# Regional aspects of the present-day climate as judged from analysis of the observed climate and environmental changes in Siberia

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Regional and subregional (mesoscale) peculiarities of observed climate and environmental changes in Siberia and their dynamic features (time scales of changes) are discussed based on statistical analysis of the relevant ground-based and spaceborne instrumental data. The role of different global factors (cosmophysical, geophysical, biospheric, and anthropogenic) in the observed regional peculiarities, including the retrospective of the last ones on the geological time scale, is analyzed. The climatic phenomenon of the 20th century has been separated out based on correlations between the wavelet spectra for the annual mean near-surface temperature in Western Siberia and Index of the North Atlantic Oscillation with their phase shift being estimated to be up to 7 years. Urgent tasks on the development of integrated regional studies in Siberia are formulated.

## Introduction

Investigations of the global and regional climate and environmental changes face an extremely complicated problem, consisting in that interrelated changes of the environment and climate cannot be explained within the framework of the simple “cause-and-effect” paradigm (Amsterdam Declaration, 2001). Moreover, in describing these changes, it is necessary to take into account the fact that many climate-forming factors of the cosmophysical (in particular, heliospheric), geospheric, biospheric, and anthropogenic origin determine not only the changes in the states of the environment–climate system, but also the regionally specific evolution of the physical processes and phenomena, forming the basis for these changes.

Results of recent scientific investigations carried out under intense international, national, and regional programs have led to a conclusion that integrated (multidisciplinary) regional studies should be given the highest priority.[1] For these studies, it becomes necessary not only to regionalize the existing mathematical models of the global climate, but also to organize combined instrumental observations of a large number of simultaneously measured parameters. Now the combination of two scientific approaches (mathematical simulation and regional monitoring) in integrated investigations face certain unsolved problems, some of them have been mentioned in Ref. 2.

The solution of these problems, as well as those discussed below, seems to be urgent for the modern climatology, in which the phenomenological discussion of empirical data still prevails over the physical and mathematical description of the observed changes.

Below we discuss the results obtained from analysis of ground-based and aerospace instrumental data for Siberia, which revealed the regional and subregional (mesoscale) peculiarities in the observed environment and climate changes, as well as their dynamic features (time scales). Such peculiarities include: manifestation of subregional temperature anomalies up to the heights above the atmospheric boundary layer; a climatic phenomenon revealed consisting in the enhanced correlation of the regional annual mean surface temperature and planetary indices with the many-year phase shift of the correlated time series of observations, and some others. The discussion of the revealed regional peculiarities and their value for the theory of climate is preceded by a brief historical review of the region under study.

## Regionally specific features of Siberia in retrospective

Contemporary scientific knowledge of the evolution of the Earth as a system provides grounds for the retrospective insight in the regional peculiarities of climate and ecosystem changes in view of the interaction between global and regional processes on the planet. We have succeeded in separating the historic past of Siberia on the geological time scale, and this past has turned to be very impressive.

Figure 1 shows the evolution of the atmosphere and continents on the log–log scale in accordance with the materials collected in the textbook on historic geology.[3]

