Development of a Web Service for Analysis of the GeoGIPSAR Geoclimatic Data

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***Abstract* — The paper discusses the creation of a Web service for the information prognostic system GeoGIPSAR developed at the Melentiev Energy Systems Institute of Siberian Branch of the Russian Academy of Sciences (MESI SB RAS). It relies on the data from modern global climate models (such as NOAA, GPCC, etc.) to predict inflow in the reservoirs of the Angara-Yenisei hydropower plant cascade. The disadvantages of the GeoGIPSAR are its limited interface (mostly understandable only to specialists) and local mode, which does not involve working on the Internet. The Web service at issue is being currently developed to expand a range of the system users. A review of modern systems for working with global climate models is presented. The main GeoGIPSAR functions and data used for the analysis of geoclimatic indicators are considered. The requirements for the basic controls of the developed Web service are considered. The development technologies applied are described. The climate maps created by the system for the Lake Baikal basin are shown as examples.**

***Index Terms*: forecasting, geoclimatic data, monitoring, web service.**

I. Overview of Web Systems for Geoclimatic Data Analysis

Over the past decades, there have been significant advances in climate monitoring and forecasting. However, there are no reliable universal methods for their application in practice, for example, in the energy sector. Global climate change has significantly affected many regional processes that influence the efficiency of energy systems: changes in statistical data of inflows, temperatures, precipitation, etc. The long-term planning of electricity generation at hydropower plants and energy balances usually relies on the runoff rate estimates based on accumulated statistical data. The extreme or prolonged low-water and high-water periods complicate such estimation, which requires new approaches.

MESI SB RAS has developed and is improving an approach to creating reliable predictive estimates of water content in reservoirs and modeling of future HPP regimes based on them [1–3]. The information prognostic system GeoGIPSAR [4, 5] makes it possible to carry out a comprehensive spatial and time analysis of meteorological and hydrological data with creation of prognostic scenarios of water content in the reservoirs of the Angara-Yenisei cascade [6, 7]. The disadvantage of the system is its limited interface (more understandable only to specialists) and local mode, which does not involve working on the Internet.

Modern technologies for global monitoring and forecasting of the state of the climate, together with the emerging open Geographic Information Systems (GIS), provide a new level of natural and climatic data analysis. Examples of well-known and convenient services that ensure access to work with geoclimatic data, including high-quality visualization, are as follows:

Ventusky [8] is an example of a modern system for monitoring and forecasting global meteorological indicators and weather changes over time throughout the globe and at individual locations. It was created by the Czech company InMeteo, which specializes in meteorology and visualization of weather indicators collected from various satellites and weather towers. Initially, the specialists focused on the weather in the Czech Republic alone, but later launched a worldwide project. Ventusky maps allow the user to visualize the interrelation between weather conditions in different parts of the world through dynamic illustrations. The service also contains a separate application that includes a classic weather forecast for a specific location. The uniqueness of the application lies in the large amount of data displayed: precipitation forecast, wind speed, cloudiness, atmospheric pressure, snow cover, and other meteorological data for different heights above sea level.

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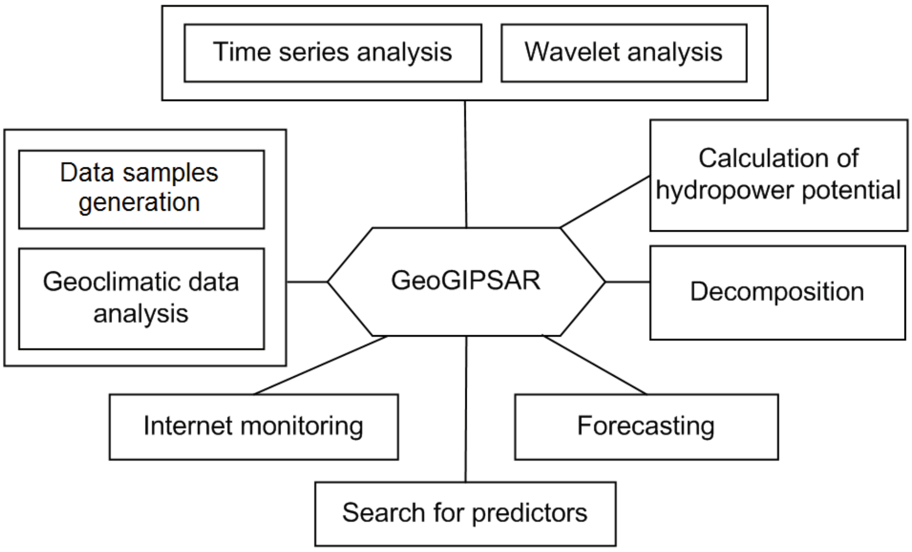

