Using information and computing system “Climate” to raise awareness among the population and decision makers about regional effects of climate change

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Abstract. The effects of global climate change will be most dramatic in the vast Russian territory. According to the Hydrometeorological Center of Russia, there is an increase in the magnitude and frequency of extreme weather events, as well as in their damage to the ecosystems and infrastructure. To develop adaptation to climate change and mitigation of its consequences, it is necessary to promote and support activities aimed at reducing possible risks. However, there is insufficient awareness and lack of scientific background among decision-makers. Persons responsible for making decisions, stakeholders, and the general public do not often have skills and knowledge to work with climate data to elaborate an adaptation and sustainable development strategy. Some new sections of a web-system, “Climate”, are tailored to provide these groups with tools, skills, and thematic information for understanding climate processes occurring in their region. A course is developed where basic concepts are explained in detail for the general public. A climate characteristics database for decision-makers is created to obtain calculated fields of the indices describing spatial distributions of extreme values of meteorological characteristics for the territory of Siberia. For work with any of the indices, it is possible to download the database in various formats for use in various desktop GIS systems.

1. Introduction

Observations and simulation results indicate that Earth’s climate is changing [1], and Russia belongs to Earth’s regions with the maximum observed and anticipated climate change due to the size of its territory and the fact that a large part of it is located in the high and polar latitudes. A long-term rise in the average temperature of the Earth's climate system continues, and according to authoritative climatic centers (Center Hadley; NOAA), for the whole globe 2018 was the fourth among the warmest for the entire period of instrumental observations from the second half of the 19th century. The global average annual temperature (together for land and ocean) exceeded the average for 1961-90 by 0.662 °C according to NOAA [2]. In the territory of the Russian Federation, in general, the warming continues throughout the year and in all seasons, and its pace is much higher than the average over the globe. The average growth rate of the average annual air temperature in Russia in 1976-2018 was 0.47 °C / 10 years. This is 2.5 times the growth rate of the global temperature over the same period: 0.17-0.18 °C / 10 years, and more than 1.5 times the average warming rate of the surface air over the Earth’s land: 0.28-0.29 °C / 10 years. The temperature of the northern polar region grew most rapidly, especially in the last three decades: at some meteorological stations on Russia’s coastline of the Arctic Ocean the growth rate of the average annual temperature in this period exceeded 1.0 °C / 10 years.
Currently, global climate change has led to an increase in the frequency of dangerous
d hydr o meteorological phenomena in Russia, such as floods, heavy snowfalls, and blizzards,
accompanied by storm and even hurricane winds, severe long frost, ice, and late spring frost. During
the warm period, torrential rains with thunderstorms, hail and wind or severe droughts are frequent.
The number and strength of extreme climatic manifestations are increasing every year. For example, in
many regions of Russia at the beginning of the 21st century, the frequency of catastrophic floods
increased by 15% compared with the last decade of the 20th century. The report of the World
Economic Forum on global risks in 2018 (http://reports.weforum.org/global-risks-2018/) includes
risks associated with the climatic factor in the top ten. The increase in the magnitude and frequency of
occurrence of extreme climatic phenomena has already damaged ecosystems and infrastructure.
According to the latest data from Hydrometeorological Center of Russia, 2018 was the third in the last
23 years in the number of dangerous hydrometeorological phenomena that caused significant damage
to natural resources, human health and livelihoods: 465 cases are reported (the maximum was in 2012
- 469) [3].

Considering all these facts, assessment of environmental, economic, political, and social impacts of
global climate change on a particular region, as well as the development of measures to adapt to these
changes and reduce their negative impact are needed.

2. Approach
According to the IPCC, future vulnerability depends not only on climate change but also on the
development pathway. Sustainable development is believed to contribute to reducing vulnerability to
climate change impacts. To succeed, adaptation must be integrated into sustainable development plans
at both national and international levels. To develop an effective adaptation strategy, it is necessary,
first of all, to develop educational programs, improve practical training, and increase public awareness
of this problem. The system of adaptation to climate change should include various administrative
levels from federal to local, taking into account regional natural and socio-economic features. This
requires cooperation and coordination of actions between different administrative levels, as well as the
maximum involvement of all stakeholders in defining the strategy for adaptation to climate change.