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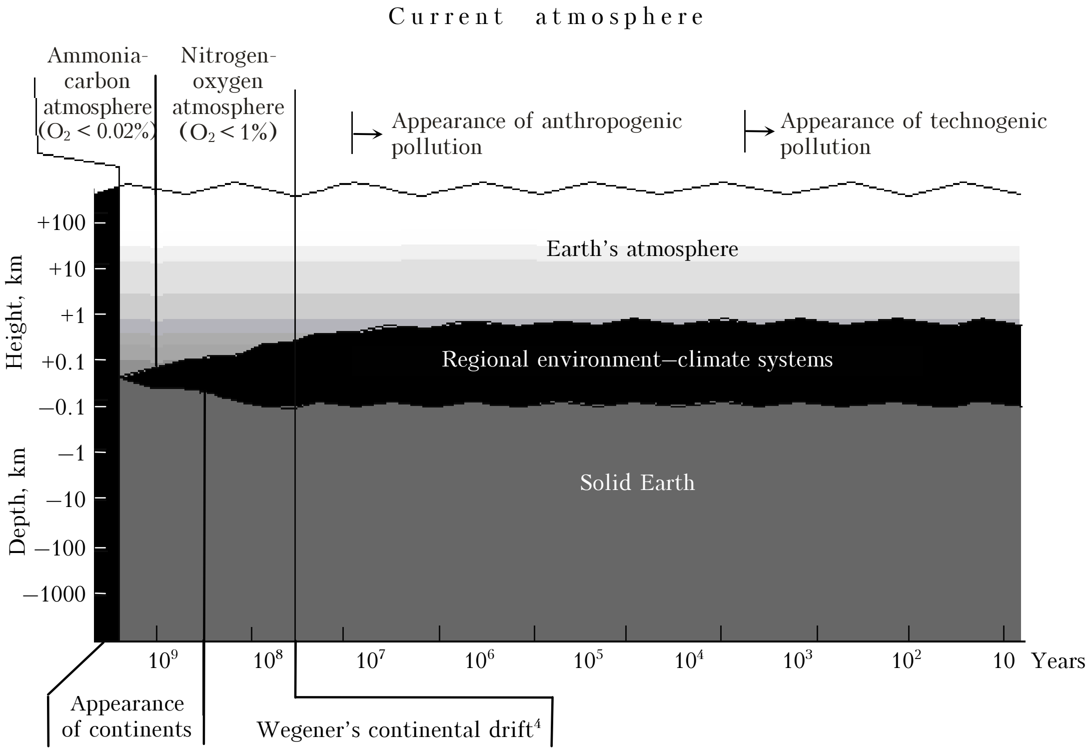


**Fig. 1.** Some geological stages in the evolution of the Earth's atmosphere and solid Earth.

The origin of coordinates on the time axis (abscissa) corresponds to the Earth's age (about 5 billion years). The thin vertical lines show approximately the scale of some evolutionary events for the atmosphere and solid Earth. The wavy horizontal lines conditionally outline the regional environment–climate systems over land (the upper line is drawn at the height of the atmospheric boundary layer, and the lower line corresponds to the depth of lithospheric active layer). The beginning of both lines is usually dated to 2.5 billion years ago, when first areas of land appeared on the Earth.

The evolution of the Earth's atmosphere is characterized by the first important event, associated with the appearance of the land. Before this the ammonia–carbon atmosphere (oxygen content lower than 0.02%), which was the cradle of anoxybiotic living organisms, became to gradually enrich with oxygen and transform into the nitrogen–oxygen atmosphere (oxygen content up to 1%), in which the living nature pass on to the new line of development (oxygen-containing).

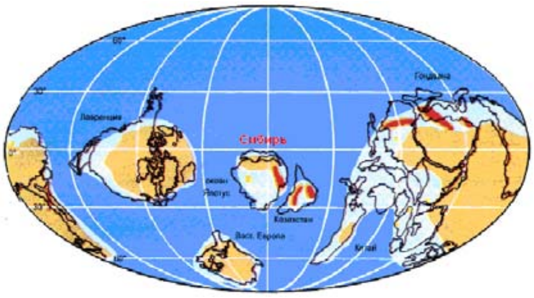
This geological stage including the Paleozoic and Mesozoic Eras (from 500 to 65 million years ago) is characterized by the evolution of the atmospheric composition to that close to the current one.

Another event, important for the atmosphere, is associated with the advent of human (about 10 million years ago) and with the gradually increasing anthropogenic impact on the atmosphere. The anthropogenic impact on the environment and climate became especially marked in recent centuries, when the technogenic load on the atmosphere has increased significantly and its role in the currently observed changes became indisputable, at least, for some regions of our planet.

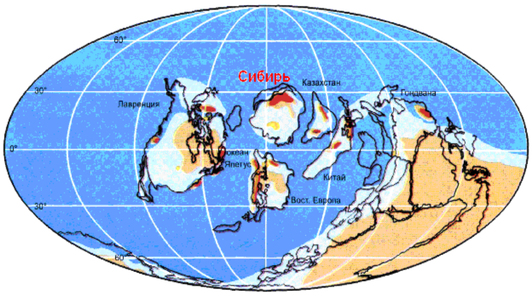
The evolution of the solid Earth in the geological past led to cardinal changes in regional environment–climate systems. The geological stage, during which the continental drift occurred,[4] can be considered as the initial for the region of Siberia. Figure 2 shows some fragments of maps on historical geology from Ref. 5, which depicts the continent referred to as Siberia.

It can be seen from Fig. 2 that Siberia drifted from the initial geographic position in the Southern Hemisphere to the Northern Hemisphere with the displacement to the east. It is quite natural that, during this drift for several climatic epochs, cardinal environment and climate changes occurred in Siberia, as well as in other regions.