Fig. 1. Main functions of the GeoGIPSAR.

Nullschool [9] is one of the first services created with dynamic 3D visualization maps of global weather conditions, which works directly in the browser. The service includes a universal map that can be rotated and scaled in real time. It shows wind movement, air pollution, wave heights, and more. The data is updated every 3 hours for land and every 5 days for ocean surface parameters.

Windy [10] is a Czech company providing interactive weather forecasting services worldwide. In terms of functions, Windy is close to the Ventusky service, but is more focused on wind animation, for which it was originally created. Currently, there are other basic meteorological parameters such as temperature, pressure, relative humidity, cloud base, and additional sources with extended data.

EarthAtlas [11] is an example of a modular map service developed by the University of New Hampshire (the USA). It is designed to provide the user with access to and interaction with various Earth data and water layer modeling results. EarthAtlas is part of an application that provides its own full-featured Web service, including customization of styles, map types, mapping tools, selection of datasets, layers, and others. The main purpose and functionality of EarthAtlas is the dynamic display of maps that contain raster and vector polygonal datasets (spatial coverage of observational or modeling data), and point datasets (from stations and objects).

Meteologix [12] is a European service that has forecast data from various global models with the display of various indicators, images from space, and forecasts for the whole world. The uniqueness of the service is a large set of predictive models from different countries.

Lobelia.earth [13] is a European service where user can work with Earth observations and climate models for risk analysis and climate scenario assessments using the ERA5 dataset. It provides hourly estimates of a large number of atmospheric, terrestrial, and oceanic climate variables (covering the Earth's atmosphere on a 30 km grid using 137 levels from the surface to an altitude of 80 km).

Despite powerful visualization tools and extensive GIS tools, these systems are difficult to apply to assess indicators in a given area (e.g. a watershed) and generate statistical data. Usually they do not contain unique data but use common global models (such as NOAA, GPCC, and others).

II. The GeoGIPSAR System

The GeoGIPSAR [4] system is a development of the GIPSAR [5] information prognostic system, which was implemented in the late 1990s. It relied on several diverse methods of long-term forecasting (background, estimation, probabilistic, approximate learning) based on a special methodology for generating forecasts of increased reliability, and tools for data analysis and verification.

The GIPSAR system is implemented in the experimental universal programming environment ZIRUS [5] with a flexible model of dynamic typed objects (segments and types of segments) and has been successfully used for a long time to analyze and predict the hydropower potential of various hydropower power plant (HPP) cascades. The ZIRUS environment represents universal mechanisms for the construction and interaction of components with a logical-functional link description language (OLFIS) built into it. The modernization of the GIPSAR system to integrate it with a set of programs for geoclimatic data analysis and processing formed the basis for the modern version of GeoGIPSAR, which makes it possible to study many aspects of the global and regional climate in order to improve the efficiency of methods for long-term forecasting of the hydropower potential and climatic factors affecting the performance of energy systems.

