Modelling of the evolution of the multi-behavioural dynamics from the regulatory climate theory

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Abstract. The regulatory ability in the local climate dynamics to evolve in accordance with the environmental changes is modeled in the paper. The specialized software provides the following research program: to calculate the solutions of the nonlinear nonstationary multi-behavioural model of the dynamical system with variable structure; to determine the nonlinear dynamics regularities on the basis of these solutions; to reconstruct these regularities by processing the meteorological observations; to solve the inverse problem of building the multi-behavioural portraits of local climate dynamics by use of the reconstructed regularities. Thus factually realized and potential evolutorial vacancies of the local dynamics are visualized in the form of the multiple attractors. The physical basis of the research originates from the regulatory climate theory, in accordance with which the local climate dynamics is conceptually considered as the dynamics of the solar energy converter under the astronomically forced hysteresis control with double synchronization. Here landscape and ecological relations are taken into account via the adaptation unit, and the recent dynamics is compared with the one observed as far as possible distant in time. So, structural modifications within the multi-behavioural portrait of local climate dynamics are revealed and crucial evolutionary tendencies are demonstrated.

1. Introduction

Accelerating atypical climate processes, for example [1-4], stimulate to try to make decision concerning responses to them at the expense of the development of the global market for environmental goods and services, for example [5-9]. So, let a local climate system really change its habitual behaviors. Then this system should possess the corresponding potentialities to behavioral modifications (i.e. it is a topic on multiple attractive volumes in the phase space) and the corresponding mode to control such modifications (i.e. it is a topic on a control law with adaptation). The bifurcation theory is required necessarily to analyze without bias the first topic, and the control theory is required necessarily to analyze without bias the second topic. Since these requirements are not supposed in accordance with the general usage to analyze climate changes, for example [4; 10-11], then the cause-and-effect mainstream of evolutionary changes remains originally beyond the considerations, for example [12].

So, the traditional uncertainty of climate predictions, for example results in [13] as well as in [14], originates from the stop in the classic climate theory but not from the computational power. Per se, the appropriate conceptual model is required to resolve this paradoxical situation. Building such model supposes that the observed climate oddities should be thoroughly summarized but not excluded in order to specify a kind of the nonlinear system, dynamics of which could be associated with the
climate dynamics. The main indicator on whether a conceptual model is successful or not seems to be connected with the problems generated by the phenomenon of the so-called interannual variability, for example [15-17]. This phenomenon seems to be naturally built into the dynamics demonstrating by nonlinear systems under the hysteresis control with double synchronization (the so-called HDS-control, for example [18]).

In other words, the unique peculiarities of the HDS-dynamics are in very close agreement with the ones observed in local climate dynamics, for example [12; 19]. The regulatory hypothesis on local climate dynamics proposed in [20] accepts this fact; and till now it remains the first and only chance to reconstruct local climate evolution from the nonlinear regularities excused by the bifurcation and control theories on the basis of processing the data of meteorological observations, for example [12; 19-20]. Yes, in this case, the field of the classic climatology becomes extremely specific shifted towards the intersection with the nonlinear dynamics and control theory in application to systems of variable structures (i.e. towards the problems of the numerical methods to analyze nonlinear dynamics discussed in [12; 21-23]), including corresponding unusual imitations of geodynamical processes, for example [19; 24-26]. Nevertheless, this problem statement is conceptually resolvable.

The peculiarity of the research consists in the following: the potentiality of the local climate dynamics is detailed by the adaptation feedbacks taking into account variation of the parameters associated with landscape and ecosystem characteristics in order to estimate whether the anthropogenic impacts can change habitual climate behaviors. Here the phase portrait of the local climate dynamics is reconstructed as the five-component multiple attractor, where factual realizations and potential vacancies of the dynamics are visualized. The evolutionary differences in local climate dynamics over the last century are discussed, and the corresponding conclusions are presented. In particular, we believe that the consequences of anthropogenic influence on the “erosion” of local climate are underestimated as well as it seems to be underestimated in what extent local climate changes can influence on regional and global ones.

2. Data and Methods
The particularities of the instrumental data on the dynamics play important pole to plan the research. Namely, there are circumstances, for example [12; 27-29], due to which the following point becomes crucial: what is the normal climate (i.e. the climate without the man's impact) if the horizon of the reliable meteorological observations is too short (60-140 years and even shorter)? In particular, the research is based on the open-access data on the air surface daily mean temperature in the continental part of Siberia retrieved from [30]. At the same time, any meteorological record registers only one of many evolitional scenarios, and it is impossible to return to the same initial conditions to realize physically other variants. That is why it seems to be very interesting to find a way to reconstruct the spectrum of all the behavioral potentialities for a particular local climate system (hereafter, the ensemble of attractive phase clouds). Thus, recent and distant in time states can be compared to make the sound conclusion on acting and forthcoming evolutionary tendencies or on their absence.