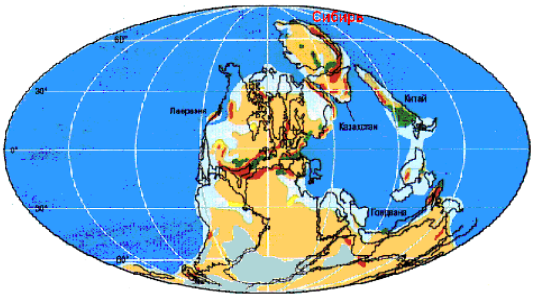
Modern precision instrumental observations indicate the continuing marked (beyond the observation errors) changes in the positions of the continents and the Earth's surface terrain.[6] These and other geospheric processes (volcanic eruptions, earthquakes, thermal fluxes in the lithosphere, and others) form the category of natural factors, which continue to considerably affect the current climate and ecosystem. Therefore, the investigations of this climatically significant factor remain an urgent task of the modern climatology, in particular, for integrated regional studies.



523–505 million years ago (Cambrian)



448–438 million years ago (Ordovician)



300–286 million years ago (Carbonic)

144–65 million years ago (Cretaceous)

**Fig. 2.** Positions of the continents for some periods on the geological time scale (from Ref. 3 according to Ref. 5).

## Spatial scales of observed regional peculiarities

Modern mathematical models of the Earth's climate (the INM model[7] is recognized as an advanced one) take into account both the global processes of the atmospheric and oceanic circulation and the well-known physical processes at any height levels in the atmosphere and the active layer of the lithosphere. This global approach, based on the physical theory of climate,[8] has no boundary conditions on the spatial coordinates.

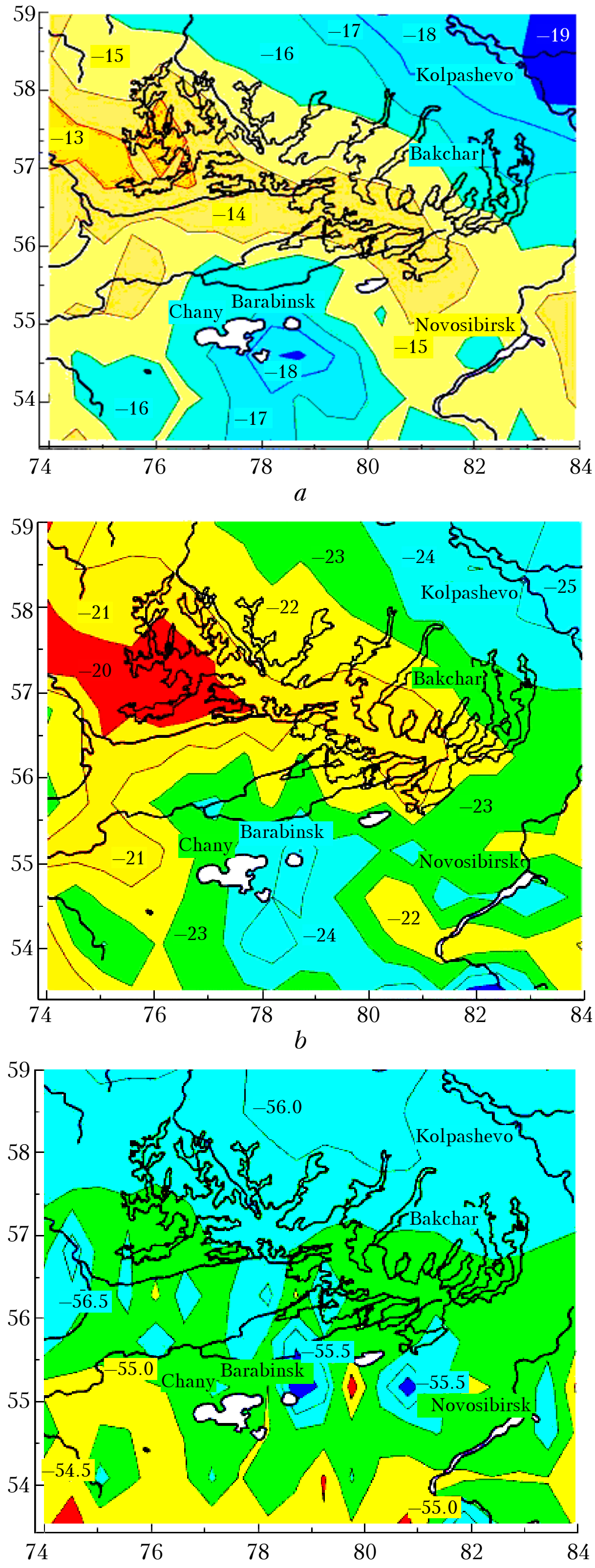
It is difficult to verify the trajectories calculated by such models, since the global observation network is arranged non-uniformly on the Earth's surface (mostly, on the land), and a limited number of parameters are acquired instrumentally. Nevertheless, as was noted in Ref. 8, there are likely no other ways to better understanding of the climate sensitivity than the modeling of climate. It is a risky gamble with uncertain and, probably, quite low chances for success, however, the game is worth the candle, since our hopes for useful returns are high.

