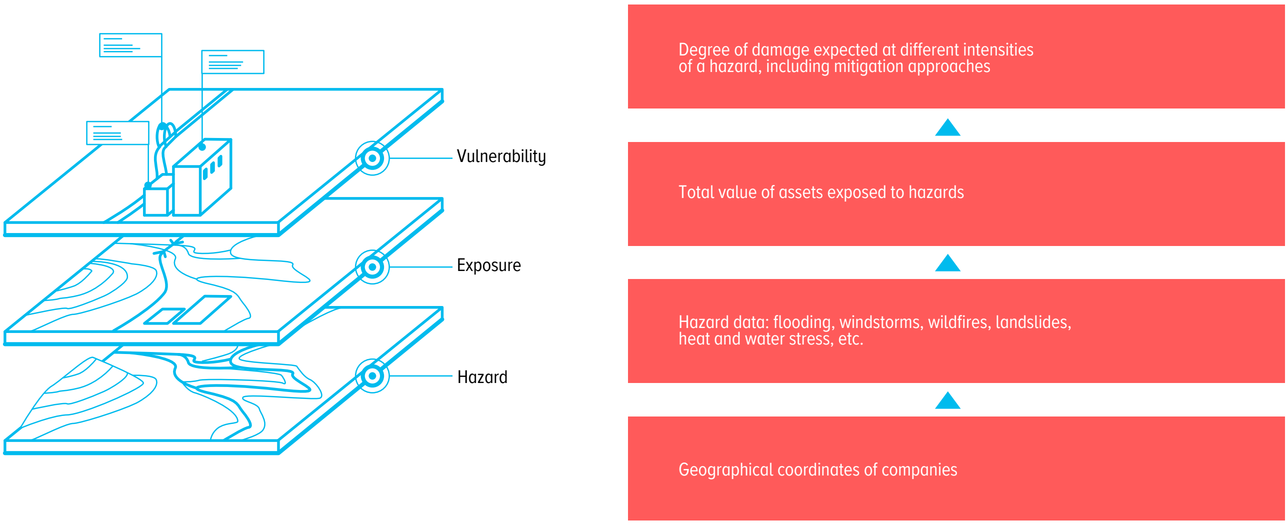
This assessment can be used to greater effect thanks to specialised instruments developed and tailored to the needs of the financial sector. For example, the European Banking Authority published an ESG dashboard – key climate risk indicators for the banking sector, built on data disclosed by banks. The indicators cover both physical and transition risks, as well as indicators related to banks' alignment with the EU Taxonomy.[75] Furthermore, geospatial models need to be created for the distribution of risks across assets. It is necessary to use climate scenarios and build aggregate risk indicators at the portfolio level.

Despite the methodological differences in existence, the assessment of climate risks comes down to a hazard-exposure-vulnerability model. It is based on the systemic analysis of three components (Figure 15): the probability and scale of natural hazards (hazard), the value of assets affected by such events (exposure), and the sensitivity and recoverability of these assets (vulnerability).

All facilities in an insurance or loan portfolio are subject to accurate identification and must have spatial references. The IMF notes that a key enabler of improvement in exposure assessments of companies and, by extension, financial institutions' portfolios to physical risks is information about the geographical location of an asset, especially if used as collateral. As regards companies, it is important that not only the office location is considered, but also the location of production facilities, points of sale and the associated infrastructure.

[75] The EBA also notes that the data collected suggest high exposure of EU/EEA banks to climate transition risks, explained by the high levels of financing for companies whose operations are marked by strong climate change impacts. Banks' exposure to physical risks, measured as assets in geographical areas exposed to physical risks as a share of total assets, is relatively low (under 30% in most countries).

NOTIONAL PHYSICAL RISK INDICATORS *Figure 15*



Source: ECB. Climate change-related indicators. Methodological report. 2023.

A second important component is the availability of information about adaptation measures, including insurance, to ensure a more accurate assessment of financial impacts and asset recoverability after the physical risk has realised.

This must be followed by a hazard assessment, aiming to understand which climate risk drivers pose the greatest threat to portfolio facilities. The scope of analysis is both statistics and their forecast changes depending on the selected climate scenarios. The assessment is based on quantitative metrics: event frequency, intensity, duration and spatial distribution. It is important that the calculations account for geographical details consistent with the type of threat. For example, flood risk assessments for urban areas may have to rely on high-precision maps with a resolution of up to 5–30 m per pixel; for an assessment of agricultural damage from a drought, a 10 km resolution may be sufficient.

Insured or loaned assets are then compared with the spatial distribution of risk. For each asset in the portfolio, spatial analysis allows the calculation of exposure at default (EAD) or the amount of insurance liabilities potentially exposed to climate factors. The result is an aggregate indicator – the share or absolute volume of the portfolio exposed to climate factors. It can be broken down by hazard type and geographic region.

Finally, facility vulnerability is analysed, that is, the degree to which specific facilities can suffer if climate risk realises. To this end, analysis is made based on both physical characteristics (type of construction, presence of flood / overheating protection systems, equipment wear) and financial attributes (residual value, depreciation period, insurance coverage). Additionally, social and economic vulnerability can be factored in, for example the region's hard-to reach location, immature utility infrastructure and high reliance on climate-sensitive industries. The result is a classification of objects by susceptibility to climate effects. It is however desirable to calibrate this classification regularly using current data on damage and medium and long-term scenarios, aiming to account for adaptation measures being implemented.

The resulting hazard, exposure and vulnerability assessments are integrated into one climate risk indicator or immediately converted into financial metrics (e.g. a decrease in collateral value or an increased number of insurance claims).

Given the complexity and diversity of climate risks, the analysis of all possible combinations of hazards and facility types is not feasible or cost-effective. This is why global practice and sectoral recommendations suggest focusing on the most substantial and typical risks which make tangible effects on the financial stability of banks and insurance companies. Such key risks for Russia include floods, droughts, storm winds, wildfires, permafrost thawing and extreme heatwaves. Table 5 and 6 show possible standard metrics of physical risk for insurance companies and credit institutions. Various metrics of exposure and the calibration of their vulnerability functions are possible following a detailed study of data sources and their applicability to risk management at financial institutions.

POSSIBLE STANDARD PHYSICAL RISK METRICS FOR INSURANCE COMPANIES *Table 5*

Hazard	Exposure	Vulnerability
Floods	Total insurance coverage for real estate in the flood area	Damage function depending on the depth of flooding and building type
Wildfires	Total insurance coverage for property in rural areas	Damage function depending on the potential fire hazard
Strong winds	Total insurance coverage for real estate	Damage function depending on wind speed and building type
Droughts	Total insurance coverage for agricultural producers	Damage function depending on the standardised precipitation index
Permafrost thawing	Insurance coverage for projects in permafrost areas	Fixed asset retirement function depending on the depth of permafrost thawing
Extreme heat	Insurance coverage of voluntary health insurance policies	Function of the frequency of requests for medical care depending on temperature
Extreme heat	Number of credit life insurance policies	Function of the incidence rate depending on temperature

Source: Bank of Russia.

POSSIBLE STANDARD PHYSICAL RISK METRICS FOR CREDIT INSTITUTIONS *Table 6*

Hazard	Exposure	Vulnerability
Floods	Total mortgage and market loans secured by real estate in the 100-year flood area*. Number of housing and commercial mortgages in the flood area	Function of collateral revaluation depending on the depth of flooding and building type
Droughts	Portfolio of loans to agricultural producers	Function of default probability calibration depending on the standardised precipitation index
Wildfires	Total loans secured by rural real estate	Function of loss adjustment depending on the potential fire hazard
Permafrost thawing	Loan portfolio in permafrost areas	Function of collateral amortisation rate depending on the depth of permafrost thawing
Storm winds	Total loans secured by buildings	Function of correction of collateral value depending on wind speed and building type
Extreme heat	Consumer loan portfolio	Function of default probability correction depending on heatwave frequency

** A 100 year flood area is an area with a 1% probability of a strong flood each year. This does not necessarily mean that a flood occurs there every 100 years: it can occur in two consecutive years or there can be no flood in decades, but annual risk remains. This area is used in engineering calculations, insurance and development planning as an area with a potentially dangerous level of flooding during extreme precipitation or snow melting.*
Source: Bank of Russia.

Problems of data availability and data quality for risk assessments

Model data enable a detailed view of future climate and its associated hazards. Global and regional trends in climate change are outlined in the Physical Science Basis assessment reports.[76] There are also global atlases, such as the IPCC WGI Interactive Atlas, the Copernicus Interactive Climate Atlas, the Climate Change Knowledge Portal of the World Bank and the Climate impact explorer. Among useful national resources are Rosgidromet's assessment reports and Rosgidromet's Climate Centre data. Appendix 4 presents a detailed description of the atlases and similar tools. These sources are difficult to use primarily because the data are dispersed across various platforms and often lack sufficient spatial detail to be applied to a specific region, insured asset or collateral.

Exposure and vulnerability data should be generated consistent with standard approaches to assessing physical risk at financial institutions. This means that current data cannot be used in their original form and need to be transformed to meet risk management tasks. For example, IPCC Working Group II in their Sixth Assessment Report[77] presents sustainable-development-related climate impact indicators. The following indicators are calculated:

- the number of days per year when the population is at risk of death from extreme heat
- the number of days per year when outdoor physical capacity is reduced by at least 40%
- the return period for 100-year river flood (years) relative to 1970-2000.

Additionally, the sources of exposure and vulnerability data include indicators from Annex 1[78] to 'Impacts, Adaptation and Vulnerability' (Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change). These indicators show how climate change affects crop and animal productivity, as well as the risk of droughts and increased incidence rates due to temperature and humidity changes. However, these indicators cannot be directly converted into metrics for a financial institution to immediately use them for risk assessments.

Another important challenge is to develop a solution to store, access and update data. Such a platform can be implemented by a team with versatile skills:

- climate experts – to search for climate data, identify the most relevant climate risk factors and assess vulnerability functions
- GIS experts – to develop and maintain a geographic information system
- IT specialists (frontend / backend developers, DevOps engineers) – for data processing, automatic calculation of metrics, maintaining access to the system for employees from business units
- a financial methodologist – to link climate and financial metrics
- a product manager who is competent in all the aspects.

It will take significant costs and time to implement such a solution. A toolkit of this kind can only be affordable to major financial institutions.

[76] IPCC. Summary for Policymakers. Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. 2021.

[77] Schipper E.L.F., A. Revi, B.L. Preston, E.R. Carr, S.H. Eriksen, L.R. Fernandez-Carril, B.C. Glavovic, N.J.M. Hilmi, D. Ley, R. Mukerji, M.S. Muylaert de Araujo, R. Perez, S.K. Rose, and P.K. Singh. Climate Resilient Development Pathways. In: Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. 2022.

[78] IPCC. Annex I: Global to Regional Atlas [Pörtner, H.-O., A. Alegría, V. Möller, E.S. Poloczanska, K. Mintenbeck, S. Götze (eds.)]. In: Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. 2022.

Box 1. National Risk Office, Russian National Reinsurance Company's project

Joint-stock Company Russian National Reinsurance Company (RNRC) provides reinsurance under all corporate property programmes in the Russian market, including the most complex catastrophe risks. RNRC has launched the National Risk Office project (Risk Office), aiming to create a knowledge base on such risks and build models for assessing the impact of disasters on insured assets and the Russian economy. This project is a joint effort (involving the Russian Academy of Sciences, Rosgidromet, the Ministry of the Russian Federation for Civil Defence, Emergencies and Elimination of Consequences of Natural Disasters and Roskadastr) focused on developing the methods of modelling and assessing damage from possible or real floods and earthquakes.

The models are built on official Russian data and rely on open scientific research, which increases their transparency and verifiability. The main goal of the models is their relevance to applied economic problems.

The project is based on an automated information and analytical system – a digital tool that reduces calculation time. The system takes into account geographical and climate data, the vulnerability of facilities and insurance parameters, and can generate damage scenarios for specific cities, streets and even buildings.

The Risk Office currently provides the following information for the insurance market:

- data for billing and underwriting
- data for stress testing
- assessments of insurance portfolio accumulation
- data for the calculation and calibration of reserves and capital
- identification of parameters for portfolios to be reinsured.

The constituent entities of the Russian Federation may find the following data useful for:

- assessment of territories by exposure
- economic feasibility assessments of preventive measures
- rapid assessments of expected and actual damage from catastrophic events
- data for management decisions related to disaster risks.

