HYDROMETEOROLOGICAL DATABASE (HMDB) FOR PRACTICAL RESEARCH IN ECOLOGY

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ABSTRACT

The regional HydroMeteorological DataBase (HMDB) was designed for easy access to climate data via the Internet. It contains data on various climatic parameters (temperature, precipitation, pressure, humidity, and wind strength and direction) from 190 meteorological stations in Russia and bordering countries for a period of instrumental observations of over 100 years. Open sources were used to ingest data into HMDB. An analytical block was also developed to perform the most common statistical analysis techniques.

Keywords: Hydrometeorological database, Climate, Temperature, Precipitation, Russia

1 INTRODUCTION

Analysis of the reactions of biodiversity parameters to climate fluctuations and the monitoring of common trends of vegetation changes are important tasks in modern ecological research in Northern Russian. Meteorological observations in this region reveal a steady trend of warming since the 1970s, with a peak in the 1990s—the modern 'warming' of climate (Anisimov & Belolutskaya, 2003; Pavlov, 2003). To accurately assess this climate change, it has been highly important to use instrumental observations such as temperature, precipitation, and other climate characteristics collected by weather stations. At this time, vast numbers of such data are available from these weather stations (the exact volume is station-dependent), and the average duration of observations is 100–120 years or more. The volumes and temporal periods make these data very difficult to process manually. Moreover, the use of spreadsheets (e.g., Microsoft Excel) for data manipulation is not appropriate, and the best solution, in our opinion, is to use a database management system. This approach requires considerable effort to design the database structure and a user-friendly interface; however, working with Internet-oriented databases is especially promising because users can access the stored data from anywhere in the world.

Our aim was to create and test an information resource that can be accessed via the Internet and that is linked to databases containing daily meteorological information, temperature, precipitation, pressure, humidity, wind strength and direction, and so on, with a greater than 100-year temporal coverage. Specifically, we had the following objectives: (1) to develop the database structure and to construct the user interface; (2) to implement the most frequently used data-processing algorithms (generation of average monthly and annual characteristics, sums of temperature and precipitation, sliding means, wind roses, etc.); (3) to query the climate data using an open source search engine; and (4) to fill the database and to develop a simple method for export of data and data analysis results (tables and images) in different formats.

2 DESCRIPTION OF DEVELOPED SYSTEM

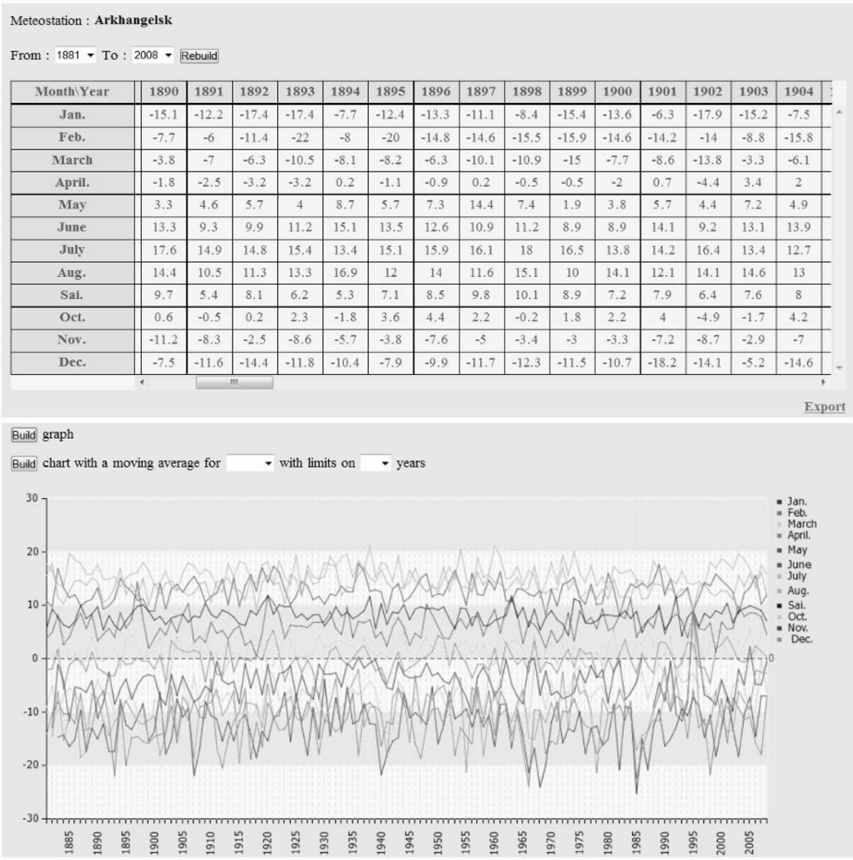
The basis of any information system is its fullness real data. Currently, the developed HydroMeteorological DataBase (HMDB)[†] contains information from 190 weather stations located in Russia and its bordering countries (Figure 1), where the data used to fill the database were obtained from the following openly accessible portals: http://aisori.meteo.ru/ClimateR and http://rp5.ru. Parameters with daily resolution, such as temperature and precipitation amount were ingested for each station. The typical observation time in each case is about 100 years; the earliest data observation is from 1882 and the latest is from 2012. In contrast, data for other climate variables, pressure, humidity, and, wind strengths and directions, span much shorter timeframes (from 2005 onwards).