On the other hand, the series of instrumental observations compiled in many regions of the planet already many times exceed the time interval needed (30 years), within which it is believed that the averaged meteorological parameters characterize the climatic system. The statistical processing of these observation series allows one not only to verify the existing mathematical models for significant time periods, but also to reveal possible empirical regularities. However, to reveal these regularities, it is necessary first to study the scales of the territories (spatial scales) and times (time scales), within which one or another dynamic characteristics of the regional climatic system are homogeneous as concerning the governing factors.

The horizontal scales of regional peculiarities in the observed environment and climate changes in Siberia can be estimated from the map of linear warming trends, which we have drawn for the period from 1955 until 1998 (Refs. 2 and 9). It follows from this map that with the characteristic trends of 0.3–0.4°C per 10 years the major part of the Siberian territory includes also the spots of more fast warming (0.5°C per 10 years) having the subregional scales of 100 to 200 km. This mesoscale inhomogeneity of the observed warming coincides in the scales with the inhomogeneities of some other meteorological parameters (for example, thunderstorm activity[10]), and, consequently, it should be taken into account in monitoring and modeling the regional climatic systems.

The influence of ecological systems on the horizontal scales of inhomogeneities in the observed changes follows from the results of processing of MODIS satellite data for the territory of the Great Vasyugan Bog.[11] Figure 3*a* shows the map of the monthly mean near-surface temperature (at a height level of 1000 mbar) for February 2004. The latitude and longitude in degrees are plotted as the ordinate and abscissa, respectively.

The Great Vasyugan Bog, whose total area is 53 thousand km$^2$, is outlined at the center of the figure. As can be seen from Fig. 3*a*, the contour of the territory with the increased near-surface temperature in February is close to the contour of this bog ecosystem. We attribute this warming effect to the particular thermophysical properties of the peatbog. The analogous maps for the summer months clearly demonstrate the cooling effect of this bog having the mesoscale dimensions.



a

b

c

**Fig. 3.** Distribution of the temperature field at different heights over the territory of the Great Vasyugan Bog as judged from the satellite data (MODIS spectroradiometer, February 2004): 1000 mbar (~0 km) (*a*); 700 mbar (~3 km) (*b*); 300 mbar (~ 9 km) (*c*).

The vertical scales, within which the subregional peculiarities of ecological systems manifest themselves, follow from Figs. 3*b* and *c*. The configuration of the temperature field at different heights, as can be seen from Fig. 3, appears to be inhomogeneous over the Great Vasyugan Bog and adjacent territories up to the tropopause (300 mbar). Thus, the vertical scales of the subregional inhomogeneities significantly exceed the height of the atmospheric boundary layer (about 1000 m), within which the state of the atmosphere is commonly believed to be dependent on the properties of the Earth's surface.

The above estimates of the spatial scales for the regional and subregional peculiarities in Siberia seem to be quite reliable and agree with the phenomenological observations. Despite the qualitative estimates made using absolute values of the observed parameters may have some errors of the instrumental and methodic character, the obtained relative values of these parameters (spatial distribution) cast no doubt and can be used for the justification of territorial scales of the combined climate and environmental monitoring and for the modeling of regional climate systems.