The GeoGIPSAR system uses dynamic objects and

Table 1. The main functions of the GeoGIPSAR and their description

Functions	Description of functions
Time series analysis	Smoothing filters, extreme envelopes (Huang), integral-difference filters, attractors
Wavelet analysis	Waveletograms, spectral characteristics, cross-coherent, discrete analysis
Data samples creation	Spatial, time, aggregation, indices
Geoclimatic data analysis	Aggregation, averaging, visualization methods, indicator distributions, velocity fields
Spatial and time decomposition	Spatial: tributaries, basins, reservoirs; time: year, quarter, month
Calculation of hydropower potential of flow	Statistics analysis, dynamics forecast, verification
Internet monitoring	Information resources, monitoring methodology, integrity support, data verification
Forecasting	Qualitative, probabilistic, learning, astrophysical methods
Search for predictors	Hydrological, meteorological, experimental

a universal data storage (segment database), as well as storage files for multidimensional grid data of a special format (gi3) with various aggregate indicators included in them. The main functions of the system are shown in Fig. 1 and Table 1.

Using the information from world data centers and global forecasting models, the GeoGIPSAR constantly monitors global and regional climate changes and provides various probabilistic forecast estimates of inflows for the studied basins, for example, the Angara-Yenisei cascade of hydroelectric power plants, including the basins of the large rivers such as the Angara and the Yenisei [6, 7]. A set of standard converters and templates for processing various data samples from open sources has been implemented. Sites are periodically polled for updated data, the necessary files are downloaded, converted to the desired format, and sent to the appropriate storage.

III. Basic Data Sets of the GeoGIPSAR

The GeoGIPSAR implements the processing of various data samples from the sources presented below.

NOAA datasets [14] are reanalysis data of the National Oceanic and Atmospheric Administration (the USA). NOAA is engaged in various types of meteorological and geodetic research and forecast, and the study of the world's oceans and atmosphere. It provides the following data services:

- Monitoring and observing Earth systems with instruments and data collection networks;
- Describing Earth systems through the data exploration and analysis;
- Assessing and predicting changes in these systems over time;
- Involving, advising, and informing the public and partner organizations;
- Managing the resources to improve society, the economy, and the environment.

NOAA data are used in reanalysis studies. Reanalysis is a scientific method designed to obtain complete information about how weather and climate change over time. According to this method, the observation data and a numerical model that simulates one or more aspects of the earth system are objectively combined to produce a synthesized estimate of the state of the entire system. The reanalysis usually takes several decades or longer and covers the entire globe from the Earth's surface and to the upper atmosphere. Reanalysis products are widely used in climate research and services, including monitoring and comparing current climate conditions with past conditions, identifying the causes of climate fluctuations and changes, and making climate forecasts.

The site includes the main meteorological indicators for various layers of the atmosphere and stratosphere in daily resolution (temperature, geopotential, indicators of atmospheric circulation, etc.) with a delay of 2–3 days.

GPCC [15–17] is Global Precipitation Climatology Centre (Germany), which houses monthly data for more than 100 years of global precipitation on the surface of the Earth. It employs the data from about 85000 weather stations around the world. The service allows researcher to use operational data with different resolutions on a regular grid (from 0.25° to 2.5°) and a monthly time interval. GPCC provides the following products:

- Climatology 1951–2000 (GPCC_Clim), which is used for application as a reference, for utilization of the anomaly interpolation method, and has high representativeness.
- Full Data Reanalysis (GPCC_FD), which is used for verification of models, analysis of historic global precipitation, or for research into the global water cycle, and has high accuracy.
- Full Data Daily Product (GPCC_FD_D) is recommended to be used when the daily precipitation information is of highest importance.
- Monitoring Product (GPCC_MP) is characterized by high availability and reasonable timeliness, and can be used for satellite data calibration or early annual reporting.
- First Guess Product (GPCC_FG), First Guess Daily Product (GPCC_FG_D), and Drought Index Product (GPCC_DI_M) demonstrate high timeliness and can be used for drought monitoring.

GPCC is the basis for generating precipitation reanalysis data. It also supports regional climate monitoring, model validation, climate variability analysis, and water assessment studies.

TABLE 2. The Web Service control parameter requirements.