The Risk Office already operates data on earthquakes for 30 constituent entities of the Russian Federation, and data on floods for 40. A geoinformation system (GIS RNRC) was developed and introduced to assess the exposure of territories and facility portfolios.

The project is consistent with the National Action Plan for the Second Phase of Adaptation to Climate Change for the Period up to 2025 approved by Directive of the Government of the Russian Federation No. 559-R, dated 11 March 2023.

In the course of the project, systemic limitations became apparent, including the immature understanding and practice of accounting for catastrophic risks and insufficient legal regulation, as well as fragmented and unequal access to data.

The areas for further development of the Risk Office include:

- modelling the impact of weather risks on crop farming
- comprehensive exposure assessments of the constituent entities of the Russian Federation (Risk Zoning) to material risks.

Abroad, climate risk assessment is often outsourced to specialist contractors. For example, JBA Risk Management integrates client data (such as collateral or insurance policies) through APIs and combines them with flood, hurricane and storm data. This is the basis for assessments of expected losses and maximum possible damage, as well as for the resulting risk management strategies. A similar tool is available from Moody's: its Climate on Demand API enables a forecast impact assessment of climate physical risks (floods, heat stresses, hurricanes, sea level rise) on financial assets and portfolios.

Regulators' methodologies for assessing climate physical risks

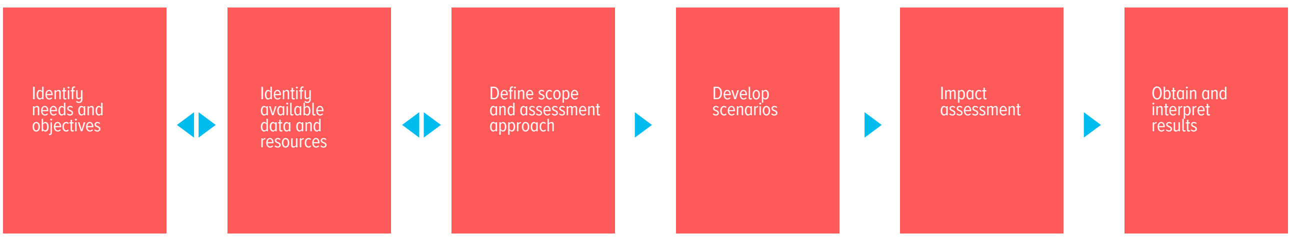
Regulators lack the data needed to assess and respond to such risks given the lack of full data at the macrolevel and the practice of organisations assessing these risks on an individual basis. This has led the South African Reserve Bank (SARB), holding the G20 presidency, to initiate efforts to address the data gaps. Among results expected for 2025 is the identification of data gaps in insurance coverage of climate-related damage. The Reserve Bank of India has initiated the creation of a Climate Risk Information System (CRIS), in collaboration with a team of external experts. CRIS is a data repository for financial institutions to assess climate physical and transition risks. A physical risk assessment is based on historical data: the damage function for 14 types of climate threats relevant to India and satellite-based asset geolocation data (accuracy is planned to rise to 10m).

Regulators currently have mature methodologies for assessing climate physical risks. International organisations (NGFS, the World Bank, the Financial Stability Board) have developed universal approaches to the assessment. This means that the barrier today is not the absence of methodologies as such, but data to be filled in practice, tailored to a national context and integrated into existing risk assessment and response systems. This is particularly evident in countries with limited resources and access to high-quality climate and financial data. The current methodologies are shown below, alongside the gaps preventing their effective application.

Globally, there is a wide range of methodologies and tools for assessing climate physical risks for the overall financial sector. Physical risk assessment tools vary depending on the scope of climate vulnerabilities, transmission channels, asset classes, assessment methods and data granularity. A number of providers offer tools that are mainly based on proprietary data, and their solutions are tailored to the needs of a particular customer. In addition to the limited regional coverage of some publicly available methodologies, this approach limits access to physical risk assessment tools for regulators in emerging markets and developing countries.

Recommendations by international organisations and initiatives are focused on describing best practices and qualitative approaches to regulators' assessment of climate physical risks. The NGFS and the World Bank offer regulators and supervisors a top-level phased approach to assessing acute physical risks, making up six core phases (Figure 16).

ACUTE PHYSICAL RISK ASSESSMENT PROCESS *Figure 16*



Source: NGFS-World Bank.

The Financial Stability Board (FSB) defines climate-related vulnerabilities of the financial system as a causal relationship between climate shocks and traditional vulnerabilities. This assessment is based on the FSB's financial stability surveillance framework. The FSB offers the following toolkit for assessing climate, in particular physical, risks:

- indicators providing early signals on potential drivers of physical risks: the European Central Bank (ECB), the Bank of France and the Bank of England use economic losses from adverse weather events

- exposure indicators to assess the impact of climate risk drivers on various sectors: exposure of financial institutions' assets to climate hazards (ECB, Bank of England, Hong Kong Monetary Authority), LTV adjusted for weather damage (Bank of the Netherlands), reinsurance premium and market concentration (Bank of England, IAIS)
- risk indicators quantifying potential financial losses associated with climate shocks: expected credit losses due to asset damage (ECB), insurer capital requirements for covering natural disaster risks (IAIS, Bank of France).

Box 2. Integration of climate physical risks into banks' credit models: Bank for International Settlements approach[1]

Regulatory experience suggests the need to incorporate climate physical risks into banks' credit risk management frameworks. At the same time, globally accepted industry standards have yet to be developed. The main challenge is how to convert physical risks into adjustments in financial measures such as PD (Probability of Default) or LGD (Loss Given Default).

Natural hazards are rare over a one-year horizon, and their historical data are not consistent with the current probability of their occurrence. One solution could be an upward adjustment of PD based on expert opinion. However, this approach distorts the average risk level and fails to consider the problems faced by multiple borrowers simultaneously in the event of a violent act of nature. Therefore, the subject of adjustment should not be the average probability of default but the asymptotic single risk factor (ASRF) model, used as part of an internal ratings-based (IRB) model approach to credit risk assessment.

Bank for International Settlements experts suggest the option of accounting for physical risk in the ASRF model. They suggest adding a separate climate factor: it is unlikely, but when it realises, the value of affected borrower assets drops and the risk of default rises sharply. This is enabled by recognising direct damage to assets, but also by an increasing correlation of defaults in individual regions or industries. Insurance coverage reduces loss volatility but fails to completely eliminate risk.

The model opens up opportunities for further specification of physical risk, for example ranking events as relatively frequent with moderate damage and rare catastrophic events. Furthermore, this assessment enables risk hedging through climate damage index swaps or catastrophe bonds. In addition, this approach is convenient for supervision since it includes physical risk but still relies on traditional credit risk models, which lowers the costs of its implementation and improves comparability of results between banks.

[1] V. Pozdyshev et al. Incorporating physical climate risks into banks' credit risk models', BIS Working Paper No. 1274, 2025.

Regulators have extensive experience of stress testing climate physical risks. Regulators make assessments to quantify financial impacts of climate risks and even explore updating financial institutions' risk management frameworks. At the same time, given the lack of data, most stress tests are still pilot projects, used as a tool to improve the understanding of vulnerabilities and build competencies of regulators and market players (Figure 17).

Acute physical risks are assessed over a short-term horizon (one to three years), and chronic risks are assessed over a longer period stretching to 2050 and, in some cases, 2080–2100. Central banks use both top-down and bottom-up approaches, as well as a hybrid version. Most stress tests specify the source of physical risk, the most common sources being floods, drought, sea level rise, heatwaves and average temperature increases. The most common financial risks under assessment are credit, operational, market and insurance risks, as well as funding and liquidity risks.

NGFS scenarios are the preferred tools for regulators to assess physical risk, with some countries tailoring the scenarios to national contexts and climate goals. Starting from Version 3, NGFS climate scenarios take into account, in addition to chronic risks, acute risks: heatwaves, drought, floods and cyclones (subsequently with more coverage of hazardous events, in Version 4). Regulators tailor NGFS scenarios to national contexts. For example, in its Guidelines for Banking Sector Climate Risk

MAIN OBJECTIVES OF STRESS TESTS FOR REGULATORS *Figure 17*

Source: UNEP. A Comprehensive Review of Global Supervisory Climate Stress Tests. 2024.

Stress Test, the Hong Kong Monetary Authority (HKMA) outlines scenarios that include frequent and prolonged precipitation. Climate stress tests developed jointly by the Bank of Korea and the Financial Supervisory Service of the Republic of Korea (FSS) are based on the NGFS scenarios for 2023, adjusted for the national economy (industry's share of GDP is high at 25% and the country's reliance on carbon-intensive industries), as well the country's climate conditions (high exposure to floods and typhoons).

The quantitative assessment usually targets the components of the hazard-exposure-vulnerability model. Stress testing of the insurance sector widely uses catastrophe modelling (CatModels) to quantify the potential damage caused by specific natural phenomena in a physical risk realisation scenario. An example is the French stress test for the insurance sector. The regulators' assessment relies on such metrics as loan to value (LTV) ratios, probability of disasters, loss given default (LGD), PD, exposure at default (EAD) and NPL.

The impact of climate physical risks on banking sector stability at the country level is also assessed by the IMF as part of its Financial Sector Assessment Program (FSAP). The methodology, published in July 2022, describes the IMF's general approach to assessing the impact of climate change on the banking sector in countries whose physical risks are deemed material. The time horizon of the analysis spans both the ultra-long-term period up to 2100 and the standard forecast horizon for the FSAP ranging from three to five years.

Another new aspect of climate change effects is **nature-related risks**. The Taskforce on Nature-related Financial Disclosures (TNFD) recommends that corporations and financial institutions develop internal competencies in nature-related risk assessment.

Supervisory disclosure requirements

In late 2023, the Basel Committee on Banking Supervision (BCBS) proposed that information on banks' exposure to climate-related financial risks should be included in Pillar 3 supervisory reporting. As regards climate physical risks, the BCBS suggested disclosing the following quantitative indicators:

- gross carrying amount (before adjusting for impairment / loss provisions) of loans, debt and equity securities in bank assets linked to locations with high exposure to physical risks, in absolute terms and as a percentage of the total value of respective asset classes on the bank balance sheet, including:
    - the value of assets of non-financial companies
    - the amount of loans secured by residential or commercial real estate
- non-performing assets as a share of assets exposed to climate physical risks
- the amount of impairment / loss provisions / losses related to assets with high exposure to physical risks
- average maturity of assets with high exposure to physical risks, with a breakdown by group based on residual maturity.

Most regulators do not mandate credit institutions to submit climate risk information as part of their supervisory disclosures. The most common method of assessing physical risks is stress testing, which does not use supervisory reporting data and does not assess the risks of individual entities, which may vary significantly. Underestimation of risk heterogeneity can have strong negative implications for financial stability. This is why some regulators are increasingly requiring submission of specific data to assess physical risks of credit institutions.

ESG risks are part of supervisory reporting in the EU since 2022 ('Implementing Technical Standards (ITS) on prudential disclosures on ESG risks in accordance with Article 449a CRR').[79] Under a section of the approved form (Annex I – Templates for ESG prudential disclosures), large public credit institutions are required to provide information on on-balance sheet exposure, in millions of euros, at least once a year (deadlines may vary depending on national requirements), broken down by:

- the geographical area related to counterparties' business processes exposed to climate change. Companies independently define such areas using scientific portals and databases, including those recommended by the standard
- maturity
- exposure susceptible to the impact of long-term climate changes (chronic risks)
- exposure susceptible to natural hazards (acute risks)
- exposure susceptible to both long-term climate changes and natural hazards
- by stage 2 exposure in accordance with International Financial Reporting Standards (IFRS) 9 'Financial Instruments' – loans with a significant increase in credit risk since initial recognition. This means the need for credit risk changes to be monitored and provisioning for expected credit losses
- by loans overdue more than 90 days or with signs of impairment
- by accumulated impairment losses, accumulated negative changes in fair value related to credit risk, and by provisions: includes all impairment provisions for the above exposures.

Additionally, financial institutions' supervisory forms specify historical losses associated with climate change.

In March 2024, the US Securities and Exchange Commission (SEC) published rules to enhance and standardise climate-related disclosures by public companies and in public offerings. The following

[79] European Banking Authority. Implementing Technical Standards (ITS) on prudential disclosures on ESG risks in accordance with Article 449a CRR.

examples[80] were cited as indicators measuring the impact of natural hazards on companies' financial performance:

- changes in revenue or costs caused by operational or supply chain disruptions
- the amount of impairment and a change in the carrying amount of assets (inventories, intangible and fixed assets) caused by natural hazards (floods, droughts, wildfires, extreme temperatures) and by long-term changes (sea level rise)
- changes in loss provisions or loan loss provisions (for credit institutions)
- change in aggregate insured potential losses in the event of a flood or forest fire.