There are two methods of data retrieval build into the database. The first ('View data') displays raw climate data. The second ('View statistics') was designed using several data processing algorithms, and the HMDB system

[†]An English version of HMDB is located at http://ib.komisc.ru/climat/index.php?lang=en.

contains a set of the most commonly used algorithms in meteorological data analysis. For temperature data, the following algorithms were implemented: calculation of average temperatures over different time periods (ten-day, monthly, winter, summer, and annual); summer temperature summation; dates of stable transition across 0 °C, 5 °C, and 10 °C, and the duration of these periods; effective temperature summation (temperatures above 0 °C, 5 °C, and 10 °C); and number of days experiencing extreme temperatures (above 20 °C, 25 °C, and 30 °C or below –20 °C, –25 °C, and –30 °C). Average annual, monthly, and ten-day temperatures can be presented in chart form (Figure 2). It is also possible to smooth these data using the rolling average. For the other climate parameters (precipitation, pressure, and humidity) only monthly, summer, winter, and annual summations or average values are available. Furthermore, wind diagrams can be constructed to indicate wind strengths and directions. All tabulated results can be export to Microsoft Excel format.

Figure 1. Location of weather stations with data in HMDB (Russia and bordering countries)



Month\Year	1890	1891	1892	1893	1894	1895	1896	1897	1898	1899	1900	1901	1902	1903	1904
Jan.	-15.1	-12.2	-17.4	-17.4	-7.7	-12.4	-13.3	-11.1	-8.4	-15.4	-13.6	-6.3	-17.9	-15.2	-7.5
Feb.	-7.7	-6	-11.4	-22	-8	-20	-14.8	-14.6	-15.5	-15.9	-14.6	-14.2	-14	-8.8	-15.8
March	-3.8	-7	-6.3	-10.5	-8.1	-8.2	-6.3	-10.1	-10.9	-15	-7.7	-8.6	-13.8	-3.3	-6.1
April.	-1.8	-2.5	-3.2	-3.2	0.2	-1.1	-0.9	0.2	-0.5	-0.5	-2	0.7	-4.4	3.4	2
May	3.3	4.6	5.7	4	8.7	5.7	7.3	14.4	7.4	1.9	3.8	5.7	4.4	7.2	4.9
June	13.3	9.3	9.9	11.2	15.1	13.5	12.6	10.9	11.2	8.9	8.9	14.1	9.2	13.1	13.9
July	17.6	14.9	14.8	15.4	13.4	15.1	15.9	16.1	18	16.5	13.8	14.2	16.4	13.4	12.7
Aug.	14.4	10.5	11.3	13.3	16.9	12	14	11.6	15.1	10	14.1	12.1	14.1	14.6	13
Sai.	9.7	5.4	8.1	6.2	5.3	7.1	8.5	9.8	10.1	8.9	7.2	7.9	6.4	7.6	8
Oct.	0.6	-0.5	0.2	2.3	-1.8	3.6	4.4	2.2	-0.2	1.8	2.2	4	-4.9	-1.7	4.2
Nov.	-11.2	-8.3	-2.5	-8.6	-5.7	-3.8	-7.6	-5	-3.4	-3	-3.3	-7.2	-8.7	-2.9	-7
Dec.	-7.5	-11.6	-14.4	-11.8	-10.4	-7.9	-9.9	-11.7	-12.3	-11.5	-10.7	-18.2	-14.1	-5.2	-14.6