Parameters/Section	Requirements
Basic parameters	Coordinates, month, range of months (when averaged), graph type (precipitation, pressure, temperature, etc.), anomaly search feature
Data visualization	Scale, layer selection, grid adjustment, legend range
Date setting	Current date (for a separate period), start and end dates (for a time interval)
Comparison of average indicators by period	Initial data for processing each period
Analysis of correlation fields	Correlation type (Pearson), series names for correlation
Trend analysis	Correlation type (trend), interval of dates
Index analysis	Graph and data type sets

NOAA National Centers for Environmental Information (NCEI) [18] maintains the archives and provides data on the solar and upper atmosphere, ionosphere and space environment, including observations of the Earth from space. It estimates the daily terrestrial solar UV index and predicts UV levels for the next day.

Pogodaiklimat [19] (Weather and Climate in Russian) is a service with meteorological data for individual points (together with archives), which provides the most complete and prompt monitoring of weather and climate on a global scale. The service presents weather forecasts for most cities in the world, and ensures climate monitoring and climate data, current weather data from all international exchange stations that regularly transmit information about actual weather, weather records, and information about dangerous and extreme events.

CFS [20–22] is a Climate Forecast System model from NOAA National Centers for Environmental Prediction (NCEP). In the context of global and regional climate changes, the use of only hydrometeorological statistics for predictive estimation of water content and temperatures becomes ineffective. Given the significant progress in the creation and development of global climate models over the past decades, it seems appropriate to use them for long-term estimation of water content and other hydrometeorological indicators. One of such models is the global climate model CFSv2. Its simulation results are refined daily in the form of ensemble forecasts of the state of the atmosphere and ocean with a time interval from several hours to ten months for the entire globe. The ensemble approach used in the model makes it possible to generate probabilistic estimates of the state of the atmosphere in the long term.

In addition to these basic data, the GeoGIPSAR also uses regional sources and observational statistics, such as annual river flow data, air temperatures, and others.

IV. Requirements for the basic Web service controls

Along with the development of spatial data processing services as independent GIS resources that provide researchers with tools for visualizing heterogeneous geoclimatic data, it is also of particular importance to create dedicated software for analyzing data for a given territory, basin, time interval, certain indicators, and others. For example, the GeoGIPSAR system components for processing prognostic data ensembles can show the dynamics of changes in prognostic meteorological indicators for any selected cell of grid data and allow setting weighting factors, as well as their spatial distributions.

A draft interface of the GeoGIPSAR has been developed in the form of a dedicated Web service to expand the range of its users.

The Web service requirements include:

- interaction with the GeoGIPSAR through transmission of the parameters and processing of its work results;
- HTML interface with data entry and validation;
- creation of output data templates (graphs, tables, reports);
- visualization of work results;
- differentiation of access to data (multi-user mode).

The Web service implementation features are:

- cross-platform, portability, small (compact) size, and the ability to replace external applications;
- the ability to use external plotting systems for high-quality visualization (Gnuplot [23]) with flexible output templates;
- performance through the use of modern technologies for data processing and output of results (programming languages Lua and PHP);
- reliability and uninterrupted operation (for example, creation of filters to block bots, use of authentication);
- integration with common databases (MySQL).
- *A multi-user mode of operation* is provided using access control in the form of various user groups such as:
- viewer (generates templates and views maps);
- editor (monitors, changes and adds data to the system);
- programmer (creates applications and interfaces);
- GIS-specialist (provides conformity of maps to given requirements, creates extended 2D and 3D maps, visualizes and analyzes them);
- analyst (analyzes the results; examines the data; performs spatial, statistical, and predictive analysis; and searches for relationships and regularities);
- administrator (delimits the rights of access to data and monitors the state of the system).

The considered Web service includes the following basic functions for working with the GeoGIPSAR:

1. Generation of climatic maps of absolute and relative indicators for the selected catchment basin of HPP

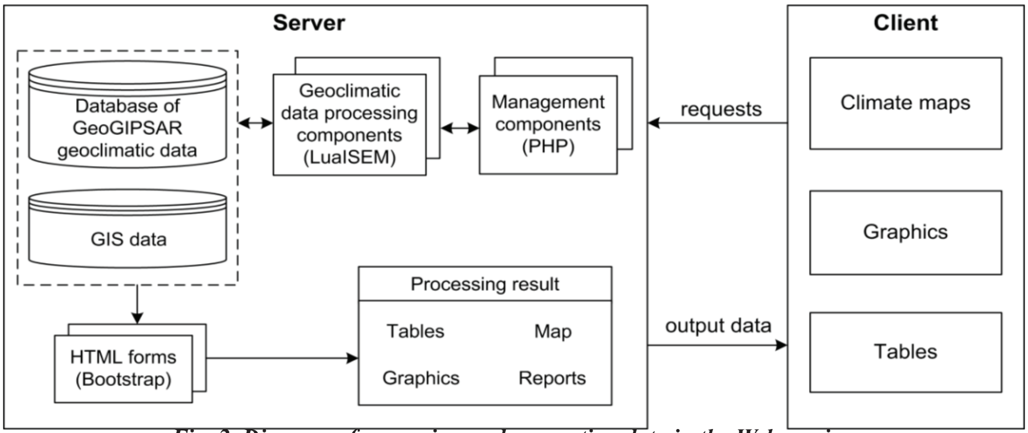

Fig. 2. Diagram of managing and generating data in the Web service.

reservoirs;
2. Analysis of data for a given year with the display of the indicator distributions;
3. Analysis of the indicator differences for the given two periods;
4. Comparison of average indicators for the periods of several years;
5. Analysis of correlation fields (links) for selected time series;
6. Analysis and selection of trends;
7. Analysis of vorticity, humidity, and atmospheric circulation indices.

Table 2 shows the requirements for the Web service control parameters for interaction with GeoGIPSAR.

V. Development Technologies of the Web Service

The Web service implementation relies on the following programming languages, systems, and frameworks.

Lua programming language. Scripting languages, unlike compiled ones, greatly simplify the technology of creating modules, because they need to have only an editor of the text code and debug it through the command line of a file manager or other system tool. The Lua language is unique in its following main properties:

- compactness and portability (the size of a single executable module with dedicated api-functions does not exceed 200 Kb);
- simplicity of syntax combined with powerful tools for using dynamic data (associative tables) and high performance of the implemented algorithms;
- ease of reading and writing text files with advanced processing tools through regular expressions;
- use as a stand-alone program text processor and as an extension of technologies in C/C++ (and other languages);
- the possibility of implementing various programming paradigms (imperative, object-oriented, functional);
- openness of the program code and cross-platform.

Experience of using the Lua language has shown that it can be effectively applied in various aspects (coding of individual algorithms; task launch control; text file conversion, and others). The flexibility, simplicity and efficiency of the language become evident when creating control scripts for controlling other software systems with the code included to organize data exchange between them.

LuaISEM is a Lua language extension developed by the MESI SB RAS by adding applied and basic functions. It contains a set of libraries of functions for processing the data of global climate models, including their downloading, analysis, output templates, and others.

The high-quality graphs are created using a cross-platform portable system Gnuplot [23] with a developed declarative language for their description. Gnuplot allows user to display data both as separate files (it supports many common graphic formats) and interactively in Web scripts.

PHP language is employed to run server-side programs and call Lua functions (LuaISEM). It is used to process the data of forms, generate dynamic pages, and save entered user data and sessions (through cookies technology). One of the PHP advantages is that it supports a wide range of databases and many extensions.

PhpMyAdmin server is used to administer PHP. It supports a wide range of database operations such as MySQL and MariaDB. All operations on them (creating, viewing, and modifying tables, columns, relations, indices, and others) can be performed through the user interface, while the user remains able to directly execute any SQL statement.

RedBeanPHP [24] is a powerful PHP add-on that makes working with databases much easier. It allows exchanging different types of models, in particular, between a data store and a program. It is used to simplify the process of storing objects in a relational database and retrieving them.

Bootstrap [25] is a large collection of easy-to-use code snippets written in HTML, CSS, and JavaScript, which enable developers and designers to quickly create fully responsive websites.

The operation of the considered Web service is implemented as a client-server architecture. The diagram of managing and generating data in the Web service is shown in Fig. 2.