Effective from 2023, Brazilian credit institutions supervised by the Central Bank of Brazil are required to provide climate-related disclosures according to 'Documento de Risco Social Ambiental e Climático' (DRSAC).[81] Such duly executed disclosures must include consolidated assessments of physical risks in monetary terms with a breakdown by potential damage from acute and chronic physical risks.

Both banks and insurance companies are not required to disclose quantitative indicators related to physical risks. Supervisory reporting includes quantitative financial metrics of the insurance business that may signal an increase in climate risk. The EU Solvency II Directive sets forth the requirements for calculating and reporting the amount of capital needed to cover insurance losses (SCR). The European Insurance and Occupational Pensions Authority (EIOPA) subsequently issued a set of rules for the application of Solvency II, including the standard formula for SCR calculations related to disaster insurance, submitted as part of a Regulatory Supervisory Report. A key indicator of the impact of physical risks on insurers and underwriting is the average annual loss and the probable maximum loss from sales of disaster insurance (IAIS). Growth in these indicators suggests a rise in damage, the likelihood of natural disasters and exposure of insurance companies to physical risk. Furthermore, the data gaps create gaps in disaster risk insurance. The International Association of Insurance Supervisors (IAIS) and the World Bank developed a practical guide addressing risk insurance gaps, including efforts to promote availability and affordability of insurance products and services, risk transfer solutions (global reinsurance, catastrophe bonds, insurance pools) and incentives for public-private partnerships.

Questions for consultations and promising areas of focus for the Bank of Russia, federal executive bodies, academic communities, financial and non-financial companies, and other stakeholders

Given the potential consequences of climate-related events, including growing credit and market risk, it may be feasible to develop a methodology for assessing the largest and most important climate-sensitive portfolios. Such a methodology may be aimed at identifying risks in highly vulnerable regions, industries or client groups.

The following information is required to determine the future path of the methodology:

- Which direct and indirect climate physical risks do you consider to be most material?
- How do you factor in these risks in your portfolio assessments?
- What sources and formats of information do you use to identify, monitor and assess information?
- How do you manage these risks? Which adaptation measures do you use to reduce your operational risk?

It is also feasible to create a public service that:

- is intended to consolidate existing data on hazard-exposure-vulnerability components
- will involve a model-based approach, enabling data conversion into indicators that can be easily integrated into credit or insurance processes

80 This list is illustrative, and specific indicators were not included in the final version of the requirements following concern expressed by public consultation participants about the discrepancy between some metrics of the Generally Accepted Accounting Principles (GAAP) and the need to request missing information from counterparties and private information providers for their calculation.

81 Banco Central do Brasil. Documento de Risco Social, Ambiental e Climático. 2022.

- will be easily accessible to financial companies (e.g. via APIs) and have a reliable infrastructure to prevent customer data breaches.

The Risk Office of Russian National Reinsurance Company (RNRC) has extensive experience of flood modelling and flood scaling to other types of climate threats.

Limited information remains the key barrier to assessing physical climate risks at the financial sector level. For all the existing methodological approaches, including those adjusted to regulator needs, quantitative assessments are limited in terms of both coverage and quality of source data.

The first stage may involve targeted assessments of exposure of certain asset classes and activity types to specific climate risks (e.g. by means of surveys of credit institutions and insurance companies and analysis of existing internal methods).

The next step may be a stress test with a shift in focus away from making an accurate estimate of damage to identifying vulnerable segments and indicators reflecting sensitivity to physical risks. This approach makes it possible to use stress testing as a tool to identify gaps in data and generate a relevant request.

In the long term, the key focus of efforts will remain on improving the volume and granularity of available information, including global experience.

To create a map of the financial system's exposure to climate risks and subsequently develop risk management tools, a database is needed to enable the Bank of Russia to gauge financial institutions' exposure to physical risks. In particular, the quantitative metrics of exposure to climate physical risks can be based on the following information:

- geographical location of loaned assets or insured facilities, for example according to the Russian Classification of Territories of Municipal Formations (OKTMO)[82]
- additional conditions or limitations in corporate borrowing or insurance, which are related to natural and climate conditions (e.g. operational limitations, shorter timelines, exclusion of some risks from coverage, additional protection requirements, etc.)
- more detailed breakdowns of insurance benefits:
  - information related to the realisation of natural hazards by their type (floods, storm winds, droughts, permafrost thawing)
  - identification of fires caused by wildfires.

Do you agree with the suggested areas of activity? What kinds of support (including methodological, digital and legal) are needed from the Bank of Russia and federal executive bodies to enable progress in these areas of activity?

[82] Specifically, data may be collected as part of a pilot project to assess the possible formats of submission.

APPENDIX 1. GLOSSARY

Acute physical risks – climate physical risks associated with natural hazards, including intense heat or frost, extreme precipitation and floods, abnormal wind, wildfires, etc.

Adaptation (adaptation to climate change) – the adjustment of ecological, social or economic systems in response to actual or expected climatic stimuli and their effects. Adaptation involves adjustments of processes, practices or structures to moderate potential damages or to benefit from opportunities associated with climate change.

Chronic physical risks – climate physical risks associated with long-term changes in climate characteristics and conditions, such as rising ocean levels, rising global average air temperatures, changes in permafrost conditions and ocean acidification among others.

Climate – the statistical description of weather in terms of mean[1] and variability of relevant quantities over a period of time ranging from months to thousands or millions of years. The relevant quantities are most often near-surface variables such as temperature, precipitation, and wind.[2]

Climate change mitigation – a set of measures to reduce greenhouse gas emissions and increase their absorption. Since there is a direct relationship between global average temperature and the concentration of greenhouse gases in the atmosphere, climate change issue must be addressed, firstly, by reducing emissions into the atmosphere and, secondly, by reducing the concentration of greenhouse gases (GHGs) by enhancing sinks (for example, increasing the area of forests).

Climate physical risks – the likelihood of losses associated with natural hazards arising from climate change. Climate risk results from dynamic interactions between hazard (see ***Hazard***) related to climate change, exposure (see ***Exposure***) and vulnerability (see ***Vulnerability***) of affected societies and ecosystems. Climate physical risks are categorised into acute (see ***Acute Physical Risks***) and chronic risks (see ***Chronic Physical Risks***). Economic damage resulting from the realisation of climate physical risks is divided into direct (see ***Direct Economic Damage***) and indirect damage (see ***Indirect Economic Damage***).

Climate risks – the likelihood of losses associated with the impact of climate change, as well as of measures aimed at climate change mitigation, adapting to climate change, including those taken by governments and regulatory authorities. Climate risks include climate physical risks (see ***Climate Physical Risks***) and climate transition risks (see ***Climate Transition Risks***).

Climate scenario (climate change scenario) – a probable description of the future state of the climate system, based on historical information about the state of the climate system and its main characteristics (temperature, precipitation, etc.) and assumptions about future changes (in particular, an increase in the concentration of greenhouse gases) and the impact that climate change will have on social and economic indicators.[3]

Climate transition (transition to a low-carbon economy) – a transition from existing production and consumption models to a low-carbon economic model to achieve the goals of the Paris Agreement. Examples of activities implemented at the national and global level as part of the climate transition are the energy transition, as well as the decarbonisation of industry, agriculture, and transport.

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1 The classical period for averaging these variables is 30 years, as defined by the World Meteorological Organisation.

2 GOST R ISO 14091-2022. National Standard of the Russian Federation. Adaptation to Climate Change. Guidelines for Vulnerability, Exposure and Risk Assessment' (approved and enacted by Rosstandart Order No. 1188st-, dated 25 October 2022).

3 For details of climate scenarios, see Appendix 3.

Climate transition risks – the likelihood of losses associated with the transition to a low-carbon economy, including measures taken by governments and regulators aimed at climate change mitigation and adapting to climate change, which are divided into political, legal, technological, market and reputational risks.

Climate-related opportunities – potentially promising areas of activity that take into account climate change, as well as measures aimed at climate change mitigation taken by governments and regulators of countries being parties to the Paris Agreement (see the ***Paris Agreement***), can be used and developed by organisations to create competitive advantages and maintain the necessary level of confidence.

Direct economic damage – damage caused by the direct impact of natural hazards on infrastructure, real estate owned by individuals or tangible assets owned by companies. Examples include the destruction of buildings, roads, bridges, power lines or plant equipment due to hurricanes, floods, droughts and other natural hazards. Direct damage is immediate and quantifiable once the climate risk has realised.

Drought – lengthy and pervasive water shortage, most often with high temperatures and low humidity. Atmospheric (meteorological), soil (agricultural) and hydrological droughts are distinguished.

EAD (Exposure at Default) – a bank's estimate of a borrower's outstanding balance at default, including principal, interest and fees.

Ecosystem – a set of jointly living organisms and conditions for their existence, which are in a natural relationship with each other and make up a system of interconnected biotic and abiotic phenomena and processes.

Ecosystem services – benefits for humankind obtained from ecosystems, that is ecosystem services providing human beings with natural resources, a healthy living environment and other environmentally and economically important 'products'. Ecosystem services include: provisioning (food, water, forest, raw materials), regulating (climate impact, flood control, natural disasters, water quality, etc.), cultural (recreational resources, aesthetic and spiritual values of nature) and supporting (soil formation, photosynthesis, nitrogen cycle, etc.) services.

Exposure – a component of climate physical risk that characterises the presence of people, livelihoods, species or ecosystems, ecological functions, services, resources, infrastructure or economic, social or cultural assets in places and conditions that may be affected by physical events or trends related to climate change (see ***Hazard***).

Extreme heat – from April to September, for five or more days, the average daily air temperature is 7°C or higher above the climate normal.

Extreme precipitation – precipitation of high intensity with a very rare occurrence at a particular place on record. The thresholds are set according to statistical data, taking into account the risk of damage, for example for heavy rainfall at least 30mm in one hour or less.

Flood – a significant overflow of water onto land as result of rising water levels in a river, lake, reservoir or sea, causing material damage to the economy, social sector and natural environment. It can occur as a result of rising water levels, surface or underwater ice blocking river channels, as well as failure of hydraulic structures.

Greenhouse gases – gaseous constituents of the atmosphere, both natural and anthropogenic, which absorb and re-emit infrared radiation. According to Annex 1 to the Methodology for Quantifying Greenhouse Gas Emissions approved by Order of the Russian Ministry of Natural Resources No. 371, dated 27 May 2022, the list of greenhouse gases includes: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), sulphur hexafluoride (SF_6), perfluorocarbons (CF_4), hydrofluorocarbons (CHF_3) and hexafluoroethane (C_2F_6).

Hazard – a component of climate physical risk that describes the potential occurrence of a physical event or trend that could result in damage due to: 1) human deaths or other health effects; 2) damage and/or loss of property or infrastructure; 3) degradation and/or loss of ecosystems, ecosystem services or natural resources. Hazards include slowly evolving processes (e.g. long-term temperature increases) and rapidly evolving natural hazards (e.g. heatwaves) or increased climate variability (fluctuations). The IPCC Working Group I also uses the term 'climatic impact-drivers' to refer to such processes and phenomena.[4]

Heatwave – a period of extreme heat, often determined with reference to a relative temperature threshold, lasting from 2–5 days to months.

Hurricane – a wind of destructive force and lengthy duration, the speed of which exceeds 30m/s. It is a natural hazard that threatens human life and the animal world, brings heavy destruction to residential and household buildings and facilities.

Indirect economic damage – damage which shows up through secondary effects affecting the economic system in the medium and long term. For example, the destruction of infrastructure cause disruptions in logistics chains, triggering supply delays, pushing up prices and decreasing economic activity. Crop losses and lower yields following the occurrence of climate physical risks may put pressure on agricultural prices, especially in developing countries. Additionally, climate change may intensify migration in a number of regions, reducing the affordability of labour resources and increasing social liabilities of the economy. Indirect losses are often less evident, but their cumulative effects can be more devastating than direct losses.[5]

LGD (Loss Given Default) – the percentage of a bank's exposure that is lost when a borrower defaults on a loan less proceeds from the sale of collateral and other sources of repayment.

LTV (Loan-to-Value) – the ratio of a loan to the fair value of an asset purchased.