Figure 2. Monthly average temperatures presented as a table (top) and chart (bottom)

3 PRACTICAL USE OF HMDB

The rate that plants grow in the Arctic region is low in comparison with many other areas of the world. However, this region is characterized by an excess of water and light. High precipitation and low evaporation leads to water logging of land, and there are many small rivers and lakes. In addition, the long polar days during the summer give plants sufficient light. Thus, we believe that the primary factor limiting the rate of plant growth in the Arctic region is the lack of heat. The low temperatures experienced in this zone also reduce the rate of decomposition of organic matter by microorganisms, leading to a reduction of mineral elements in the soil.

The relationship between the annual mean temperature in the Arctic region and annual increments of willow growth (*Salix phylicifolia* L.) is shown in Figure 3. These data were collected near Vorkuta (in northeast European Russia) for the period 1976–2007. The left axis shows the annual growth in *Salix phylicifolia* L. (mm) whereas the right axis shows the annual temperature measured at the Vorkuta weather station (°C). The observed linear trends in the temperature changes and increments of willow growth are almost identical although the correlation rate between these two parameters is low and not statistically significant.

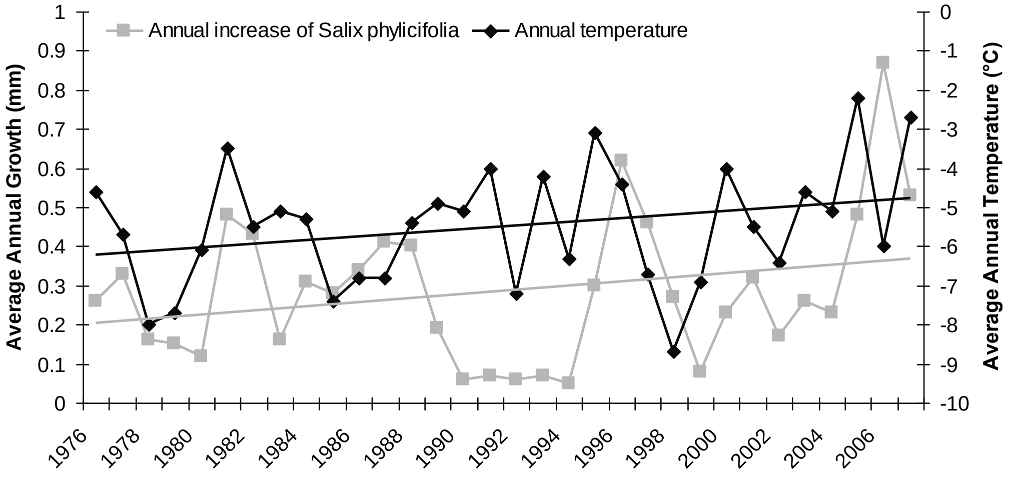


Figure 3. Correlation between annual temperature and annual growth of *Salix phylicifolia* L

Another example of the close relationship between morphological vegetation characteristics and annual temperatures is shown in Table 1. We compared the canopy height, leaf weight, and leaf area of four species that are widespread within the region: *Fragária vésca* L., *Rubus chamaemorus* L., *Vaccínium myrtíllus* L., and *Vaccínium vítis-idaéa* L. These data were collected near Syktyvkar (average annual temperature for the last 10 years = 1.6 °C, mid-taiga) and Vorkuta (-5.3 °C, polar region). As can be seen, all morphological parameters (except the leaf weight of *Fragaria vesca* L.) are significantly lower in the more northerly Vorkuta. For canopy height, the values for Vorkuta were lower by greater than two-fold.