## Time scales of observed changes

The investigations of dynamic characteristics of regional climate–environment systems are necessary not only in trying to reveal regularities in the observed climate and environmental changes, but also to solve the methodological problems of integrated regional studies. Yet in 1986 Academician M.I. Budyko said that, in the absence of the common definition of the time scale separating the weather-forming and the climate-forming processes, it is not always possible to distinguish between weather catastrophes and climatic catastrophes.[12] But the issue of extreme meteorological phenomena (in particular, catastrophes) caused by weather or climate processes is one of the aspects in the problem of individual description of climate changes (processes). This problem also gives rise to the issues of the spatiotemporal scales of the observed climate changes and the governing factors causing these changes, as well as the dynamic characteristics, which can be used for the adequate description of these changes.

Below we present the results obtained from correlation analysis of the compiled time data series for some instrumentally observed parameters, used widely as dynamic characteristics of the climate. The time series were analyzed using the wavelet transform approach,[13,14] which is, in our opinion, more adequate in application to the spectral-band character of climatic changes as compared to the Fourier transform of such series.[15]

Based on data from Ref. 16, Fig. 4 shows the correlations between the wavelet spectra of the time series of the annual mean surface temperature at the territory of Western Siberia and some planetary indices. The wavelet position on the current year scale is plotted as an abscissa, and the scales of periodicities in the wavelet spectrum are plotted as an ordinate. The different degree of blackening in Fig. 4 corresponds to the different values of the correlation coefficient (numbers).

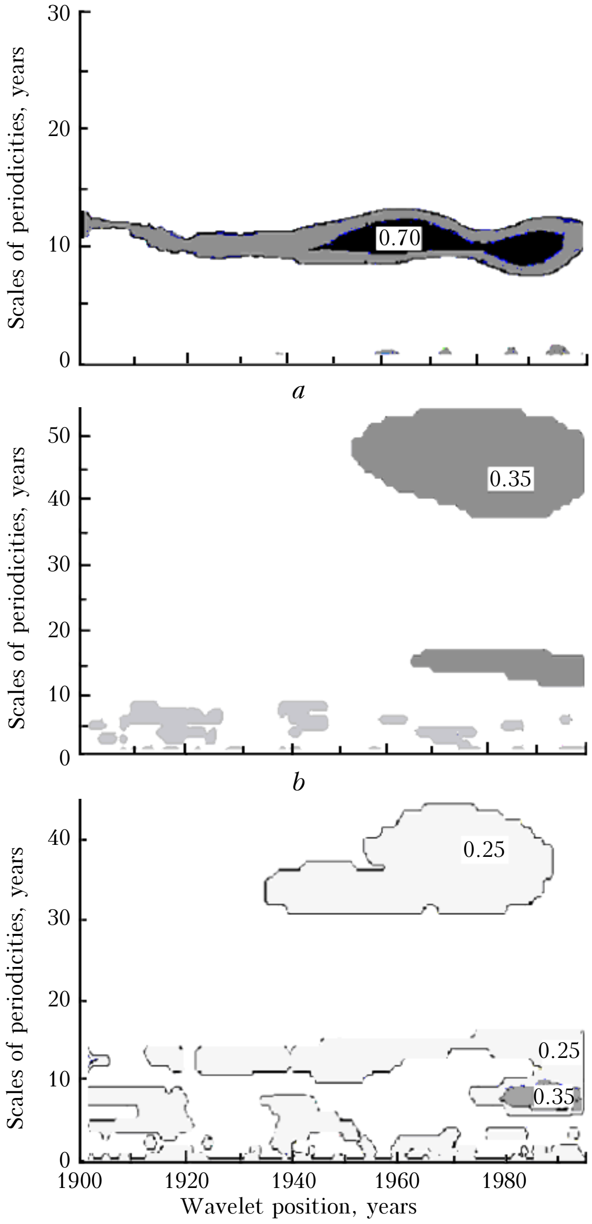


**Fig. 4.** Wavelet correlation of the annual mean surface temperature for Western Siberia with the Wolf numbers (*a*), Southern Oscillation Index (*b*), and North Atlantic Oscillation Index (*c*).

It can be seen from Fig. 4*a* that for the scales of periodicity equal to 9 to 14 years, which are revealed by the wavelet transform of the time series, in the last half of the 20th century the stable correlation was observed between the annual mean surface temperature and the Wolf numbers. This result with the rather high value of the correlation coefficient (0.7) is indicative of the significant role of the solar activity in these years for the revealed scale of periodicities, which reflect the rhythm of climate, rather than weather processes. It should be noted that for other scales of periodicity the correlations between the wavelet spectra of these parameters appeared to be statistically insignificant.