Natural hazard – an event of natural origin or the state of elements of the natural environment as a result of the activity of natural processes, which, by their intensity, scale of distribution and duration, can cause a damaging effect on people, economic entities and the environment. This report covers only natural hazards associated to climate change and excludes volcanic eruptions, earthquakes, tsunamis and others.

NPL (non-performing loan) – outstanding debt on which the principal and interest payment is overdue (usually, more than 90 days).

Ocean acidification – a reduction in ocean pH, accompanied by other chemical changes (primarily in the levels of carbonate and bicarbonate ions), over an extended period, typically decades or longer, which is caused primarily by uptake of carbon dioxide (CO_2) from the atmosphere, but can also be caused by a change in the balance of other chemicals. Current intense ocean acidification (pH reduction) is associated with anthropogenic greenhouse gas emissions.

PD (Probability of Default) – the statistically estimated likelihood that a borrower will fail meet their debt obligations to the lender within a specified time period (normally one year).

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4 They are detailed in the contributions of Working Group I to the IPCC assessment reports (Change Climate 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change).

5 IPCC. Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the IPCC Sixth Assessment Report. 2022.

Storm – a long and very strong wind with a speed of over 20m/s, causing strong unrest at sea and destruction on land.

Strong wind – air movement relative to the earth's surface with a speed or horizontal component of more than 14m/s. Strong wind varieties are squalls, cyclones, vortices and other atmospheric phenomena with the speed of 50–100m/s or more.

Intergovernmental Panel on Climate Change (IPCC) – a joint body of the United Nations Environment Programme (UNEP) and the World Meteorological Organisation, established in 1988 to obtain the most reliable and authoritative scientific data related to climate change. The IPCC engages hundreds of scientists from around the world and publishes reports with detailed intergovernmental recommendations. The IPCC regularly publishes extensive (three-volume) reviews (Assessment Reports). Volume 1 sets out the physical basis of climate change, volume 2 describes the impact of climate change on nature and human life, and volume 3 discusses efforts at climate change mitigation.

Paris Agreement – an international treaty adopted at the 21st session of the Conference of the Parties to the UN Framework Convention on Climate Change in 2015; the main goal of which is to keep the increase in global average temperature well below 2°C above pre-industrial levels and to make efforts to limit the increase in temperature to 1.5°C. The agreement calls for all countries to commit to reducing their greenhouse gas emissions and working together to adapt to the impacts of climate change. The Russian Federation is a party to the Paris Agreement (Decree of the Government of the Russian Federation No. 1228, dated 21 September 2019 , ‘On Adopting the Paris Agreement’).

Typhoon – a long storm cyclone of significant intensity with a strong wind (30–50km/h with gusts of up to 100km/h), rain, storm or hurricane. Heavy rains are associated with typhoons, often causing severe floods. They pose a serious threat to all life support infrastructures in Russia’s Far East, Sakhalin, the Kuril Islands and Kamchatka.

Vulnerability – a component of climate physical risk that characterises the propensity or predisposition of people, livelihoods, species or ecosystems, environmental services, resources, infrastructure, or economic, social or cultural values to adverse effects of physical events or trends related to climate change (see ***Hazard***). Vulnerability is a function of the nature, magnitude and speed of the climate impacts to which they are exposed, as well as of their sensitivity to such impacts and their inability to cope with or adapt to them.

APPENDIX 2. CLIMATE MODELS AND SCENARIOS

The most relevant climate scenarios to date are ***Shared Socio-economic Pathways (SSPs***). They were developed based on climate models used in Phase 6 of the Coupled Model Intercomparison Project (CMIP6) of the World Climate Research Programme. These scenarios are also used in the IPCC Sixth Assessment Report.

The calculations produce five scenarios helping understand how anthropogenic factors of climate change are expected to change. This means the scenarios differ in socio-economic assumptions and the levels of climate change mitigation. Scenario nomenclature follows the SSPx-y format, where 'SSPx' represents a Shared Socio-economic Pathway and 'y' denotes the approximate level of radiation exposure (in W/m^2) under this scenario in 2100 (RCP scenarios are detailed below).

SSP1 and ***SSP5*** suggest relatively optimistic trends in human development with significant investments in education and health, rapid economic growth and well-functioning institutions. However, SSP5 assumes that such development will be driven by an energy-intensive economy based on fossil fuels, while SSP1 projects an increasing shift towards sustainable methods.

SSP3 and ***SSP4*** are more pessimistic in terms of economic and social development, with little investment in education or health in poorer countries, combined with rapidly growing populations and increasing inequality.

SSP3–7.0 and SSP5–8.5 are therefore both high and very high GHG emissions scenarios, where CO_2 emissions double relative to current levels by 2100 and 2050 respectively.

Conversely, SSP1–1.9 SSP1–2.6 are scenarios with very low and low greenhouse gas emissions respectively. They are premised on CO_2 emissions declining to net zero around or after 2050, followed by various levels of net negative CO_2 emissions.

SSP2 is the 'middle of the road' scenario whereby historical development models continue throughout the 21st century. CO_2 emissions in SSP2–4.5 remain at current levels until the middle of the century.

Representative Concentration Pathways (***RCP***) are scenarios for the evolution of anthropogenic greenhouse gas emissions into the atmosphere in the future. The four basic scenarios are RCP 8.5, RCP 6.0, RCP 4.5 and RCP 2.6.

The numbers in the scenario name indicate the expected maximum permissible value of radiation forcing (W/m^2) in 2100 from the beginning of the industrial era (1750). The smaller the amount of radiation forcing, the more severe restrictions are imposed on greenhouse gas emissions into the atmosphere. Thus, social and economic development is constrained by a cap on such emissions, which ensures that climate change remains below a specified threshold (Table 1).

DESCRIPTION OF RCP SCENARIOS *Table 1*

RCP2.6	Radiation exposure rises to 2.6 W/m2 in 2100	The concentration of greenhouse gases on average drives up the radiation impact from 2.3 to 2.6 Watts per square meter (W/m^2). In RCP 2.6, the average global temperature remains below 2°C by 2100
RCP4.5	Radiation exposure rises to 4.5 W/m2 in 2100	IPCC views RCP 4.5 as an intermediate scenario. Emissions in the atmosphere peak and begin to decline around 2040. The average global temperature increases by 1.7–3.2°C relative to 1850–1900 by 2100. For the middle of the century (2046–2065), this suggests the warming range of 1.5–2.6°C
RCP6.0	Radiation exposure rises to 6 W/m2 in 2100	Emissions peak and begin to decline around 2080. In this scenario, by the end of the century, global temperatures will increase by 2.0–3.7°C relative to pre-industrial levels
RCP8.5	Radiation exposure rises to 8.5 W/m2 in 2100	The scenario assumes that no action is taken to reduce greenhouse gas emissions. Global temperatures will rise by 3.2–5.4°C by the end of the century. For the middle of the century, the likely range is 2.0–3.2°C warming

APPENDIX 3. DESCRIPTION OF NATURAL DISASTERS FOR INSURANCE COMPANIES TO CALCULATE MAXIMUM POSSIBLE LOSS

Flooding on Black Sea coast and Caucasus	Between the first half of July and the first half of August, the Black Sea coast receives a record amount of precipitation In early July, Gelendzhik, Novorossiysk and Krymsk receive 3–4 monthly precipitation norms within a few days; the Sochi region gains similar amounts in late July. In early August, heavy rains take place in Dagestan (Derbent and Buinaksk). Such precipitation amounts cause floods. Also, tornadoes are likely to occur on the coast and mudslides in mountainous areas, with negative impacts on economic activity in the following areas: • significant damage to car and railway infrastructure, destruction of settlements and production facilities • breakthrough of hydraulic structures • crop losses due to abundant water, in particular, grapes • fatalities
Typhoons and hurricanes in the Primorye Territory	In the first half of summer, the Primorye Territory is hit by strong typhoons (a long intense storm with a strong wind of 30–50km/h and gusts of up to 100 km/h) associated with heavy rains. Strong winds, heavy rains and the accompanying floods cause significant damage to life support and port infrastructure in the region, damaging ships in the port and bringing port operations to a halt for two weeks.
Drought in the European part of Russia	Between the second half of July and the first half of August, the European part of Russia is left almost without precipitation for 30 days as average daily temperatures top 25°C in the region around Moscow and about 30°C around Volgograd. This brings about adverse effects in economic activity in the following areas: • damage to infrastructure, settlements and production shutdowns due to forest and peat fires • smog from wildfires causes a collapse in major cities with a switch to remote work • rising mortality rates and policy holders' requests for medical care • significant crop losses due to adverse weather • shortage of water for production and utility services due to shallowing water bodies • rising costs of cooling industrial and transport equipment and increased risks of its failure

APPENDIX 4. TOOLS TO ANALYSE FUTURE CLIMATE CHANGE AND CLIMATE PHYSICAL RISK

Tools to analyse future climate change

Below we discuss the publicly available tools to analyse the hazard component of climate risk to understand how the key climate system parameters will change in the future. These tools include:

- IPCC WGI Interactive Atlas[6]
- Copernicus Interactive Climate Atlas (C3S Atlas)[7]
- Climate Change Knowledge Portal (CCKP) of the World Bank[8]
- Climate Impact Explorer (CIE).[9]

Each of these solutions helps explore projected changes in temperature, precipitation and a number of other indicators by visualising them on geographical maps and various charts. However, each of the tools is specific. Below is the comparison of the following parameters: 1) indicators; 2) scenarios and horizons; 3) scale; 4) visualisation formats.

Sets of climate indicators

The following set of indicators may be used as key indicators in the analysis of long-term trends in climate change:

- average mean surface temperature
- average minimum surface temperature
- average maximum surface temperature
- precipitation.

They help identify areas marked by critical levels of change that may affect living conditions and economic activities. For each of them, spatial and temporal patterns need to be analysed, in the first place. Also, before assessing future climate change, it is essential to determine whether historically observed trends specific to each indicator remain unchanged or are increasing, and whether there are regional differences.

As for changes in the indicators under a future climate scenario, in order to better understand the scale of future changes, not only median values have to be analysed, but also the range of likely variability (between the 10th and 90th percentiles).

The IPCC and the Copernicus Interactive Climate Atlas include a core set of indicators that provide insights into future temperature changes. Among them are indicators of average, minimum, maximum and extreme temperatures. Both atlases also reflect changes in the number of degree days of heating and cooling periods,[10] the indicators necessary to assess the needs of energy infrastructure.

The Climate Impact Explorer is limited to three indicators: average daily temperature, minimum daily temperature and maximum daily temperature. The widest list is available from the World Bank Climate

6 https://interactive-atlas.ipcc.ch/.

7 https://atlas.climate.copernicus.eu/atlas.

8 https://climateknowledgeportal.worldbank.org/country/russian-federation/climate-data-projections.

9 https://climate-impact-explorer.climateanalytics.org/impacts/.

10 Cooling and heating degree days. A heating degree day is calculated by multiplying the absolute value of the difference between the average daily ambient temperature for the days when it is below the base temperature (18.3°C) and this base temperature by the number of such days per year. A cooling degree day is calculated in the same fashion for days when the ambient temperature is higher than the base temperature (18.3°C). Indicators are essential to estimating energy infrastructure needs.

Change Knowledge Portal. For example, for extreme temperature analysis, more thresholds were introduced than in the IPCC and C3S atlases. Also, added were the Cold and Warm Spell Duration Indices,[11] the indicators of the number of tropical nights[12] with different thresholds. The full list of temperature indicators by resource is shown in Table 1.

TEMPERATURE CHANGE INDICATORS *Table 1*

Unit	Indicator	IPCC	C3S	CCKP	CIE
°C	Average daily temperature	+	+	+	+
°C	Minimum daily temperature	+	+	+	+
°C	Maximum daily temperature	+	+	+	+
°C	Minimum value of daily minimum temperature	+	+	+	
°C	Maximum value of daily maximum temperature	+	+	+	
days	Number of days with maximum temperature above 25°C			+	
days	Number of days with maximum temperature above 30°C			+	
days	Number of days with maximum temperature above 35°C	+	+	+	
days	Number of days with maximum temperature above 40°C	+	+	+	
days	Number of days with maximum temperature above 42°C			+	
days	Number of days with maximum temperature above 45°C			+	
days	Number of days with maximum temperature above 50°C			+	
days	Number of days with minimum temperature below 0°C	+	+	+	
days	Number of days with maximum temperature below 0°C			+	
°C· day	Heating degree days	+	+	+	
°C· day	Cooling degree days	+	+	+	
days	Cold spell duration index			+	
days	Warm spell duration index			+	
days	Number of days with heat index >= 35°C			+	
days	Number of days with heat index >= 37°C			+	
days	Number of days with heat index >= 39°C			+	
days	Number of days with heat index >= 41°C			+	
days	Number of tropical nights (T-min >= 20°C)			+	
days	Number of tropical nights (T-min >= 23°C)			+	
days	Number of tropical nights (T-min >= 26°C)			+	
days	Number of tropical nights (T-min >= 29°C)			+	

Unlike temperature, precipitation forecasts typically involve complex and uncertain processes and dynamics to scale, making them more difficult to model. This is why the ranges of uncertainty, significance and emerging trends should be determined for such indicators.