Table 1. Difference between morphological characteristics of plants near Syktyvkar and Vorkuta

	Canopy height (cm)		Leaf weight (mg)		Leaf area (cm^2)	
	Vorkuta	Syktyvkar	Vorkuta	Syktyvkar	Vorkuta	Syktyvkar
Fragária vésca L.	$13 \pm 0.64^*$	$17 \pm 0.56^*$	*60 ± 2.19*	*62 ± 2.08*	$18.2 \pm 0.83^*$	$26.1 \pm 1.12^*$
Rubus chamaemorus L.	$8 \pm 0.27^*$	$17 \pm 0.76^*$	$163 \pm 4.54^*$	$218 \pm 6.9^*$	$19.1 \pm 0.6^*$	$23 \pm 1.09^*$
Vaccínium myrtíllus L.	$19 \pm 0.52^*$	$33 \pm 1.05^*$	$8 \pm 0.25^*$	$10 \pm 0.37^*$	$1.6 \pm 0.06^*$	$2.3 \pm 0.08^*$
Vaccínium vítis-idaéa L.	$5 \pm 0.13^*$	$19 \pm 0.7^*$	$10 \pm 0.25^*$	$19 \pm 0.6^*$	$0.6 \pm 0.02^*$	$2.1 \pm 0.1^*$

*Significance level: $P < 0.05$ (n = 30)

3.1 Analysis of 10-day temperature variance

The ecosystems of Northern Eurasia, and especially the Arctic region, demonstrate heterogeneity in the types of responses they produce when subjected to climate changes. These responses have been shown to be unequal throughout this area and are distinctly related to increases of temperatures (Chapin III, Sturm, Serreze, McFadden, Key, Lloyd, et al., 2005), oceanic influences (80% of the flat tundra (3.2 million km^2) is located less than 100 km distance from the ocean coast (Bhatt, Walker, Raynolds, Comiso, Howard, Epstein, et al., 2010), permafrost, and altitudinal zonation.

The developed database was used to analyze temperature variance over ten-day intervals for the past 60 years for weather stations located mainly in the Arctic zone of Russia (Figure 4). The blue boxes represent ten-day intervals in which the temperature was lower than the annual average whereas orange and red boxes represent periods warmer than the annual average.

An increase in annual temperature was generally observed at all weather stations over the past 20 years. However, this increase was non-homogeneous across seasons and longitudinal gradients (from east to west). Western Russia was characterized by a uniform increase in temperature (during both summer and winter). In contrast, the greatest temperature increase in Siberia occurred during spring (March–April) and autumn (September–October) months, and a decrease in average temperatures was seen in late summer (August) and late winter (February).

A possible reason for such climate behavior is an increase in stability of the Rossby waves in the atmosphere (Francis & Vavrus, 2012), which play an important role in shaping the climatic characteristics of the Arctic zone. These waves have a major impact on the paths of cyclones and anticyclones across Eurasia.

