Results and problems of monitoring the current environmental and climate changes in Siberia

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Received November 12, 2001

New methods and some results of analysis of environmental and climate changes in Siberia based on the data of hydrometeorological observations are discussed. Certain regularities are revealed for the period of instrumented observations of regional changes. They are called current changes. The problems of development of methodology and instrumentation for monitoring of natural and climate systems and processes determining the evolution of their states are analyzed. The results of research and design activity at the Institute of Optical Monitoring SB RAS are evaluated from the stand point of its relation to the general research field.

Introduction

The rate of global changes in the environment and climate observed in the second half of the 20th century seems to be very dangerous for sustainable development of the Earth's civilization. A capacious alternative "the only way of saving the world will be for industrial civilization to collapse" formulated by Maurice Strong, the Secretary General of the 1992 UN Conference on Environment and Development (the so-called Earth Summit) held in Rio de Janeiro, summarized the indisputable, at that time, results of scientific research and favored adoption of documents strategically important for the further development.[1] The results of the Earth Summit were not only adoption of such documents as well-known Agenda 21, Rio Declaration on Environment and Development, UN Framework Convention on Climate Change, UN Convention on Biological Diversity, etc., but also international and local programs of research into the observed global changes and negotiation of disbalance between the social and economic development and environmental management.

The Siberian Branch of the Russian Academy of Sciences also developed regional interdisciplinary projects aimed at the research into changes in the climate and environment. One of the first projects was the Project "Climate and Ecological Monitoring of Siberia" formed in the IOM and included (since 1993) into the Regional Scientific and Technical Program "Siberia." Numerous academic and higher education organizations became co-executors of this project. Then the Project extended within the framework of both related integration projects and priority areas of the basic research.

Planetary-significant features of Siberia are of principal importance for successful development of basic and applied research into the environmental and climate changes in this region. One of such features is that meteorological characteristics here vary in a very wide range, and their spatial variability is characterized by a complex zonal structure. Therefore, climate monitoring in Siberia is of great scientific interest, especially in view of observed global changes. Another feature of the vast continental Siberian region is connected with numerous unique objects of planetary importance, which include both natural and territorial objects (boreal forests, wetlands, Lake Baikal, etc.), as well as technogenic objects (oil and coal extraction, transportation, metallurgic plants, transportation objects, etc.). Therefore, monitoring and modeling of regional environmental and climate changes in Siberia are of practical importance as well.

In this paper, we discuss some selected results and research problems on regional monitoring of the environment and climate in view of the observed global changes and with the allowance for features in the interaction of natural and climate systems in Siberia. This review is aimed at discussion of results that are most essential for further development of the concept of regional monitoring based on the material published in this issue, as well as other related publications.[2–4]

Some taxonomic regularities

Rather long and homogeneous series of instrumented observations on the global network of meteorological stations are now available for a rather long period (more than 100 years), and they allow revealing the regularities in the observed changes in many parameters of natural and climate systems. Keeping in mind that some of these parameters or their combinations can be considered as classification indices (taxons) for separation of subsystems in a natural system, regularities in the zonal (spatial) structure of the latter can be called taxonomic regularities.

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Taxonomic regularities in the temperature conditions, which can be considered as a final index (taxon) of many natural and climate processes, are revealed through statistical processing of time series for the surface air temperature. The statistical analysis used the time series of monthly mean temperatures measured at Siberian meteorological stations for several decades.[5] To decrease the effect of synoptic factors, a time series was considered as comprising of three components: long-term temperature trend, mean temperature for a particular month, and deviations (anomalies) of the monthly mean temperature of particular months from their climatic values. The results on zoning by use of temperature trends are shown in Fig. 1. It can be seen from this figure that in all Siberian regions the annual temperature increases systematically and inhomogeneously with the trend higher than that on the planet as a whole. One can see the zones of accelerated warming with the trend up to 0.5°C/10 yr: one in the West Siberia (near Surgut) and several in Eastern Siberia (including one near the Verkhoyansk pole of cold).