The IPCC Interactive Atlas provides a narrow set of key precipitation indicators for average and extreme precipitation (maximum precipitation over one and five days, consecutive days without precipitation and the standardised precipitation index), as well as the snowfall indicator. The Copernicus Interactive Climate Atlas supplemented this list with humidity indicators for open air and soils. The Climate Impact Explorer also includes individual humidity indicators. The World Bank's Climate Change Knowledge Portal expands the list of extreme precipitation indicators, for example the number of days

[11] Cold Spell Duration Index, Warm Spell Duration Index. The Warm Spell Duration Index shows a period of six or more days in which the daily maximum temperature exceeds the 90th percentile of the base period. The Cold Spell Duration Index shows a period of six or more days when the daily maximum temperature exceeds the 10th percentile of the base period. These indices give an idea of the duration of extreme temperature events that can affect human health.

[12] The number of tropical nights shows the number of nights with minimum daily temperature thresholds of above 20°C, 23°C, 26°C and 29°C. This is a very informative indicator since the combination of hot and, particularly, hot and humid days with tropical nights exacerbates extreme heat conditions.

with precipitation >= 20 mm or >= 50 mm. The full list of temperatures broken down by resource is shown in Table 2.

INDICATORS FOR CHANGES IN PRECIPITATION PATTERN *Table 2*

Unit of measure	Indicator	IPCC	C3S	CCKP	CIE
mm/day.	Amount of precipitation	+	+	+	+
mm	Maximum daily precipitation	+	+	+	
mm	Maximum precipitation over 5 days	+	+	+	
days	Number of consecutive days without precipitation	+	+	+	
days	Number of consecutive days with precipitation			+	
mm	Maximum monthly precipitation average			+	
days	Number of days with precipitation >= 20 mm			+	
days	Number of days with precipitation >=50 mm			+	
mm	Amount of precipitation in wettest days			+	
%	Change in precipitation			+	
% of deviation	Standardised precipitation index (SPI)*	+	+		
units of SPEI index	Standardised Precipitation and Evapotranspiration Index (SPEI)**			+	
mm/day.	Snowfall	+	+		+
mm/day.	Average daily evaporation		+		
kg·m^2	Surface soil moisture content		+		+
kg·m^2	Average daily runoff		+		
%	Relative humidity			+	+

** The standardised precipitation index is a quantitative assessment of water availability in the area under study. This measure is essential for monitoring and forecasting the duration and intensity of atmospheric drought, including rainy periods. The index values are the number of standard deviations from the average precipitation amount and thus enable consistent assessments of dry and wet periods: positive values indicate above-average precipitation and negative values point to a shortage of precipitation. Further details: Standardized Precipitation Index User Guide (Russian).*
*** The Standardized Precipitation and Evapotranspiration Index is based on the SPI but includes temperature and thus characterises the influence of temperature on the course of drought by calculating the water balance.*

In addition to indicators describing changes in temperature and precipitation, the solutions include information on changes in the parameters linked to climate change effects on the marine environment (IPCC and C3S), growing season length (CCKP), yields of various crops and river water content (CIE) (Table 3).

ADDITIONAL CLIMATE INDICATORS *Table 3*

Unit	Indicator	IPCC	C3S	CCKP	CIE
%	Sea ice area	+	+		
m/s	Average wind speed	+	+		+
%	Cloudiness		+		
W/m^2	Downward shortwave radiation		+		
W/m^2	Downward longwave radiation		+		+
°C	Average sea surface temperature	+	+		
Pa	Average air pressure at mean sea level		+		+
m	Sea level rise	+			
pH	Surface pH	+			
days	Duration of growing season			+	
%	Average annual corn yield				+
%	Average annual rice yield				+
%	Average annual soybean yield				+
%	Average annual wheat yield				+
%	Annual maximum river flood depth				+
%	River runoff				+
%	Maximum daily river runoff				+
%	Minimum daily river runoff				+
%	Surface runoff				+

Scenarios and horizons

The IPCC Interactive Atlas and the Copernicus Interactive Climate Atlas enable analysis of future changes in climate variables from several perspectives (Table 4). Both include information on changes in climate variables according to SSP scenarios. These changes can be explored over several time horizons (short-term 2021–2040, medium-term 2041–2060 and or long-term 2081–2100) or depending on the level of global warming (an increase in the global average temperature of 1.5°C, 2°C, 3°C, or 4°C). Analysis is possible over different time horizons for future periods, as well as their comparisons with different base years.

Unlike them, the Climate Change Knowledge Portal (CCKP) does not enable analysis providing for changing global warming levels and different base years (the default base period is 1995–2014) (Table 4). However, it introduces another scenario, SSP1–1.9, assuming that greenhouse gas emissions are very low and carbon neutrality is achieved in 2050. This scenario is tougher than SSP1–2.6, which assumes that low greenhouse gas emissions and carbon neutrality are achieved around 2050. The CCKP also provides four rather than three time horizons (2020–2039, 2040–2059, 2060–2079 and 2080–2099).

The Climate Impact Explorer relies on a slightly different approach (Table 4). First, the CIE uses earlier RCP climate scenarios as well as NGFS scenarios and the Climate Action Tracker (CAT).[13] Second, its time horizons are 2030, 2050 and 2100. As for global warming levels, the CIE has no level of 4°C but a level of 2.5°C was added.

LIST OF SCENARIOS AND TIME HORIZONS *Table 4*

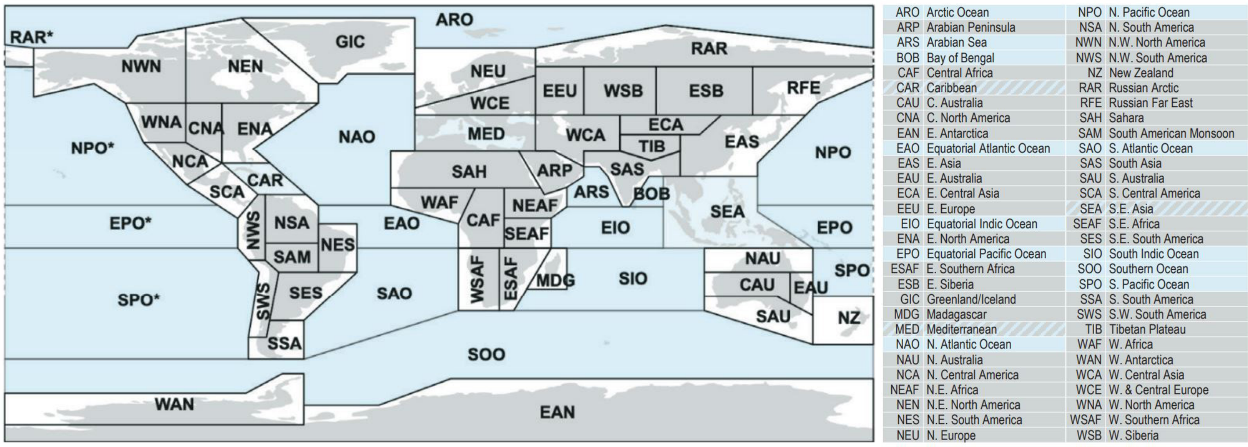
Atlas	Scenario	Time horizon	Global warming level	Base years
IPCC Interactive Atlas	SSP1-2.6 SSP2-4.5 SSP3-7.0 SSP5-8.5	2021–2040 2041–2060 2081–2100	1.5°C 2°C 3°C 4°C	1850–1900 1961–1990 1986–2005 1981–2010 1995–2014
Copernicus Interactive Climate Atlas	SSP1-2.6 SSP2-4.5 SSP3-7.0 SSP5-8.5	2021–2040 2041–2060 2081–2100	1.5°C 2°C 3°C 4°C	1850–1900 1961–1990 1986–2005 1981–2010 1995–2014 1991–2020
Climate Change Knowledge Portal	SSP1-1.9 SSP1-2.6 SSP2-4.5 SSP3-7.0 SSP5-8.5	2020–2039 2040–2059 2060–2079 2080–2099	-	1995–2014
Climate Impact Explorer	RCP2.6 RCP4.5 RCP6.0 RCP8.5 CAT Current Policies NGFS Current Policies NGFS Net-Zero 2050 NGFS Fragmented World NGFS Nationally Determined Contributions NGFS Below 2 Degree NGFS Low Demand NGFS Delayed Transition	2030 2050 2100	1.5°C 2°C 2.5°C 3°C	1986–2006

13 For further details of the Climate Action Tracker (CAT) and its methodology see: https://climateactiontracker.org/methodology/cat-rating-methodology/.

Scale

The IPCC Interactive Atlas features a breakdown into reference regions used by the IPCC Working Group I in its Sixth Assessment Report (IPCC WGI OD6) (Figure 1). Russia is divided into the following regions: Eastern Europe (EEU), West Siberia (WSB), East Siberia (ESB), Russian Far East (ESB) and Russian Arctic (RAR).

REFERENCE REGIONS USED BY IPCC WORKING GROUP I IN SIXTH ASSESSMENT REPORT *Figure 1*



Source: *IPCC. Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. 2021*.

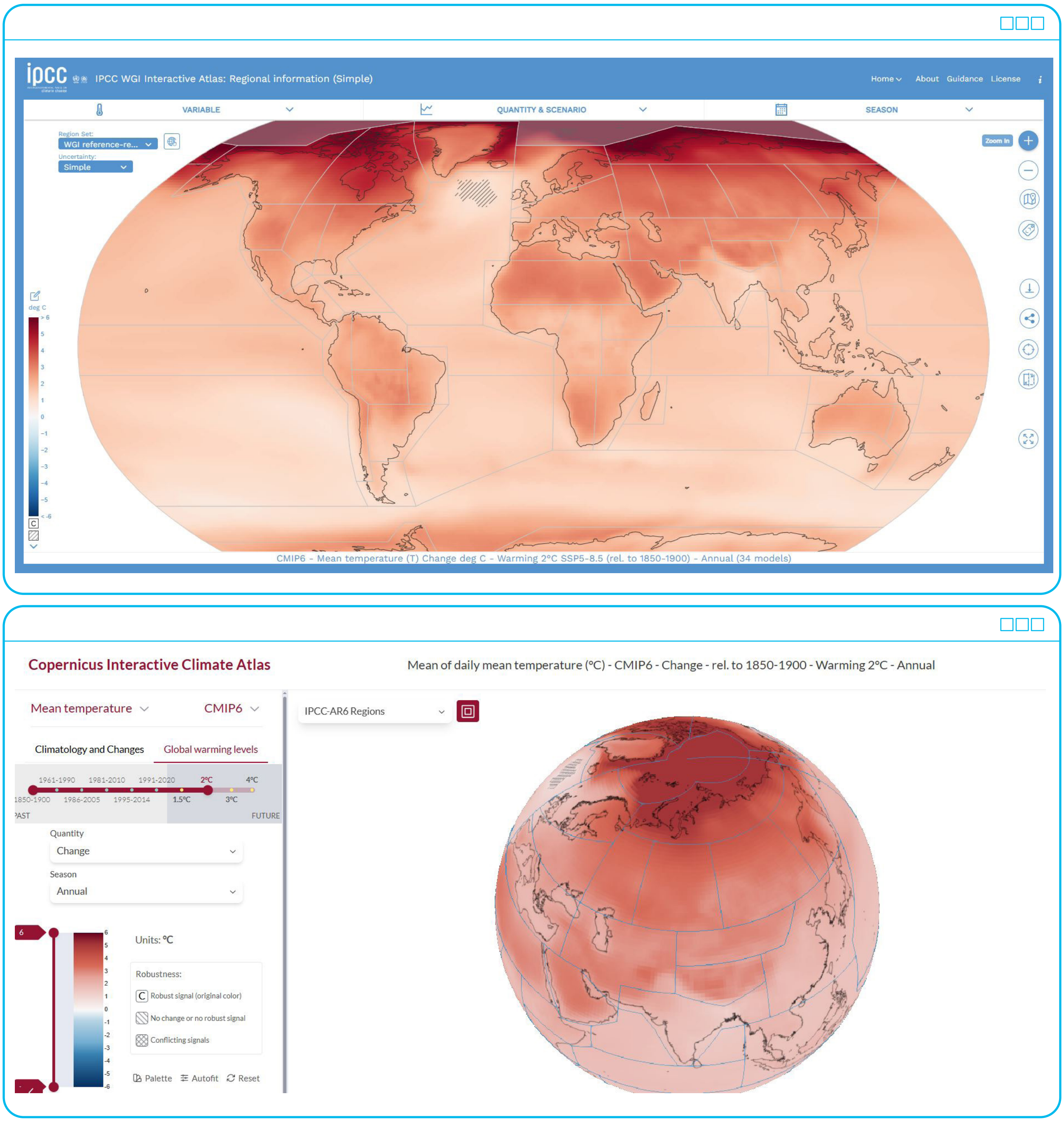
When selecting a region to study climate characteristics, the Copernicus Interactive Climate Atlas offers two options. The first is the built-in sets of regions, including 1) the WGI OD6 IPCC reference regions, 2) the regions used in the European Climate Risk Assessment, and 3) European countries, including those covered by the regional European data sets (E-OBS and CORDEX-EUR). The regional data displayed by the C3S Atlas for these regions are pre-calculated and can be displayed online. The second option is a user region. The tool plots a new region on the map. For each such user region, the C3S Atlas makes additional climatic calculations.