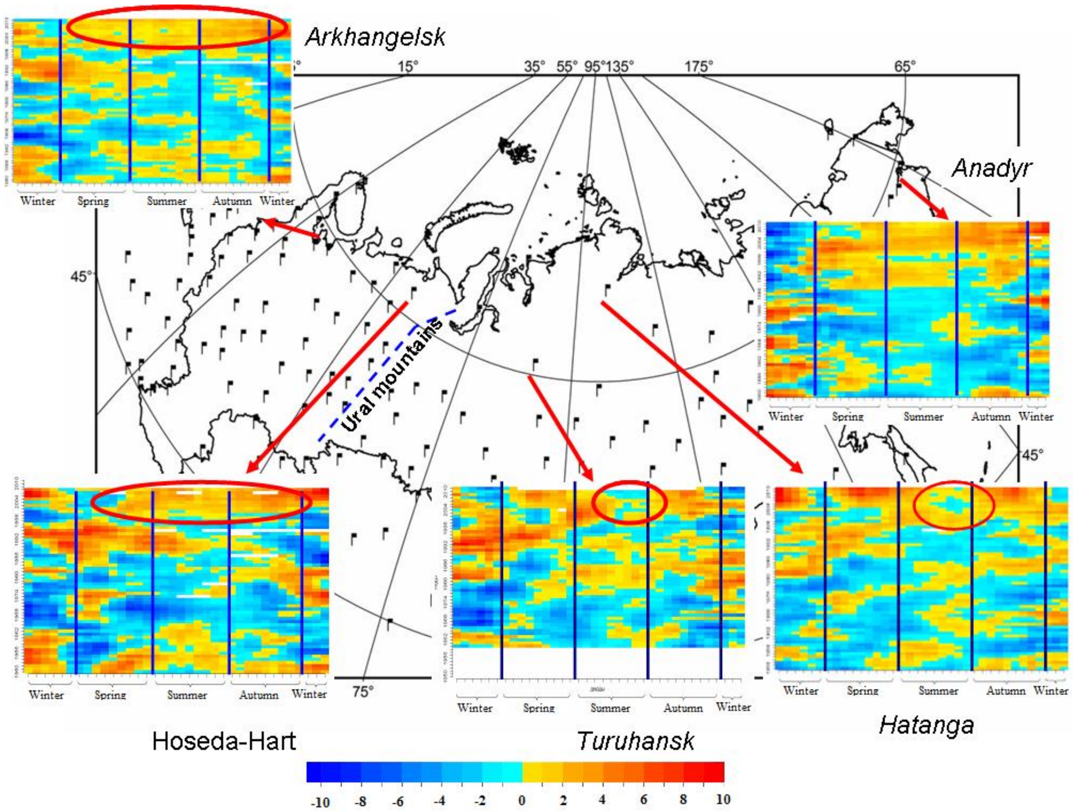
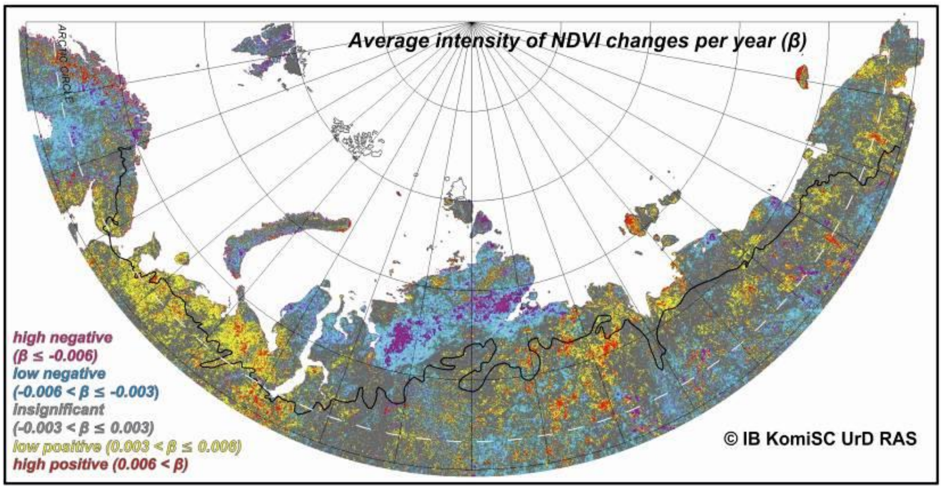


Figure 4. Temperature variance over ten-day intervals for the period 1950–2010 for a set of weather stations

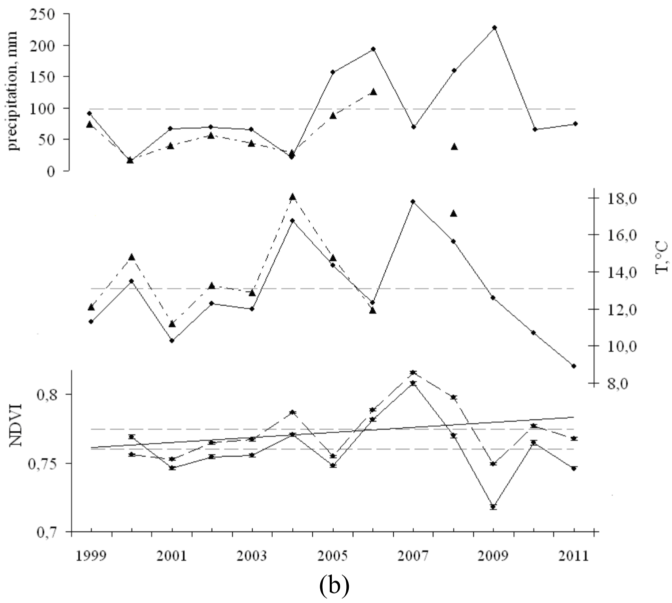
For the last 20 years, the area of sea ice in the Arctic has been reduced. The extra solar energy absorbed by open water during summer is released to the atmosphere as heat. This leads to a change of Rossby waveshape in the very northern latitudes. Moreover, slow movement of upper-level waves can cause static areas of high and low pressure to develop in the atmosphere, potentially triggering extreme weather events, for example, flooding, cold spells, or heat waves. Such a situation occurred in 2010, when the mid-latitudes (the central part of Russia) experienced an unusually hot summer, while at the same time Siberia went through a long cold spell.