The regulatory hypothesis opens such ability by considering the climate dynamics like the technical system dynamics under the same control. This statement attracts to the research the specialized scientific and engineering experience. In particular, the following verified tools were applied in this connection: the computer-based bifurcation analysis to reveal the structure of nonlinear dynamics solutions in the phase space, for example [31]; physically-based methods to verify the results of the modelling by tests carried out on electrotechnical simulators, for example [12; 19]; the concept of the dynamics reconstructions by processing the data of meteorological observations, for example [12]. Here this concept is defined more precisely with the adaptation unit (figure 1a). As a result, the initial behavioral ensemble consisting of three elementary processes (painted blue, black and red in the central part of figure 1b) is supplemented by two components (painted magenta and cyan on the left and right parts of figure 1b).

The research program was realized in the following logicality. First, the solutions of the nonlinear nonstationary multi-behavioural model of the dynamical system of differential equations with variable
structures were determined and stability of these solution was analyzed. Second, the nonlinear dynamics regularities on the basis of these solutions were revealed. Third, the regularities in the revealed form were reconstructed by processing the meteorological observations. Fourth, the multi-behavioural portraits of local climate dynamics were built from the reconstructed regularities. Let us illustrate the result of this research.

Figure 1. The equivalent scheme of the HDS-regulator with adaptation (a). Three elementary processes and their adapted versions (b), five-component multi-behavioral ensemble (c), and extending-by-parametric-variation phase volumes of L-process without (d) and with (e) adaptation.

3. Results
In accordance with the HDS-law, the elementary processes are clearly distinguished from the geometrical peculiarities (figure 1b, central part): L-process (left-process) with \( k < 0.5 \); R-process (right-process) with \( k > 0.5 \); C-process (central-process) with \( k = 0.5 \), where \( k \) is the main bifurcation parameter describing a duration of a phase variable increase in relation to the synchronization period \( T_s \). The adapted versions of L- and R-processes (L*- and R*-processes in right and left parts of figure 1b) are located about the reference. So, the ensemble includes five components with the same period \( T_s \), where phase sharp bends are obeyed the competing amplitude quantization and time quantization realized via hysteresis restrictions (H-range between the surfaces denoted by 1 and 3 in figure 1b and after) and via synchronizing regular impacts shifted in \( T_s / 2 \) (surfaces denoted by 2 and 4 in figure 1b and after).

So, let the main phase variable of the multi-behavioral portrait of the local climate dynamics (figure 1c) is associated with the air surface temperature (\( T \)). Since a local climate system exists under perpetual variation of different parameters, then each of the behavioral components unfolds into an attractive cloud consisting of a set of phase trajectories quantitatively modified with variation of the equivalent parameters. These modifications are clear interrelated via the dynamics regularities in accordance with the HDS-law (summaries to these relations are in [12; 19]). In particular, modification principles in accordance with \( k \)-variation for non-adapted and adapted versions of L-process are illustrated in figure 1d and figure 1e correspondingly. Here the physical meaning of the
adaptation originates from the control theory, namely: the initial phase trajectories of R- and L-processes (painted blue and red in figure 1b) are shifted upward (right part) and downward (left part), correspondingly, to reduce a deviation ($\varepsilon$) from the reference value ($T_{ref}$) to zero (figure 1e).

Taking into account the bilateral relations between parameters and phase trajectories, the scope and structure of the behavioral potentialities can be visualized in the phase space by two attractive clouds of $R$-$L$-processes under the switched-on adaptation (painted magenta and cyan in figure 2a), two attractive clouds under the switched-off adaptation (painted red and blue in figure 2a), and C-process attractive cloud (painted black in figure 2a) realizing the basic “transportation” function. The total phase volume covered by these clouds shows time-and-temperature limits, within which the local climate dynamics can evolve (for example, the volume contoured by gray in figure 2a). Factual realizations are reconstructed with the parameters observed over the corresponding term, and evolution vacancies are reconstructed with the parameters generalized throughout all the terms. So, let us trace the evolution of the behavioral portrait in Yakutsk (WMO-index 24959, deep continental part of the permafrost region of Siberia, Russia) over the anthropogenic forces.