In Russia, the Climate Doctrine (http://www.meteoinfo.ru/climatedoctrine) was adopted in 2009 as
a response to observed and anticipated climate change and its manifestations on different scales. It sets
up the main areas of climate policy realization. Among them there is the development of a regulatory
framework and the organization of state regulation; the development of economic mechanisms related
to the implementation of measures to adapt and mitigate anthropogenic impacts on climate; scientific,
informational, and personnel support of the development and implementation of these measures.
Possible future climate changes affect the areas of responsibility of almost all federal government
bodies. The doctrine defines tasks of the federal government in the development and implementation
of climate policy, such as the inclusion of measures to adapt and mitigate the anthropogenic impact on
climate in the medium and long term plans for the socio-economic development of the Russian
Federation and the creation of mechanisms to ensure a continuous constructive dialogue between the
scientific community, the public authorities responsible for decision-making, the public and the
business community. According to the Climate Doctrine of the Russian Federation, a prerequisite for
successful climate policy is the application of research results to assess the risks and benefits
associated with the effects of climate change, as well as the ability to adapt to these effects.
Implementing this policy requires the training of future specialists who will develop and apply
adaptation measures. Currently, decision-makers, stakeholders, and the population, on whom the
development of adequate measures to adapt and reduce the negative effects of climate change
depends, do not have the skills and knowledge to work with the accumulated climate data necessary
for analysis and development of an appropriate strategy. These groups need comprehensive
scientifically-based information about the current and expected climate changes in their region of
residence, which will prepare the public for the expected consequences and will encourage managers
to find ways to adapt to them.
Currently, there is a serious lack of resources informing the stakeholders about current and expected climate changes and their consequences in Russia. Therefore, to meet the goals of the Climate Doctrine of the Russian Federation we have tried to fill this gap by developing new blocks of the previously developed web-GIS “Climate” and use it to provide climate information to assist decision-making and raise awareness of the society.

3. Method

3.1. Information-computational Web-GIS "Climate"
The information-computational Web-GIS "Climate" [4](http://climate.scert.ru/) is aimed at monitoring and analysis of ongoing and future regional climate changes. It gives online access to climate and weather models, a large set of geophysical data, and visualization tools. It is used to develop applications by distributed research teams and for research based on these applications, as well as to organize training of students and graduate students. “Climate” provides processing and analysis of sets of geo-referenced climatic and meteorological data to study climatic and environmental changes. It provides access to four categories of users: researchers, students, common public, and decision-makers (see Figure 1).

![Figure 1. “Climate” start page.](image)

A user-scientist has full access to tools for supporting the modeling and monitoring of regional climate change based on spatial data services. With the help of the graphical interface and using the GIS functionality, the user can get the results of the processing and analysis in the form of layers on a map for a selected region. The user has access to basic, pre-prepared layers, and can select the geographical area and add new layers, process geophysical data archives available in the system. To analyze the obtained results one can use zooming in and out, get the values from all layers at a point, and make additional processing of previously obtained data (for example, compare data from different layers). Along with direct studies of geophysical data, the user is allowed to perform joint research with other users, share results, and process their own data sets. “Climate” has a forum for users’ communication, information exchange, and joint research. To get access to all tools for calculations and analysis, registration on the “Climate” site is required.

The web-GIS “Climate” is also used as a virtual learning laboratory providing undergraduate and graduate students with a profound understanding of changes in regional climate and environment. The educational section containing educational materials and interactive training courses allows them to receive first-hand knowledge in environmental sciences. This scientific field is experiencing a period of rapid development of the technologies of measurement and simulation, accompanied by an expansion of the conceptual and mathematical apparatus. Thus, the knowledge in the discipline grows quickly, and requires new tools and approaches to make it available for future specialists in environmental sciences. Large databases of observations and modeling results are created, and students should be trained to operate them and use computational models as tools for climate and
weather forecast. The existing training programs in the disciplines of environmental sciences, as a rule, do not have time to adapt to such rapid change in the domain content. As a result, faculty graduates have a superficial knowledge of mathematical modeling of processes in the environment, do not have the required skills in modeling, data processing, and analysis of observations and modeling, and do not know how to work with big environmental data archives. The absence of this knowledge and skills necessary in modern climate science leads to the fact that the graduates are insufficiently prepared to act in the modern environmental sciences, where research requires high competence in the possession of modern information-computational tools and the ability to work in a distributed team. To reduce the effects of this lag, a special course was designed enhancing students’ skills in work with modern information and computing systems [5].