3.2 Climate changes and vegetation

Another focus of the HMDB is performing joint analysis of temperature and satellite-image time series (AVHRR, SPOT-VGT, or MODIS). The availability of this analysis has enabled us to determine the origin and extent of vegetation changes over the past few years in the Arctic region according to observed climatic fluctuations. To achieve this, Terra-MODIS (MOD13Q1.005) satellite data with a spatial resolution of 0.25 km were used for the period 2000–2009 (data source: modis.gsfc.nasa.gov). First, the Normalized Difference Vegetation Index (NDVI) was calculated for every pixel on the images for each year. The maximum value was then selected, and linear equations describing the trend were fitted. The results are show in Figure 5. The highest index values were found during the July–August period of each year. The strength of each trend (β) was evaluated and categorized into the following classes in accordance with the approach of Goetz, Bunn, Fiske, and Houghton (2005): high negative ($\beta \leq -0.006$), low negative ($-0.006 < \beta \leq -0.003$), insignificant ($-0.003 < \beta \leq 0.003$), low positive ($0.003 < \beta \leq 0.006$), and high positive ($0.006 < \beta$) changes (Figure 5(a)). The initial data for each year of observation were also combined with meteorological data from the HMDB (Figure 5(b)). The reaction of the Arctic ecosystems to the 'warming' is heterogeneous and exhibits regional differences connected with differences in annual temperature increases, ocean proximity, permafrost, and altitude. It is clear from Figure 5(a) that 57% of the Russian Subarctic is presently characterized as having insignificant changes; approximately 20% of the Russian Arctic is experiencing an increase in green biomass; an essential growth in productivity is being observed in the European part of Russia; and a decrease of productivity can be noted for 23% of the Arctic area, especially in the Siberia region.



(a)



(b)

Figure 5. (a) North Eurasia vegetation green biomass changes for the period 2000–2009 using MODIS data (the forest area is indicated by the black line); (b) Average June: precipitation (top), temperature (middle), and maximum NDVI of grass willow communities (bottom) for model plots (Vorkuta and Choseda-Chard regions of Yugorsky Peninsula) using data imported from HMDB. Gray dotted lines indicate average values over the observation period. In the lower figure, sample calculation of inter-year NDVI changes are presented for the south-west area of Yugorsky Peninsula ($y = 0.0018x + 0.76$, $r^2 = 0.14$).

In many cases, $NDVI_{MAX}$, the inter-annual variability, was closely related to the climatic conditions of the observation year, in particular, during the latter half of the vegetation period. The period of accumulation of above-ground phytomass shifted with seasonal temperature increase and occurred throughout late July and early August for the majority of tundra communities. Hence, by the beginning of July, herbaceous plants form on average about 53.2% of the stock of phytomass and reach a maximum at the beginning of August. For deciduous shrubs and dwarf shrubs, the value is around 65.0% (Andreev, Galaktionova, Govorov, Zacharova, Neustroeva, Savvinov, et al., 1978). An analysis of the relationship between the meteorological data and the maximal NDVI values for willow-herbaceous communities in the model plots (Vorkuta and Choseda-Chard regions of Yugorsky Peninsula) showed that the most significant correlation ($r^2 = 0.49$, $p < 0.05$) is between NDVI values and average temperatures during the vegetation period from the second half of June to the first half of July (Figure 5(b) (middle) and (bottom)). Temperature characteristics over the entire vegetation period are dependent on solar radiation, the peak flow of which is observed when cloud cover is minimal. Therefore, feedback between the amount of precipitation and temperature indicators can be traced (Figure. 5(b) (top) and (middle)), and temperatures are lower in years with high precipitation. NDVI values for communities principally established on waterlogged tundra soils show weak dependence on precipitation amounts during the observation period ($r = 0.04$). However, a stronger correlation is found between NDVI and precipitation during winter periods ($r = 0.39$; Elsakov, 2013).

4 CONCLUSION

The developed database (HMDB) enables the storage and analysis of vast numbers of meteorological data and is considered useful for specialists in many scientific fields: geography, ecology, and botany. It facilitates fast access to essential climatic data for a specific region, primary analysis of these data, and output of the result as a chart or Excel file for a further analysis.

The system is located at http://ib.komisc.ru/climat/index.php?lang=en. (To obtain access to this system, please contact the authors.)

5 ACKNOWLEDGEMENTS

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