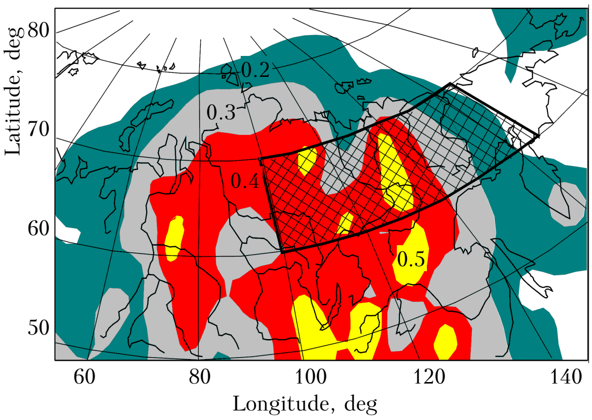

Fig. 1. Climatic zones in Siberia in accordance with the temperature trend in the surface atmosphere.

For the temperature fields in the surface atmospheric layer, the regional peculiarities were revealed in the dependence of seasonal variations of the monthly mean temperature (amplitude of the annual temperature behavior A_T) on the annual temperature T. This dependence is very close to the linear one:

$$A_T = \alpha\,(300 - T), \qquad (1)$$

(T in K). The value of α for the Northern Hemisphere is equal to 0.56, and for Siberia it takes the values from 0.4 to 0.8 in different climatic zones. It should be emphasized that the dependence (1) is closely connected with the conditions of heat and moisture transfer in the surface atmospheric layer, and it opens up new possibilities for the following interpretation of taxonomic regularities.

The following taxonomic regularity in Western Siberia was revealed for the thunderstorm activity,[5] which is a generalizing indicator (taxon) of the phenomena and processes connected with atmospheric and lithospheric electricity. Figure 2 shows the mean duration of thunderstorms for the corresponding season (solid curves); the dashed curves show the borders of the studied region. To be noted is the latitudinal distribution of zones with the maximum thunderstorm activity (70 h) near the latitude, at which the Big Vasyugan Bog is situated.

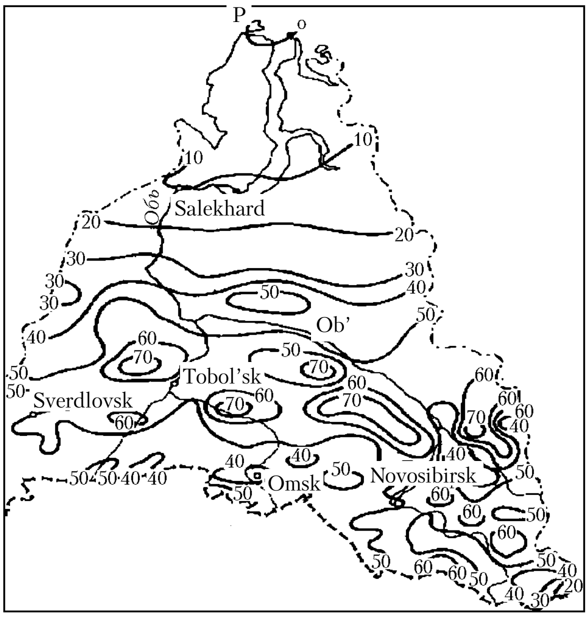

Fig. 2. Map of annual duration of thunderstorms (in hours) for Western Siberia.

These regularities, as well as some other taxonomic regularities described in Ref. 5 show that the increased warming rates in Western Siberia have a zonal character. This supports significant regional peculiarities of observed environment and climate changes and refines their spatial scales. It follows from the obtained data that the problem on arranging several basic monitoring centers in characteristic natural and climatic zones is especially urgent for Siberia.

Some temporal regularities

Analysis of temporal variability of natural and climatic systems usually reveals regularities of not only their annual variability, but also periodicities of their variation for several years. Let us use the term "temporal regularities" as common for these regularities.

Temporal regularities, which follow from processing of temporal series of some or other parameters of natural and climatic systems form the necessary experimental basis both for testing different models of global or regional changes and for optimizing the regime of monitoring of the corresponding systems. Therefore, revealing temporal regularities and development of new methods are of particular interest.