**Figure 2.** The reconstructed behavioural potentialities (a) and man-made influence (b) in Yakutsk. The phase volumes (c) during pre- and post-industrial local terms in comparison with the volume of the behavioural potentialities (gray background). Zoomed-in fragments of the multi-behavioral portraits about the non-adapted L-clouds (d, e). Tendencies of annual maximums (f) and minimums (g) compared with the annual temperature means (h). Here pre- and post-industrial local terms painted green and orange correspondingly.
The scheme in figure 2b shows the population upsurge (bold blue dotted graph) and increase in the total power of the thermo- and hydro-electric power stations about this town (bold black dotted graph), due to which the insignificant (I) and significant (II) anthropogenic impacts are clearly separated. Let us compare the total phase volumes of the behavioral realizations existed in these two cases (green and orange outlined in figure 2c correspondingly) with the potential vacancies throughout the observation period (gray background). So, the outside differences exist but they are not crucial in comparison with the inside repartition of the vacuous interval between the attractive clouds (white gaps in figure 2a and in zoom-in fragments in figures 2d and 2e). Per se, these intervals determine energy barriers from one attractive cloud to another one and their magnitudes regulate which fragments of elementary processes will compose the phase trajectories of the running annual cycle under parametric variation over this year.

So, the annual cycle is personified by the route of the phase point within and between the clouds depending on the directions permissible in accordance with the HDS-algorithm and on the distances between the attractors accessible in this connection. A widening/narrowing barrier can change crucially the local temperature portrait independently of regional and global circumstances. Namely, from the reconstructions, the surmountable barrier is about 1.5 - 2.5°C. During the I

Period in Yakutsk, the surmountable barriers provided the access to the non-adapted R-cloud only (i.e. to the comparatively cold states denoted by blue in figure 2a) and the 4°C-barrier (zoom-in fragment in figure 2d) blocked the access to the non-adapted L-cloud (i.e. to the comparatively hot states denoted by red). During the II

Period, the barrier to the non-adapted L-cloud becomes equal about 2.5°C (figure 2e), that is why this cloud can be already involved into the phase route, and the corresponding hot temperature becomes expected in annual realizations.

In other words, the regulatory climate theory states that the annual warming-cooling cycle is formed via the attractive clouds, volumes and relative positions of which are modified with variation of the parameters of the local climate system. Some of these parameters are astronomically depending and are practically fixed at least last centuries, for example [32-33]; however, parameters depending on landscape and ecological characteristics can be extremely rapid changeable, for example [29; 34-35]; the last destroys the balance of adaptive properties naturally tuned during previous thousands. So, the combination of bilateral feedbacks between climatic and geo-ecological constituents modifies and can activate the stabilization/destruction of the running environmental conditions. Anyway, changes in temperature behaviors are not monotonous shifts towards warming or cooling. For example, tendencies of annual extremums can be differ in activity and/or direction (figures 2f and 2g). Per se, it is originally impossible to determine statistical correlations between such evolutionary changes and the annual means (for example, figure 2h), to which the majority of the climate forecasts addressed.

4. Concluding discussion
The regulatory processes carried out in the local climate systems are aimed at the control error minimization at the expense of various internal qualitative and quantitative structural modifications which can be outwardly imperceptible over quite long time (over one or several decades at least). At the same time, such modifications as well as the multi-behavioral pattern are not supposed to existence in application to local climate systems in the context of the classical climatology. We believe that the strategic planning from such position seems to be irrational because it seems to be impossible to have a consistent-with-the-observed-events opinion on the local climate changes from the uni-behavioral climate norms. However, these norms are predominant at present. Per se, the habitual outward averaged indicators to characterize climate changes are already late because their atypical values occur when the catastrophic “corrosion” of landscape and ecological characteristics are already happened.

From the regulatory climate theory, the local climate dynamics observed over last centuries is visualized as multi-behavioral five-component phase portrait. And the tendency towards the surmountable temperature barriers between all the components is identified. It means that local temperature behaviors will change crucially even independently of regional and global circumstances; and extremely homogeneous local climate dynamics becomes expected. The contemporary
anthropogenic influence represents the main stimulator towards such climate. Per se, the following mechanism occurs: the regulatory processes minimize/stabilize the control error at the expense of internal structural modifications within the local climate pattern; the local ecosystems evolve throughout centuries to “promote” desirable climate tendencies and to “hinder” from undesirable ones at the expense of natural perpetual parametric variation; however, intensity and directions of parametric variation stimulated by anthropogenic forces differ extremely from the ones typical for Nature; so, the balance providing the steady-state climate is destroyed.

We believe that the feedbacks leading to atypical events and processes observed in local climate systems are intensified mainly by this mechanism. In this connection, evolutionary changes in local climate systems seem to be underestimated in the context of the global warming reasons, especially, taking into account that the already lunched “erosion” within ecosystem-climate relations can remain latent over long time, for example [36], and the historical precedents comparable with the registered indicators of the climate changes are absent, for example [29].

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