The server block is executed in PHP and includes

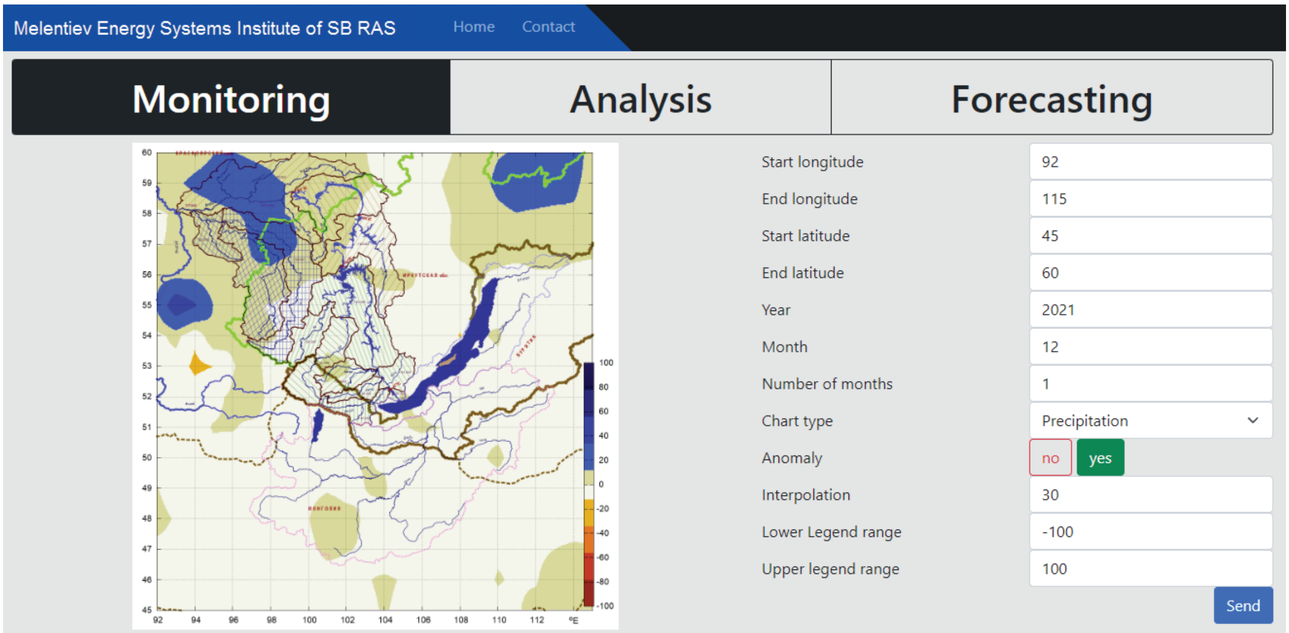

Fig. 3. An example of setting basic parameters for generating climate maps in the Web service.