An educational course on "Climate Change Monitoring and Prediction" is included in the curriculum for students of the Faculty of Geology and Geography of Tomsk State University. It covers the issues of quantitative geography of climate, a theoretical framework and tools for climate monitoring and forecast. The course contains a set of lectures devoted to basic aspects of modern climatology, including analysis of current climate change and its possible impacts, computing training with specific tasks on simulation of climate and climate change, and an information kit. The “Future Climate Analysis” training is designed to study climatic projections possible under different future scenarios, as well as the interaction of the individual components of the climate system, and statistical methods to assess the impact of global climate change on some of the parameters of the climate system. Basic skills of mathematical modeling and analysis of climate change are trained while performing the tasks. The “Climate Extremes Analysis” training describes an approach to calculating indexes of extreme values, which allow determining various characteristics of extreme climate events, such as frequency, duration, and intensity. The task is to analyze various indices and characteristics of the meteorological quantities. To carry out calculations of the indices, a series of measurements of the meteorological quantities obtained as a result of instrumental observations and as a result of global and regional climate models is used. The training also introduces a library, which contains calculated fields describing the spatial distribution of these indices for the territory of Siberia (50-65 ° N, 60-120 ° E). Calculations of climatic characteristics and statistical assessments in both parts of training are provided by the web-based GIS “Climate” tools. The course proved to be an effective way to familiarize the students with the actual situation in climate science and promote the use of modern information and communication tools.

3.2. Course for the public

Public awareness and understanding of ongoing climate change and its impacts are important steps to an effective response to this process. Implementation of a federal climate policy also means raising public awareness of the current and expected regional effects of climate change. According to a plausible scenario, changes in hydrological regime, quantity and quality of water resources, and temperature regimes will cause changes in ecological systems, agriculture, and forestry (shift of climatic zones in the northern direction and migration of wild fauna species, changes in the seasonality of growth and productivity of land in agriculture and forestry). In Siberia, the boundaries of permafrost are also shifting, which affects not only agriculture, but also the infrastructure and the fuel and energy sector. Since these changes occur gradually, it is possible to organize measures to adapt to the changing conditions and minimize their negative impacts. To reduce possible climatic risks, such measures as economical use of scarce water resources, flood control, selection of drought-resistant crops, and farming methods less vulnerable to heatwaves should be promoted among the population. Implementation of these measures requires the collaboration of scientists, decision-makers, and the public, and attempts of cooperation of these groups revealed some problems.

It became obvious that the perception by the public of climate change issues and possible risks differs from that common in climate science. Though the evidence of climate change is undeniable, a part of the public mistrusts official information. Climate change skeptics have used uncertainty in climate projections to persuade the population that climate change issues are overrated. Besides,
studies show that there are several reasons for the denial or disregard of climate change. It could be due to economical reasons. In difficult times people seem to reject science [6]. Another reason for ignoring the problems associated with climate change is the fact that in some regions they are not so brightly drawn. Therefore, there is a feeling that these problems do not concern the population of this region. Often the public believes that the effects of climate change cannot occur in the near future. Last but not least, there is a lack of reliable information on climate change and its anticipated effects. The resources available in the Internet usually use scientific vocabulary, which obscures the meaning for the average user - not a specialist. In the Russian Federation’s internet segment, this problem is aggravated by the fact that there are generally very few of these sites, and the existing ones are often not updated with new scientifically-reliable information confirming the ongoing climate change.

As far as the public awareness and understanding are important components of an effective response to climate change, the scientific community should translate climate change knowledge derived from research. It may be of little value unless it is put into practice. Thus, special internet resources are developed to promote this knowledge to the public. A serious lack of such resources in Russian forced us to add a special section to the “Climate” system. This section is designed to raise the public awareness of climate change and promote an understanding of the current processes. Such awareness is a necessary basis for the deployment of climate change adaptation processes on a regional scale. In general, the popularization of knowledge about climate change and the explanation of climate change trends and possible ways of adaptation to them stimulate active participation of the society in environmental protection. A basic course on climate and its ongoing processes is developed, aimed at improving the regional climate literacy of the population and stakeholders. While preparing this course, the features of the public perception of information about climate change were taken into account. It explains, in particular, the difference between weather and climate, climatic processes and factors, global climate change and its manifestations on different scales, extreme climatic events and climate risks. The course outlines and illustrates the main concepts and problems of modern climate change and its possible consequences. All materials are set out in a language accessible to non-specialists (see Figure 2). The course also includes links to popular science Internet resources on topical issues of Earth sciences. The aim is to increase the public understanding of climate risks, build resilience, and adapt to the impacts of climate change.

Figure 2. Pages of the course for the public.