Unlike the IPCC Atlas and C3S, the World Bank's Climate Change Knowledge Portal and the Climate Impact Explorer have a change tracking feature for selected climate change indicators at the national and administrative unit levels (constituent entities of the federation in the case of Russia).

Visualisation formats

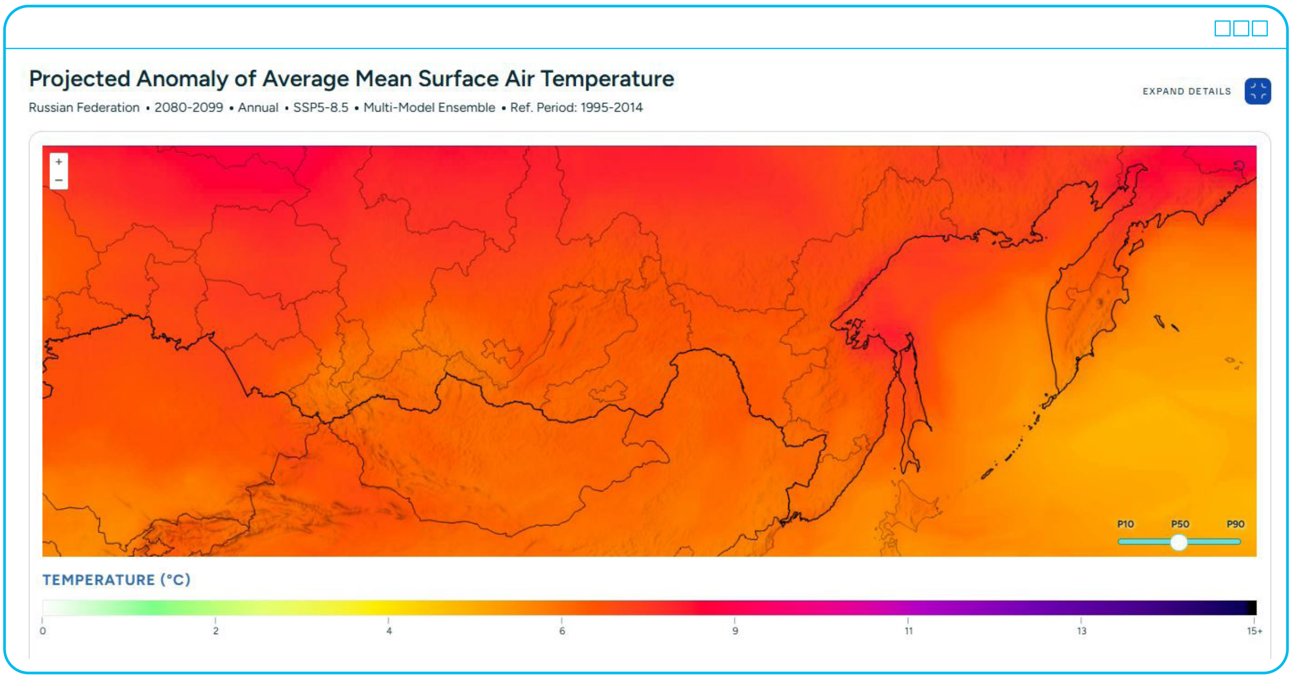
The IPCC Interactive Atlas and the Copernicus Interactive Climate Atlas (C3S Atlas) have the tools for visualising future changes in a specific climate indicator. The user sets variable, dataset, period and analysis parameters (scenario / global warming level, base period, annual / seasonal changes). For example, average daily temperature (°C) CMIP6 – 2°C warming – annual changes relative to 1850–1900 (Figure 2). The C3S Atlas has a spatial resolution from 2° to 0.05° depending on the selected data set.

SPATIAL PATTERNS OF PREDICTED CHANGES IN AVERAGE DAILY TEMPERATURE (GIVEN 2°C WARMING), VISUALISATION EXAMPLE *Figure 2*



Fewer settings are available in the World Bank's Climate Change Knowledge Portal (CCKP). Users select an indicator and then a period and a script to display indicator changes. For example, average daily temperature (°C) – 2080–2099 – annual changes – relative to 1995-2014 – SSP5-8.5 compared to (Figure3). CCKP maps have a resolution of 0.25° x 0.25° (25km x 25km). The CCKP also allows users to explore climate indicator changes in two formats: 1) average value (a 'new normal' assumed); 2) anomaly (change). Both formats can be useful to assess climate physical risk: the anomaly format allows change tracking, while the absolute value format helps identify the critical climate thresholds beyond which the likelihood of damage increases.

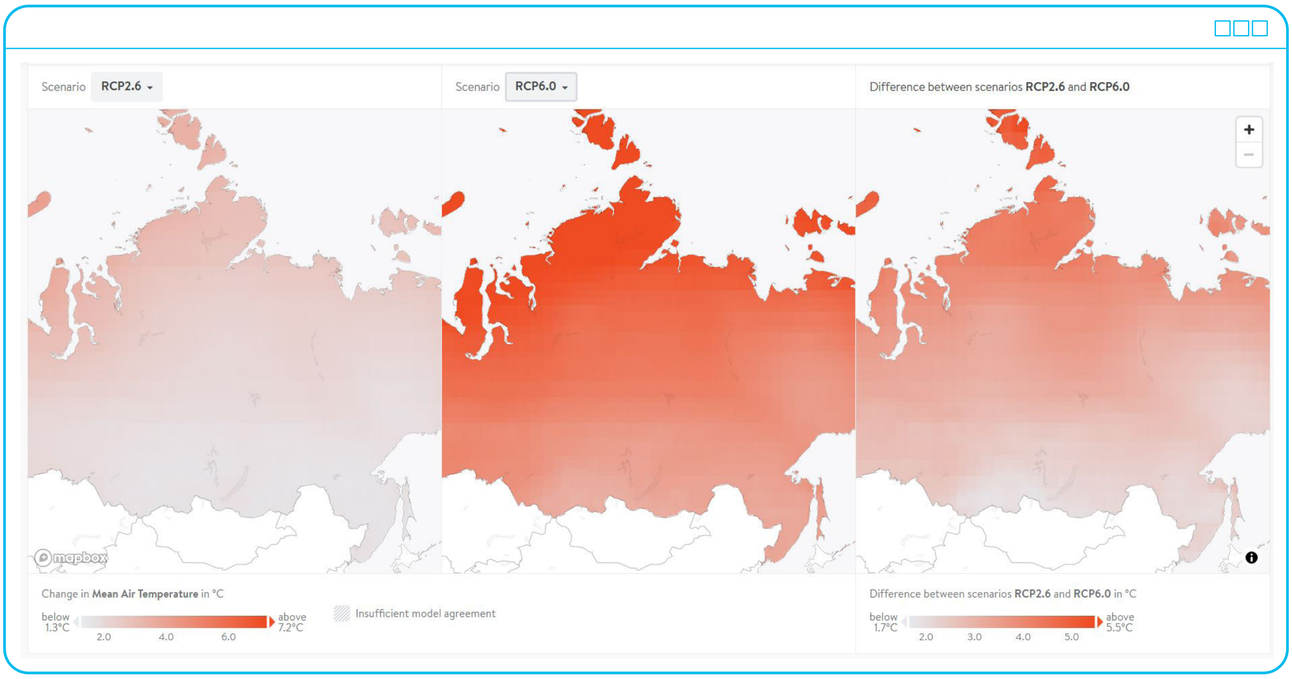
SPATIAL PATTERNS OF PREDICTED CHANGES IN AVERAGE DAILY TEMPERATURE (SCENARIO SSP5–8.5 IN 2080–2099) – CLIMATE CHANGE KNOWLEDGE PORTAL, VISUALISATION EXAMPLE *Figure 3*



The Climate Impact Explorer (CIE) allows comparing country maps in different scenarios, years, or global warming levels (Figure 4). The maps show predicted changes in the selected indicator relative to its base value calculated for the base period, with a resolution of 0.5° (about 50km in the equator).

In addition to maps, the atlas tools include graphs and tables for users to additionally explore climate indicators. Indicator changes are most often visualised through time series charts. Such charts show the annual values of a specific indicator over historical and future periods. The IPCC Interactive Atlas and the Copernicus Interactive Climate Atlas (C3S), values are shown for all model simulations making

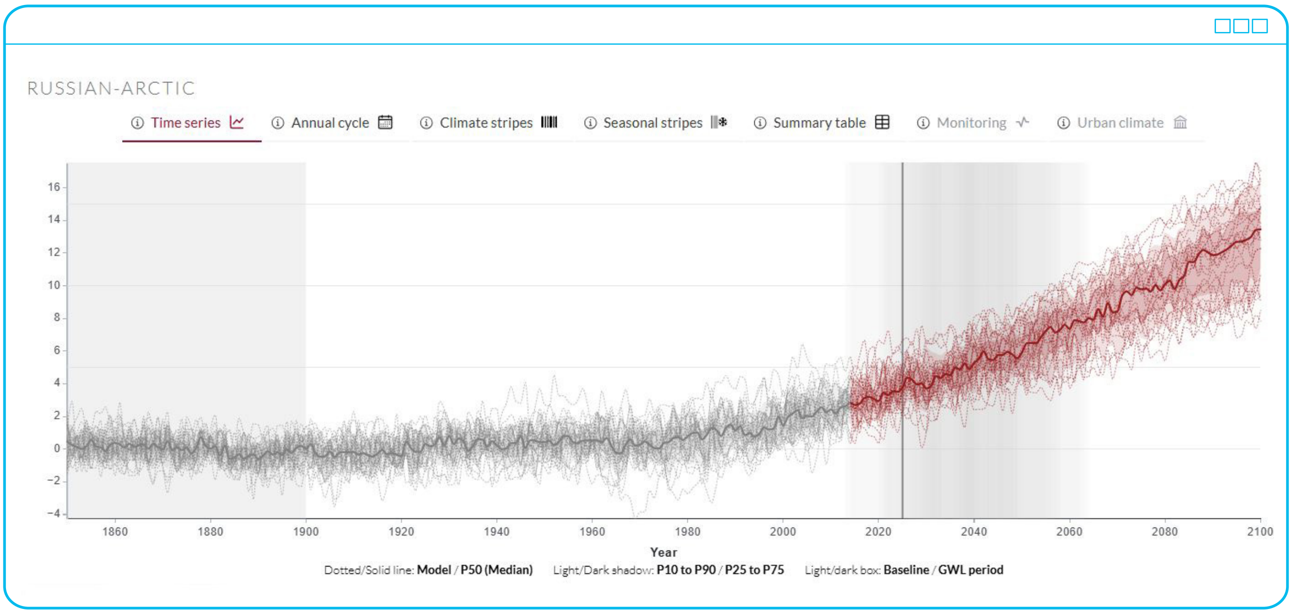
SPATIAL PATTERNS OF PREDICTED CHANGES IN AVERAGE DAILY TEMPERATURE (RCP2.6 AND RCP6.0 SCENARIOS) – CLIMATE IMPACT EXPLORER, VISUALISATION EXAMPLE *Figure 4*



up the ensemble and ensemble medians (Figure 5). Both atlases have the range of the 10th to 90th percentiles, the median (50th percentile), and the 25th to 75th percentiles.