Wavelet transformations are among the promising methods of statistical analysis of time series, which have successfully been used and developed in recent years.[6,7] Unlike the Fourier transformation, this method using a soliton-like function (wavelet) reveals the spectrum of statistically important periods in a time series. Some results of wavelet analysis are presented in Ref. 8. In this paper, we only illustrate the efficiency of wavelet transformation (Fig. 3). It can be seen from Fig. 3 that statistically significant periods (scales) in variation of the annual temperature changed markedly for the last century. The scales of 20–30 years characteristic of the early 20th century transformed into the scales of about 15 years tending to further decrease and into the scales of 30–40 years tending to unification with larger scales at the late century.

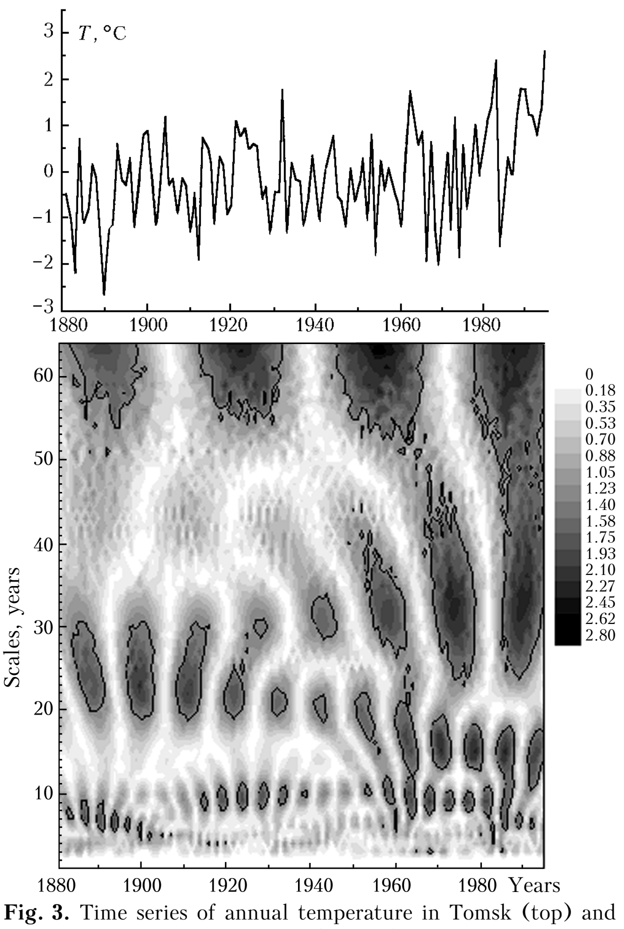

Fig. 3. Time series of annual temperature in Tomsk (top) and wavelet transform of this series (bottom).

Additional temporal regularities follow from the correlation analysis of wavelet transforms. The Table presents those correlations for periodicities in temperature series, which follow from a comparison of wavelet transforms for several cities. The term "periodicity" (in years) applies to the lower border of wavelet transforms on the "filter scale" (by the filtering parameter of the wavelet function) of 5, 11, 22, and 30 years. It is seen from the Table that for the temperature periods from 5 to 30 years, the correlation coefficients decrease with the distance from the basis (Tomsk), and in Blagoveshchensk they have no significant value for the periods of 5, 11, and 22 years (dashes in the Table). Only for the scale of 30 years the correlation coefficients are high for all cities. It is worth noting the marked deviation for Krasnoyarsk in the 30-year scale; it can be explained by such a powerful anthropogenic factor as filling of the Krasnoyarsk water reservoir in 1967–1970, i.e., within this period.

Another efficient method for analysis of environment and climate changes is based on the new system-evolutionary approach developed by us and called the method of evolutionary trajectories.[5] The advantage of this method is that it reveals regional features in climate- and environment-forming processes without distortion by smoothing averaging, which is usually applied to remove the oscillating character of temporal series and to reveal regularities of the long-term trend.