Figures 4*b* and *c* show the correlations between the wavelet spectra of the annual mean near-surface temperature and such planetary indices as the Southern Oscillation Index and the North Atlantic Oscillation Index. In both cases, for the small-scale periodicities (< 15 years), the correlation between these parameters is unstable. At the same time, the statistically significant correlation (the correlation coefficient up to 0.35) takes place for the scale of periodicity longer than 30 years. This correlation, hidden in the simple time series and revealed from the wavelet spectra, can be considered as a climatic phenomenon of 1940–1980s. The time of its appearance almost coincides with 1950, which was mentioned in Ref. 17 as a turning point in the evolution of the global atmospheric circulation in the 20th century. The finite time of this phenomenon coincides with 1980, noted in Ref. 18, after which the curves for the mean power of the solar cycle and the surface temperature near Irkutsk, averaged for the period of the solar cycle, which were earlier synchronous during the century, became to diverge (Ref. 18, Fig. 11).

To reveal the nature of this climatic phenomenon, we have determined the phase shifts of the wavelet spectra for the time series of the annual mean surface temperature and the North Atlantic Oscillation Index.[16] This choice of the correlating parameters was connected with the well-known predominating effect of the western transport on the climate in Western Siberia. The calculated results are shown in Fig. 5, where the different degree of blackening corresponds to the different values of the phase shift in years.

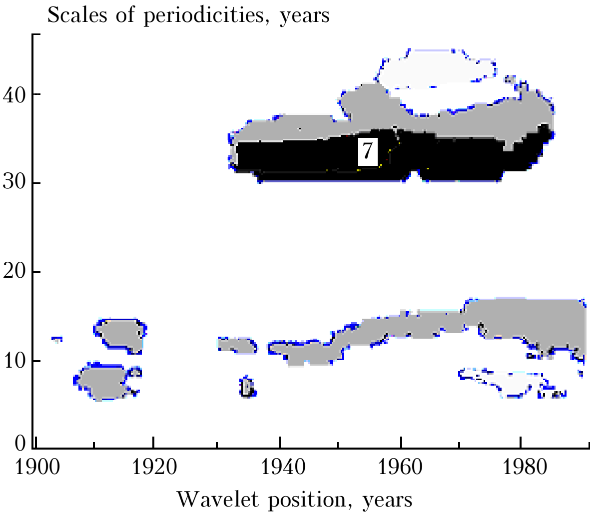


**Fig. 5.** Phase shifts between the wavelet spectra for the annual mean surface temperature in Western Siberia and the North Atlantic Oscillation Index.

As can be seen from Fig. 5, no phase shifts for the small-scale (5–7 years) periodicities can be revealed within the calculation error, while for the periodicities of a moderate scale (10–15 years) these are from 1 to 3 years and only for periodicities with the large scale (30–40 years) increase to 7 years. These many-year phase shifts for the periodicities with the moderate and large scale are indicative of the significant correlation between the warming observed in the region and not only the low-inertia mechanisms caused by the atmospheric circulation, but also with the more inertial mechanisms of the oceanic circulation.

## Conclusions

The spatial and time scales considered in the observed environment and climate changes in Siberia are from the category of significant ones, but not covering all the random and deterministic characteristics of the regional environment–climate system. Our analysis of mostly annual changes did not include, for example, systematic oscillations observed during a year, whose amplitude in Siberia many times exceeds that of the observed annual variations. Such oscillations are caused by weather processes, but the trends in changes of their amplitudes and phases are climatically significant being caused by climatic processes. Many other characteristics of regional environment–climate systems also remained beyond our consideration. Nevertheless, the results discussed above already allow us to formulate the priority tasks for the integrated regional studies.

The highest-priority tasks include:

– justified selection of territorial scales for the combined climatic-ecological monitoring, which is now being carried out at the Institute of Monitoring of Climatic and Ecological Systems SB RAS at four stationary sites separated by 200 km and situated in geographic regions characteristic of Western Siberia;

– justification of dynamic parameters for the consistent description (by models and by empirical data) of those climatic and ecological processes, which are now described either by functionals of weather processes with their following averaging over a climatic period (for climatic systems) or by phenomenological characteristics (for ecological systems);

– development of scientific methodical principles of analyzing the instrumental data compiled and revealing regularities in the current environment–climate changes for the creation of the needed empirical database for modeling, prediction, and possible regulation of the occurring regional changes taking into account the growing role of the anthropogenic impact.

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