TIME SERIES CHARTS FOR AVERAGE DAILY TEMPERATURE, EXAMPLE *Figure 5*

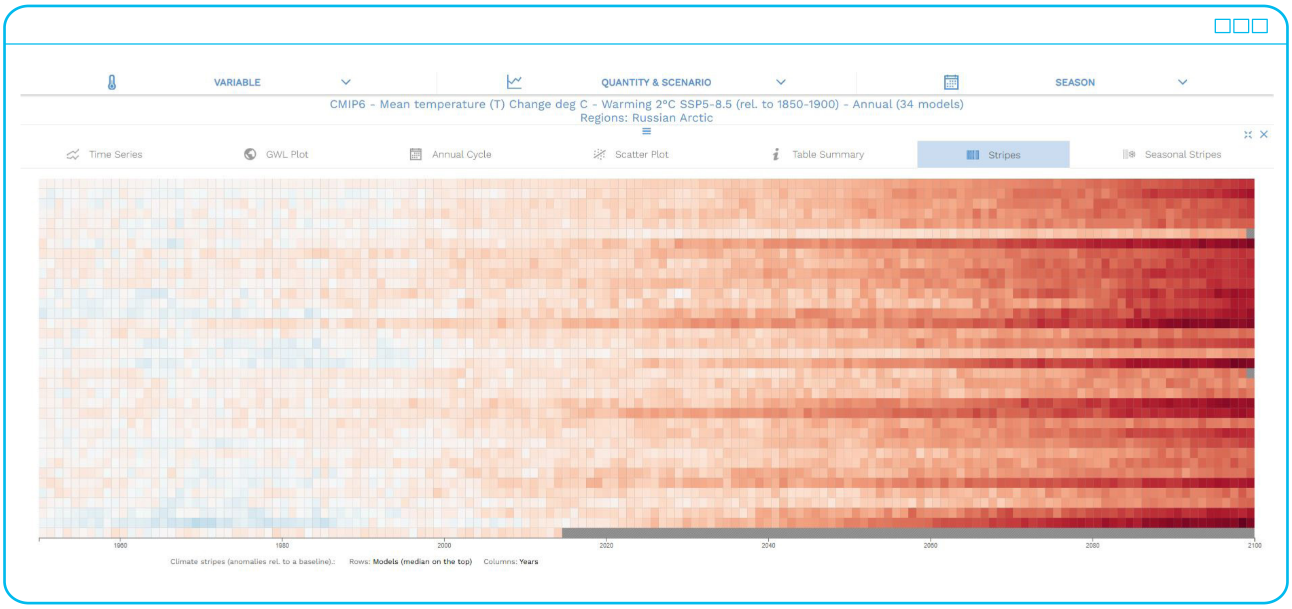
a) IPCC Interactive Atlas



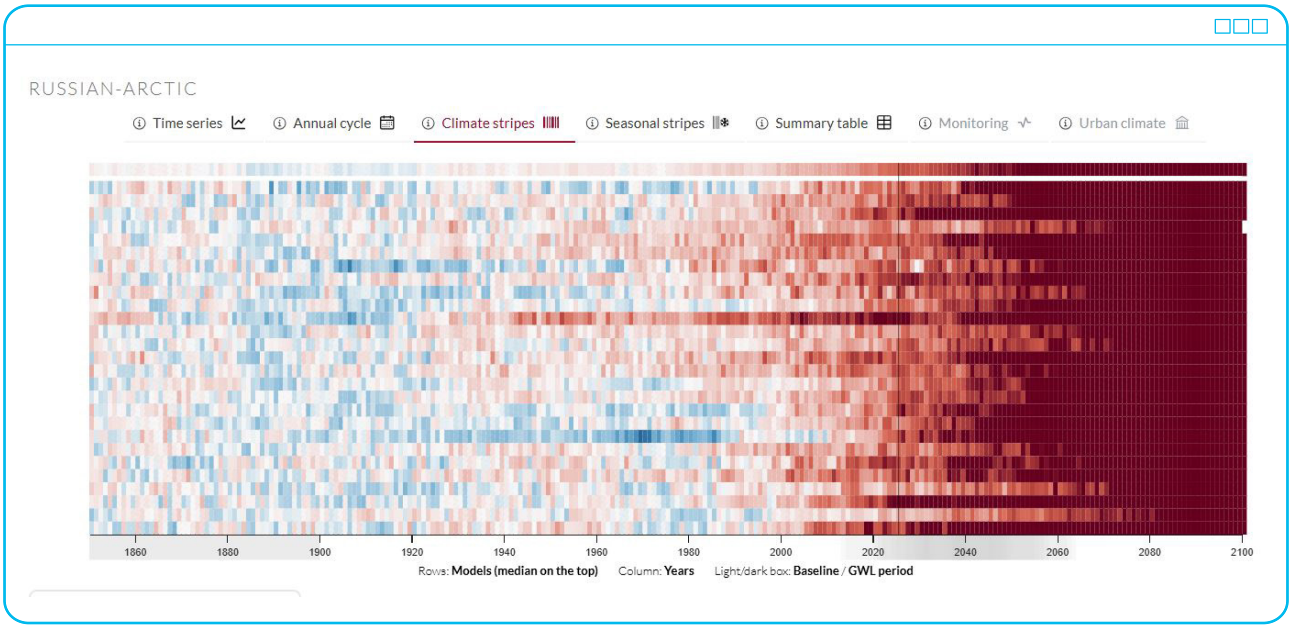
b) Copernicus Interactive Climate Atlas

More detailed visualisation is created by so-called *climate stripes plot* (Figure 6). The atlas graphs are sets of colour bars ordered chronologically. The stripes are divided vertically to represent each of the simulations/models (for climate projections) that make up an ensemble. A strip with a median along the ensemble is displayed above. The ranges of blue to red (for temperature) or brown to green (for precipitation) signal negative or positive changes (or minimum and maximum values).

CLIMATE STRIPES FOR AVERAGE DAILY TEMPERATURE, EXAMPLES *Figure 6*



a) IPCC Interactive Atlas

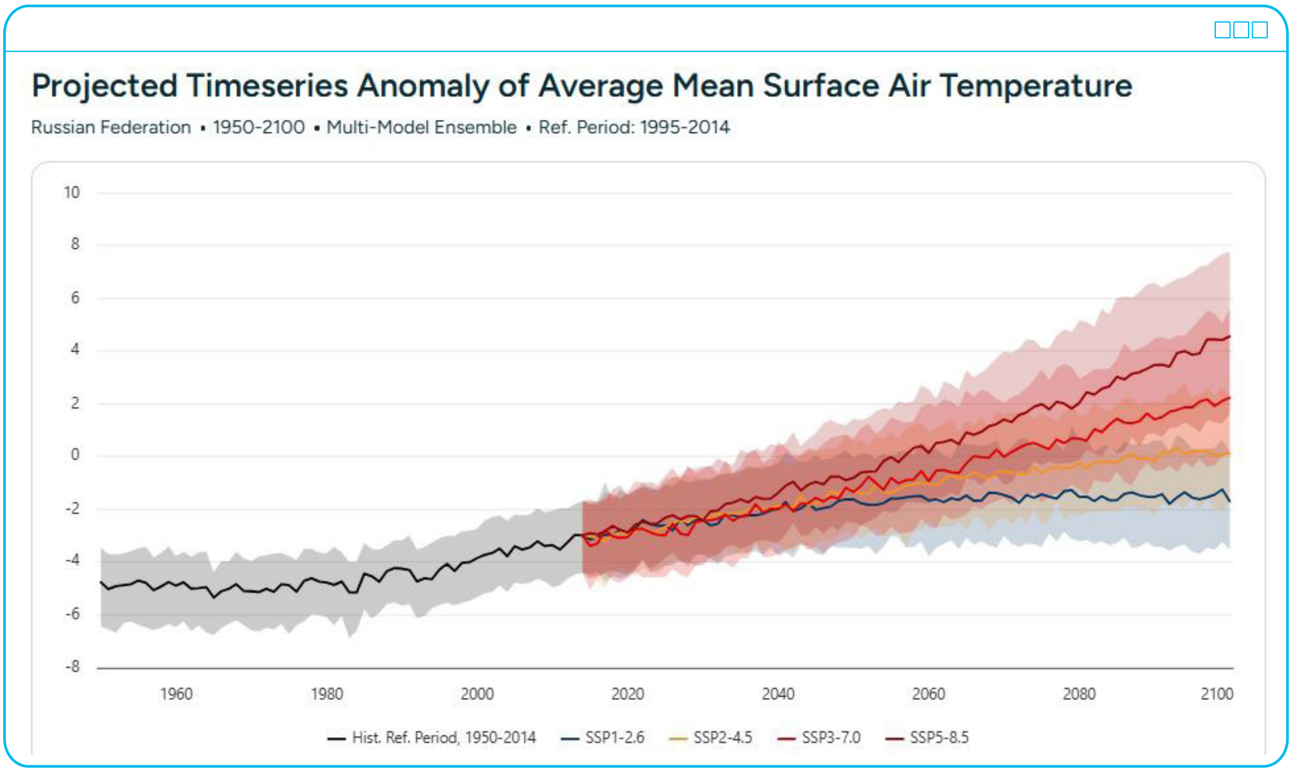


b) Copernicus Interactive Climate Atlas

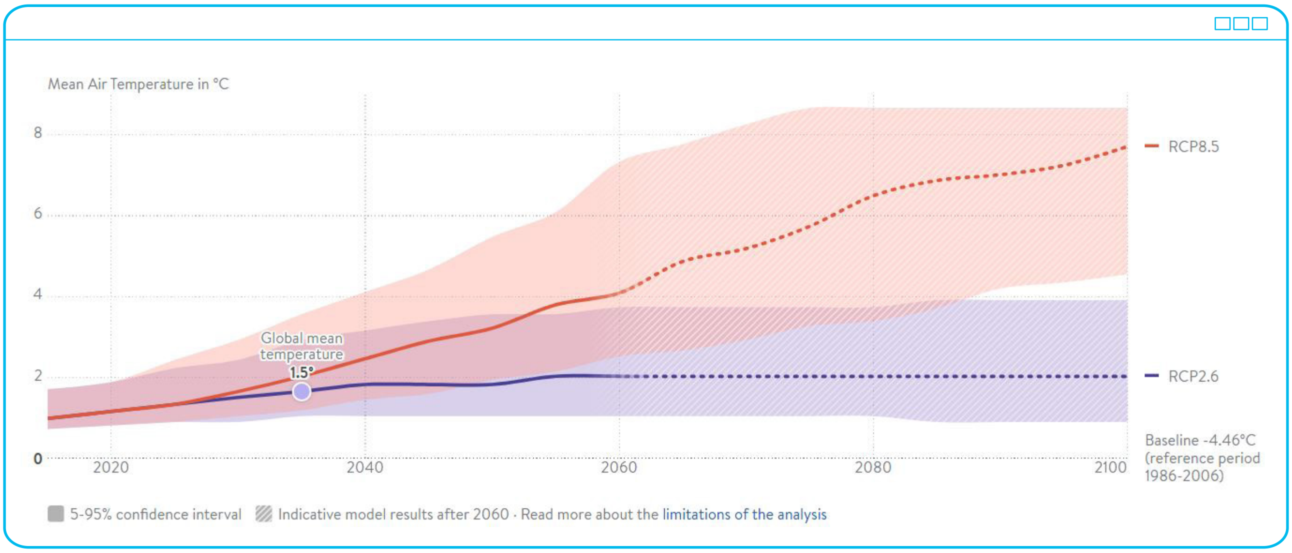
The CCKP's time series charts show changes in climate indicators in five SSP scenarios (SSP1-1.9, SSP1-2.6, SSP2-4.5, SSP3-7.0 and SSP5-8.5) (Figure 7a). The CCKP has a range of the 10th and 90th percentiles with a median (50th percentile). The Climate Impact Explorer (CIE) enables visualisation of climate indicators with a 5–95% confidence interval (Figure 7b). The purple dots on the median line show the global average temperature increase of 1.5°C, 2.0°C, 2.5°C, or 3.0°C above pre-industrial levels. The CIEA also has a comparison feature, for two different scenarios to be shown in the same chart.