Figure 4 exemplifies trajectories of the monthly mean temperature as judged from the data of relatively close meteorological stations. The parameter Z is the sum of monthly mean temperatures T_m (°C):

$$Z = \sum_{1}^{N} T_m, \qquad (2)$$

where N is the total number of months for all the summed years. Oscillations of the curves show the seasonal temperature fluctuations and, as is seen from the figure, do not hide the trajectory of the envelope of annual variability. Marked sharp turns of the depicted evolutionary trajectories (for example, in the mid-60s and mid-80s) coincide in time and character, as would be expected for the three cities situated in the same climatic zone. At the same time, the clear separation of these trajectories in the selected coordinates opens wide possibilities for the further finer analysis of available regional peculiarities and for their rigorous mathematical description. In particular, the noticed low correlation coefficient in the 30-year periodicity for Krasnoyarsk (see the Table) is supported by the obvious discrepancy in the evolutionary temperature trajectories for Omsk and Krasnoyarsk after filling of the Krasnoyarsk water reservoir.

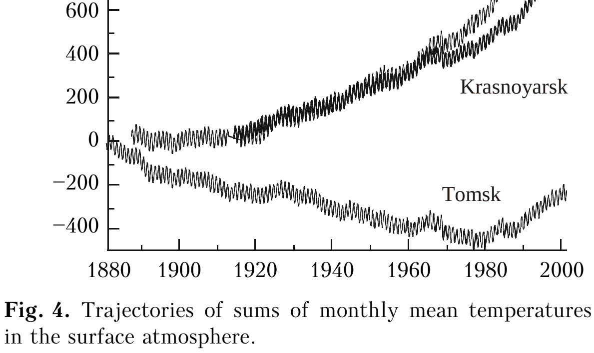

Fig. 4. Trajectories of sums of monthly mean temperatures Z in the surface atmosphere.

Table. Correlation coefficients for different scales of periodicities in temperature series between Tomsk and other cities

Periodicity, years	Omsk	Krasnoyarsk	Irkutsk	Blagoveshchensk
5	0.85	0.81	0.51	–
11	0.88	0.81	0.75	–
22	0.89	0.87	0.81	–
30	0.97	0.79	0.95	0.91

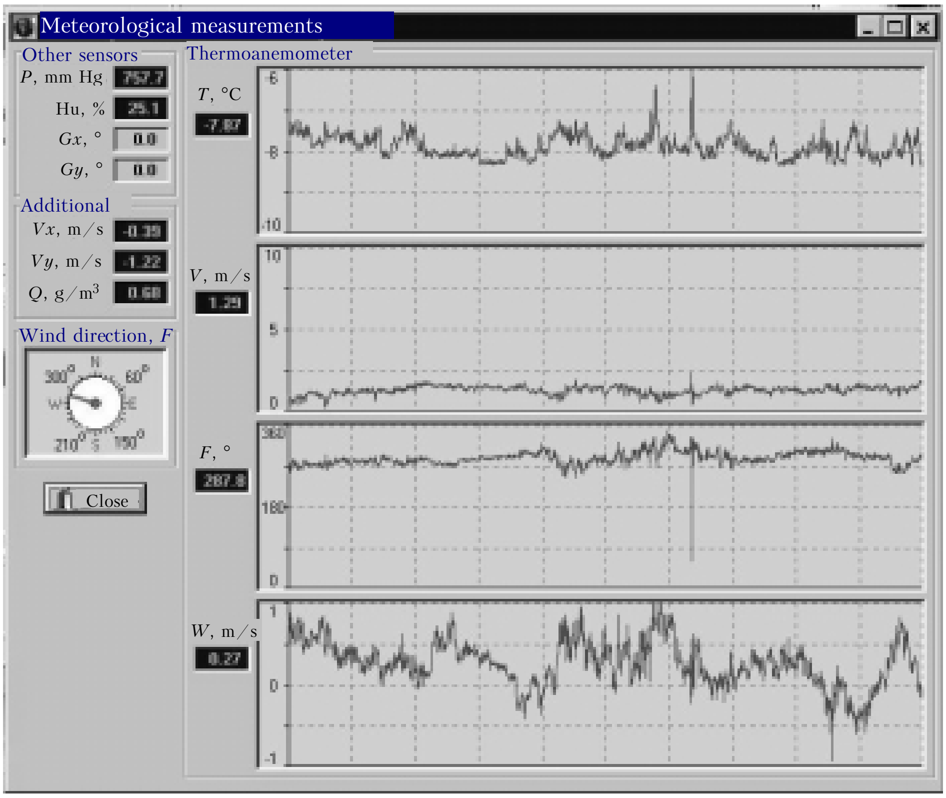

Fig. 5. Signals from AMK sensors as displayed on a monitor.