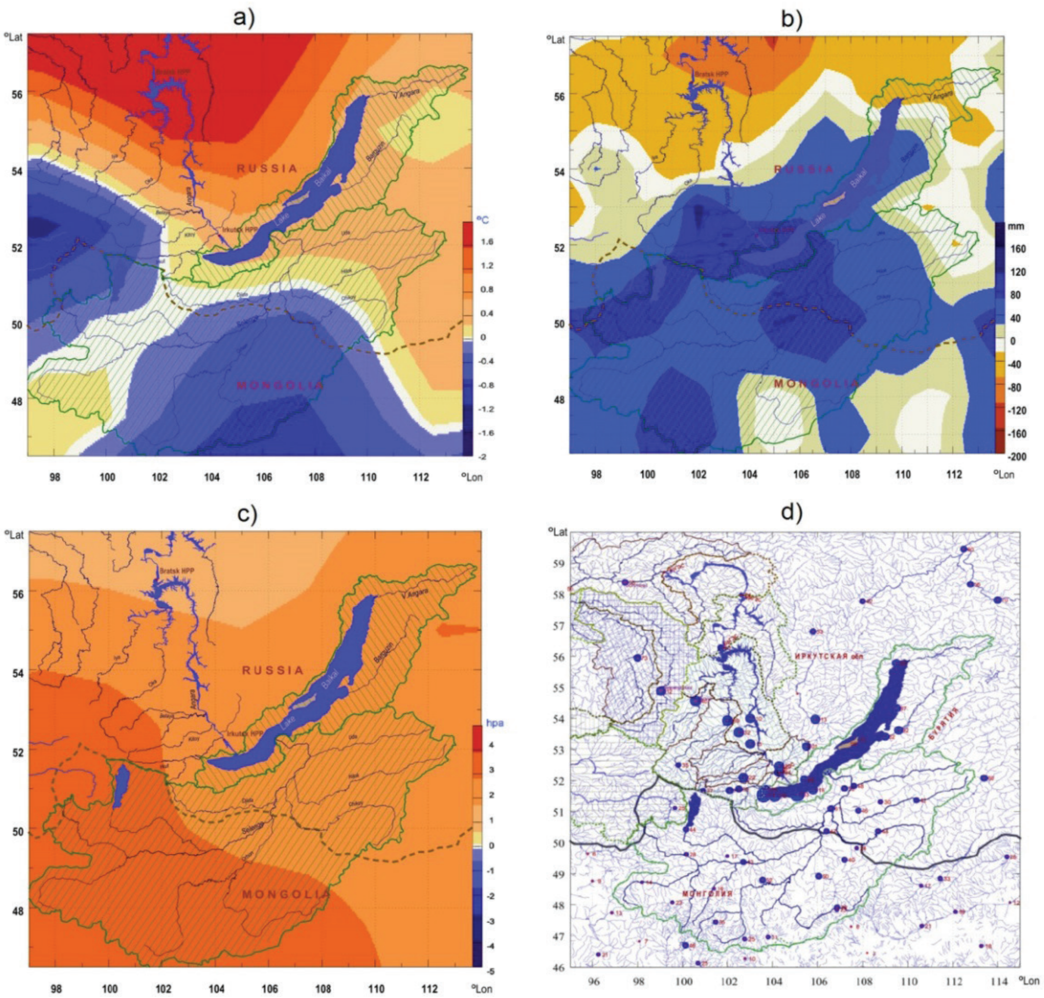

Fig. 4. An example of generating climate maps; search for deviations (anomalies) for the summer period (June-August, 2021) in the Lake Baikal basin: temperature (a), precipitation (b), and pressure (c); meteorological observation points (d).

administration of data access via RedBeanPHP, data updating, parameter and style management, and creation of input/output HTML forms via Bootstrap. Data are processed using the LuaISEM language.

To start working with the system, the user needs to log in or register. Administrator can manage the system by setting up user rights, climate databases, map templates, and others. When the user logs in with the rights of a viewer, editor, GIS specialist or analyst, a set of basic GeoGIPSAR management functions is displayed. Several sections of working with climate data are available (monitoring, analysis, and forecasting).

When the user selects the section with the analysis of climatic data, the form for entering parameters is displayed (Fig. 3). The parameters entered into the form are sent to a script written in LuaISEM. For simplicity, this script replaces the data in the template with the data entered by the user. After the replacement, a working Lua script is launched. This script is connected to the GeoGIPSAR, which processes global climate data and converts them into the required format. The result is the visualization of geoclimatic data in the form of geographic maps of various types (graphs, tables, and reports) (Fig. 4).

The Web service development and management are implemented by: 1) testing a local version; for example, USBWebserver is a lightweight local Web server using Apache, PHP, MySQL and PHPMyAdmin, which allows user to work on various systems without installing it; 2) installing the updated software to a stationary system (server). Local version improves the development speed and reliability.

VI. Conclusion

The Web service is currently actively evolving. Its further development involves the expansion of the system core with the ability to quickly select the forms of data presentation and visualization. It is planned to place the Web service on the websites of the MESI SB RAS (https://isem.irk.ru) and the scientific project for the study of Lake Baikal (http://baikal-project.icc.ru).

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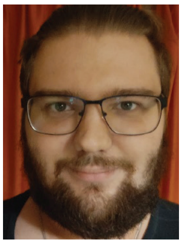

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