The IPCC Atlas, C3S and the CCKP visualise annual changes in climate indicators similarly to time series charts. Seasonal charts, as well as time series charts in the IPCC Atlas and C3S, reflect past and future changes in selected indicators for all model simulations that make up an ensemble, as well

TIME SERIES CHARTS FOR AVERAGE DAILY TEMPERATURE, EXAMPLES *Figure 7*



a) Climate Change Knowledge Portal of the World Bank

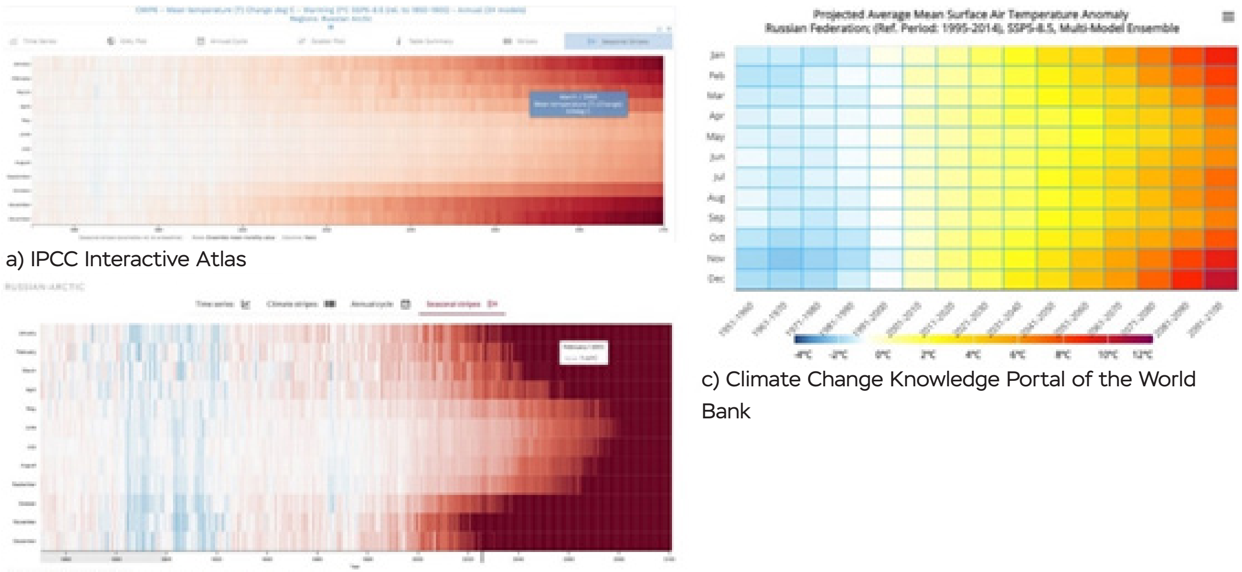


b) Climate impact explorer

as ensemble medians. The CCKP shows seasonal changes in climate indicators depending on a SSP scenario.

In the IPCC Atlas and C3S, these charts are supplemented *by seasonal stripes* (Figures 8a and 8b). *Unlike climate stripes* for seasonal charts, vertical modelling results are replaced by monthly values for the median of an multimodel data ensemble. A similar principle governs heat plots in the World Bank's CCKP (Figure 8c): it shows forecasts of anomalies with seasonal patterns over longer-term horizons.

EXAMPLES OF CHARTS OF SEASONAL CLIMATE STRIPES FOR AVERAGE DAILY TEMPERATURE *Figure 8*



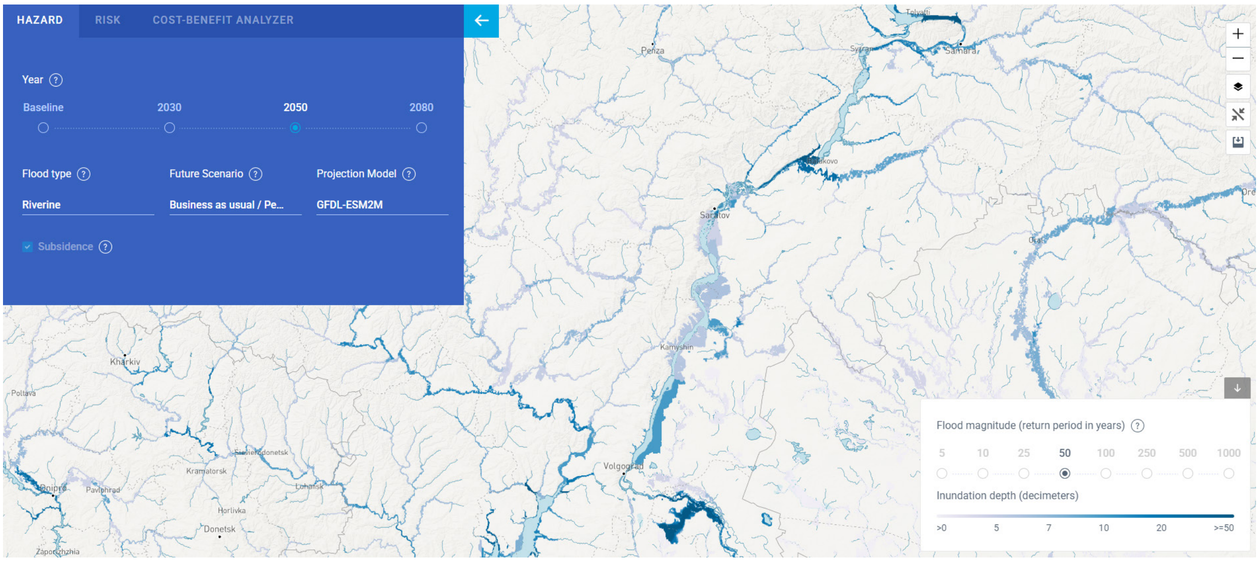
a) IPCC Interactive Atlas

b) Copernicus Interactive Climate Atlas

c) Climate Change Knowledge Portal of the World Bank

The source of data on coastal and river floods is Aqueduct Floods[14] calculations prepared by the World Resources Institute. This tool enables projections of the scale of floods (flood area and depth) in 2030, 2050 or 2080 using a pessimistic (SSP5–8.5) or optimistic (SSP2–4.5) (Figure 9) scenario.

SIMULATED FLOOD ON THE VOLGA RIVER IN 2050 UNDER PESSIMISTIC (SSP5–8.5) SCENARIO *Figure 9*



[14] https://www.wri.org/applications/aqueduct/floods/.

Additional analytical tools

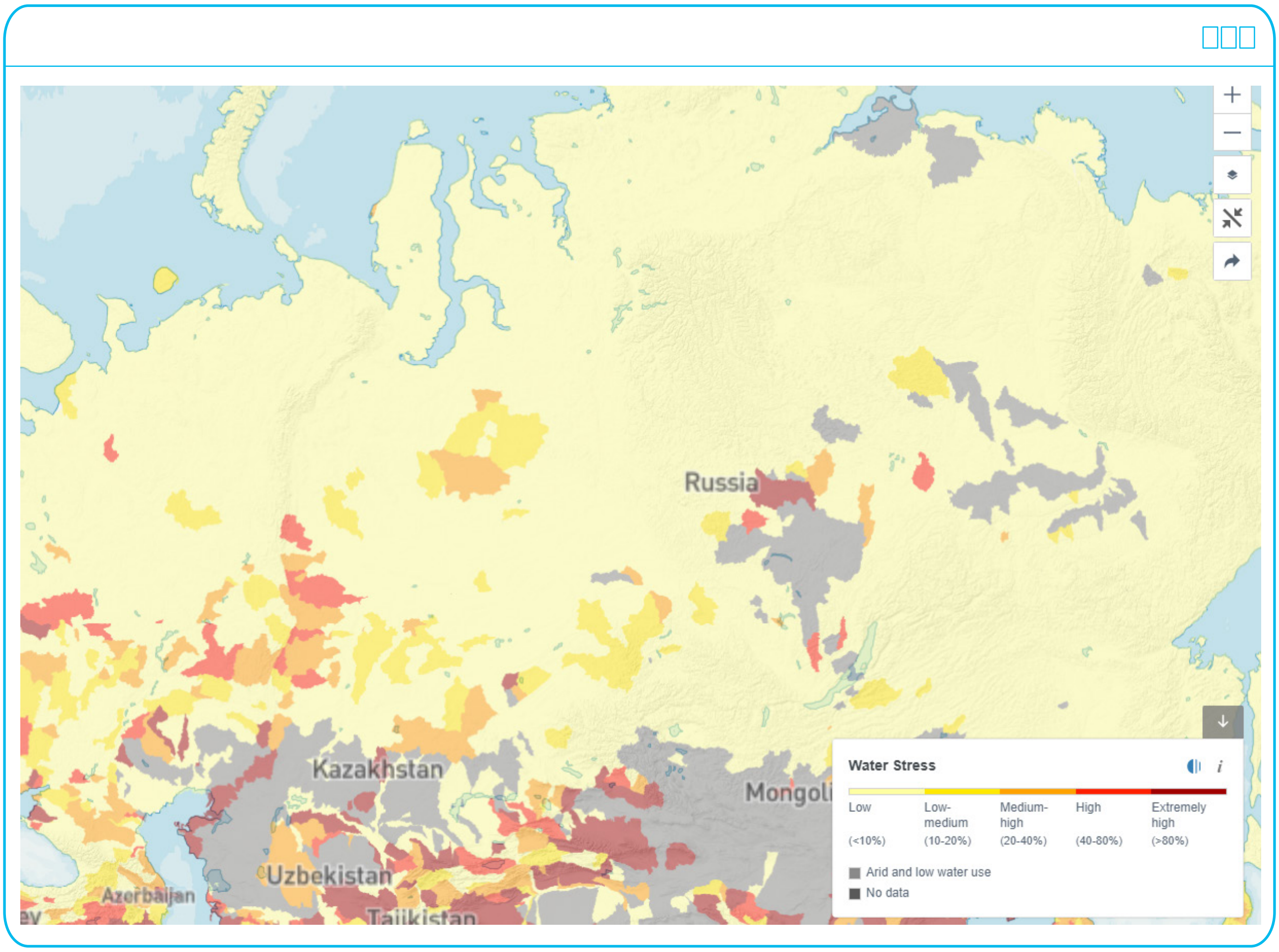
Among publicly available tools for analysing climate physical risks are the Aqueduct Water Risk Atlas and World Bank Compound Heat Risk.

The Aqueduct Water Risk Atlas [15] allows users to determine the level of risk based on several indicators: water stress,[16] seasonal and annual changes in water availability, water demand and water depletion. Each of the indicators can be analysed over several horizons (2030, 2050, or 2080) under one of three scenarios: pessimistic (SSP5–8.5), business as usual (SSP3–7.0) or optimistic (SSP1–2.6) (Figure 10). In addition, Aqueduct Flows includes an assessment of damage from river and coastal floods ('% Annual Expected Affected GDP') at the national level (Table 5).

ESTIMATE FOR RIVER FLOOD DAMAGE IN RUSSIA IN AQUEDUCT FLOODS (EXAMPLE) *Table 5*

	2010	2030	2050	2080
Annual Expected Affected GDP, billion USD	3.6	8.1	12	26
Total GDP, trillion USD	2.0	4.0	5.7	8.0
% Annual Expected Affected GDP	0.180	0.204	0.218	0.319
Estimated Flood Prefection Level	43	44	43	27

WATER STRESS – AQUEDUCT WATER RISK ATLAS, VISUALISATION EXAMPLE *Figure 10*



[15] https://www.wri.org/applications/aqueduct/water-risk-atlas.

[16] The water stress level shows the ratio of the total demand for water (including for household, industrial, irrigation and agricultural needs) to the available renewable reserves of surface and ground water. The higher the water stress measure, the higher competition for water resources among users.

The World Bank Compound Heat Risk solution provides a qualitative assessment of heat and humidity impacts on the population. The level of heat risk is a combination of temperature, humidity, population density and the level of poverty (Figure 11). Climate conditions consist of maximum daytime temperatures, minimum nighttime temperatures and a combined heat index. Heat risk is calculated for the same scenarios and time horizons as in the World Bank's Climate Change Knowledge Portal (see Subsection 1 of this Appendix).

HEAT RISK FOR RUSSIA OVER THE 2080–2099 HORIZON IF SSP5–8.5 SCENARIO REALISES *Figure 11*