The temporal regularities for Siberia that are presented in this paper and in Refs. 5, 9, and 10 show that they can be efficiently analyzed not only by the traditional statistical methods, but also by some new ones. The results of analysis with these methods show that the evolutionary trajectories for some parameters of the natural and climatic system of Siberia differ markedly from each other and from the corresponding trajectories for the observed global changes. Herefrom we have a need in the territorial integration of different monitoring networks (hydrometeorological, actinometric, ecological, monitoring of atmospheric electricity, etc.). Some experience in this field is now accumulated in the Climate and Ecological Observatory of the IOM.

New methods and technical facilities for monitoring

In the process of revealing new regularities and problems in simulation of regional environment and climate changes, disadvantages of the traditional environmental and climate monitoring become increasingly evident. They are connected with poor instrumentation and geoinformation provision as applied to the regime and format of instrumental observations in both ground-based and aerospace monitoring.[2,11] The current requirements on the experimental data needed for simulation and prediction stimulate, to some extent, the development of new methods and technical means for monitoring of the environment and climate.

Using the available instrumental base, the IOM has developed some new devices corresponding to the up-to-date standards and operated at the Geophysical Station of the Institute in the monitoring regime in parallel with traditional instrumental facilities. Among such devices having new functional capabilities for experimental studies under field conditions, are the AMK autonomous meteorological system, the MS mini-sodar, and the MGR multichannel geophysical recorder. They all, having a short time delay, can measure simultaneously the mean values of the measured parameters and their derivatives in real time, as well as provide for flexible computer processing of the measurement data.

For illustration, Fig. 5 depicts a 3-minute record of signals from the AMK sensors for the temperature T, wind velocity components (speed V and direction F of the horizontal component and the speed W of the vertical component), as well as the current values of the pressure P and humidity Hu. The following computer processing of such signals with the allowance for their functional relation and calibration of the sensors gives the values of more than 10 atmospheric parameters with acceptable accuracy. A more detailed description of this device, as well as of the others mentioned above can be found in other our papers included in this issue.

Along with the already developed devices, which are now manufactured not only in the IOM but in some foreign countries, some other devices are now at the final stage of development. In the IOM they are the laser ceilometer, the RGA modernized mercury gas analyzer, and the APL stationary aerosol polarization lidar. Many other domestic and foreign devices are of interest for monitoring of environment and climate changes. Among them, a particular place is occupied by the methods and means for remote sensing of the environment. Therefore, nonlinear optical frequency converters being very important elements in laser remote sensing that are developed in the IOM and discussed in this issue seem to be promising for the development of new-generation measurement instrumentation.

Conclusion

The studies of regularities in the global and regional environment and climate changes from the data of instrumented observations, as well as development of new methods and technical facilities for monitoring of the physical state and processes in the environment form the main branches of the research field, which can be called experimental physics of environment and climate changes. From this point of view, the known theoretical studies of physical states and processes in the environment, as well as simulation of environment and climate changes based on the revealed regularities can be called theoretical physics of environment and climate changes. Such a view on the study of the current dynamics of the global and regional natural and climatic systems is now becoming generally accepted,[12] and this provides for the needed basis for the development of both the instrumentation and technology of monitoring of the observed changes.

Another group of problems arising at the study of current environmental and climate changes is connected with the organizational aspect of monitoring. The point is that at the multiparametric dependence of natural and climate systems and processes determining their evolution, organization of monitoring of only some parameters or processes excludes the possibility of their unambiguous interpretation. Combined simultaneous monitoring of all components of the environment (atmosphere, hydrosphere, and lithosphere) and all processes (physical, chemical, biological, anthropogenic) is needed. It is just this combination of efforts that is the major task in organization of regional monitoring carried out at the IOM within the integration (multidisciplinary) research programs of SB RAS and Ministry of Industry, Science, and Technologies of Russia, as well as international projects.

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