3.3. Database for decision-makers
Climate change issues are in the spotlight now, and governments at different levels begin to develop adaptation strategies to respond effectively to current climate changes and future trends. Taking into account the ongoing and anticipated climate changes allows the authorities to reduce possible economic and social risks. At present, many adaptation projects have already been implemented over
the world. For example, following the forecast of future climate change, the designers took into account the sea level rise when planning such a vital element of the infrastructure as the Confederation Bridge in Canada. It was opened on May 31, 1997, and links Prince Edward Island with the Canada mainland. The 12.9-kilometer bridge is the world's longest bridge over ice-covered water. The planners used climate scenarios to determine an appropriate height to account for a one-meter rise in the sea level and appropriate spacing between the support beams to allow for ice blocks that float down the Northumberland Strait to pass safely underneath [7]. There are also special adaptation projects on managing the coastal zone in the United States and the Netherlands. The Dutch coastal zone is extremely vulnerable to climate change and, thus, coastal management is an integral part of a national sustainable development planning [8]. Thus, adaptation decision-making requires climate knowledge and information for actions to reduce anticipated risks.

Making climate information useful to decision-makers usually requires that data and knowledge be processed and integrated through tools that range from simple graphs and maps to complex environmental models [9]. The necessity of risk identification and management revealed that decision-makers often do not have proper skills for the direct use of modern information and computing tools. Even experienced users of climate data may have difficulties choosing reanalysis or observational data sets to assess vulnerability and plan sustainable development at a regional level. Based on the experience of working with specialists from environmental organizations of the regional level, it can be concluded that only a few of them will be able to immediately use files in the netCDF format that is standard for modern quantitative climatology. Joint activities revealed that a simple way to present climate information to decision-makers is through the use of GIS.

To meet the needs of regional decision-makers and to encourage them to analyze ongoing and projected changes and develop an adaptation strategy, we propose a specially tailored information kit. It includes a glossary of climate terms, information on current climate change and future climate projections, and a database of climate characteristics including extremes, since they are supposed to cause most economic losses. Indeed, it is expected that under the influence of global warming some regions of Russia will suffer from extremely high temperatures and droughts in summer. This will affect crop yields and the state of forestry. In the north, permafrost thawing will accelerate and floods will intensify. Thus, regional decision-makers should review strategies for the development of transport infrastructure and construction projects, as well as the policy and planning of electricity supply. Accurate knowledge of the geography of extreme climatic phenomena, their frequency and intensity is needed to develop an effective adaptation strategy and measures to reduce the negative effects of extreme climatic manifestations. Since the frequency of such events is small, it is necessary to analyze such phenomena using modern approaches of the probabilistic statistical apparatus and detailed initial meteorological information accumulated during the period of instrumental observations for the territory of the region being studied. Therefore, to provide the regional decision-makers with the information necessary for the target activity, sets of relevant climatic characteristics for the Siberian region were calculated and structured as a free-access database.

The database contains calculated fields of climatic indices (http://etccdi.pacificclimate.org/index.shtml) describing the spatial distribution of extreme values of meteorological characteristics for the territory of Siberia (50-65 ° N, 60-120 ° E). These indices can be calculated both for one period (month/year) and for the whole period chosen. The indices are calculated for a period characterized by the most significant climatic changes. For different sets of source data, the start and end dates may not coincide, but the total time interval is almost the same. Also, a linear trend was calculated for each index, which shows 10-year period changes in the index over a specified time interval (see Figure 3).
If there is need for further work with any index, it is possible to download files with calculated indices in various formats (netCDF, GeoTiff, WMS, and WFS links). Special attention in the preparation of the database was given to the presentation of climate information in formats (GeoTiff files, as well as with WMS, and WFS) that can be used later in the widely used GIS (see Figure 4). The most popular and easy to work with netCDF files is Panoply developed by the NASA Goddard Institute for Space Studies. NCL (NCAR Command Language) is more specialized and has extensive tools for analyzing and visualizing netCDF files.

Figure 3. Database page.

Figure 4. An example of adding the result of calculating the average air temperature as a new raster layer to QuantumGIS.
4. Conclusions
The above new sections of the system “Climate” are operating in a test mode now. They are being specially tailored to meet the needs of the general public and other regional stakeholders. Although there are a lot of Internet resources providing them with climate information, our experience shows that this information should be translated to educate and inform the population about possible climate changes and their anticipated effects. Decision-makers are also in need of scientifically-based information about the current and expected climate changes in the region of residence presented in a convenient format and with an easy tool to operate it [10]. The new sections developed for the public and decision-makers can give both targeted groups reliable information on climate issues in Russian. This is an important step to promote climate issues for the Russian-speaking community. To develop climate change awareness and mobilize these groups to find ways to adapt to the anticipated climate risks and build resilience to it, close attention is paid to the regional aspects of global climate change. This activity is in line with the Climate Doctrine of the Russian Federation. It underpins the initiatives of decision-makers and other stakeholders in different sectors of the national economy, business, and science to develop measures to adapt to climate change and mitigate its possible negative effects by implementing a unified federal climate policy.

Acknowledgments
The study was supported by basic research project AAAA-A17-117013050037-0.

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