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Decision-Support Technique on Risk Assessment Detailed for Local Climate and Distinct Productions

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***Abstract*—The paper is devoted to the problem on analytics tools to support expert decisions concerning economic estimations of both damages and benefits caused by climate changes. Mainly, the problem is connected with the conflict-of-units on how to coordinate reasonably methods and models originated from engineering, climate and economics, and then how to formalize analytics within some new unified scale. We restrict our research by temperature dynamics only and develop a decision-support technique on risk assessment in application to peculiarities of local climate dynamics and technological processes. With this purpose we propose a synthesis of two methods: the bifurcation analysis specialized in local climate dynamics (so-called QHS-analysis based on *quasi-homogeneous sections*) and the risk assessment specialized in technological hazards (so-called RDC-assessment based on a *relative damage coefficient*). The QHS-analysis provides more accurate processing the nonlinear time series of meteorological temperature observations (not simulations) at the expense of the guaranteed homogeneity of the samplings used in statistic estimations. The RDC-assessment provides the adapted analysis of temperature effects for various productions at the expense of unification of the scales used to describe climatic, technological and economic notions. As a result, the developed technique gives a chance to formalize estimations of both different scenarios of local temperature dynamics and the corresponding economical tendencies oriented to distinct productions. We believe that the results could be promising for practical applications connected with adaptation of industry and business to coming inevitable local climate changes.**

Keywords—nonliear time series; temperature observations; bifurcation analysis; statistical analysis; risk assessment; local climate changes; hazards; damages.

I. INTRODUCTION

At present, the probability of climate changes from the present to the nearest future is estimated as “virtually certain” [1]. So, damages and benefits caused by climate changes become more and more noticeable for industry and business [2, 3, 4, 5], where both unfavorable weather events and unfavorable climate events are usually referred collectively for simplicity (hereafter as “climate-related” events). That subject concerns mainly the field of risk assessment, where economic estimations are traditionally determined by large-scale climate events or groups of climate events in global and regional space scales [1, 5, 6, 7]. An essential part of these estimations relates to hard-formalized expert analytics, so it supposes too large team, big costs and long time [1, 2, 6]. It occurs due to so-called *conflict-of-units* [8, 9] which is formed over three main stages of risk assessment. At the first stage of the risk assessment it is necessary to define a model of dynamics in order to describe what does the notion of a local climate norm mean; and it is a point of climatology first of all. At the second stage, it is necessary to identify hazards, where the notion of a hazard means the property of a substance or a situation with the potential to create damage. Traditionally, it supposes analytics of regional climate and general considerations concerning significant clusters of human activities. At the third stage, it is necessary to estimate risk with economic damages/profits, where the notion of a risk means the likelihood for a certain hazard within a specified period. Traditionally, it supposes analytics of climate norms from economic viewpoint taking into account general peculiarities of a certain sector of the national economy. However, climatology, engineering and economics operate with different methods, models, and measures, so, usually, a final decision needs too much time and is represented in a quite fuzzy generalized form [1, 2, 3, 4, 6].

There are different suggestions on how to modify and develop the techniques of the risk assessment [9, 10, 11, 12, 13]. In particular, we focus on the following moment: a distinct production within a sector of the national economy relates to local peculiarities of climate, business, and its current state. It seems to be practically inadvisable to attract large expert team for each production. Here we develop one of the techniques intended for formalization of expert analytics, at least, in general [9], where the *conflict-of-units* for temperature hazards was proposed to resolve on the basis of both the bifurcation analysis specialized for local climate dynamics and the risk assessment specialized for technological hazards. The specialized bifurcation analysis (so-called QHS-analysis) uses the notion of a *quasi-homogeneous section,* where the homogeneity of statistical estimations is guaranteed by the results of the bifurcation analysis [14, 15]. Why does the bifurcation analysis seem to be promising to attract? Because the bifurcation analysis remains the unique tool to provide the ability to reveal reasonably the qualitative changes in climate dynamics [8, 14, 15], including latent events which remain unforeseen for the traditional viewpoint on the local temperature dynamics. Exclusion of such latent events from the consideration can lead to mistakes in estimations of the expected hazards [9, 15]. The specialized risk assessment (so-called RDC-assessment) uses the notion of *a relative damage coefficient,* where economic estimations are made in the common scale unified for climatic, technological and economic notions [8, 9]. Then the analysis of various temperature effects can be considered for distinct productions in more details. So, to avoid the mistakes in estimations of the expected technological hazards, we attract QHS-analysis into a logical chain of RDC-assessment (section 2). Then we illustrate formalized estimations of different scenarios of local temperature hazards and discuss economic tendencies caused by these hazards (section 3). Main outcome and future outlook are presented in the conclusion.

II. Methods and Data

The QHS-analysis supposes presentation of a local climate norm in the ensemble form instead of the average form traditionally used. Let us illustrate it. A climate norm in the average form is built by the regular fragmentation of the temperature time series from one 1st January to the next one; and then the regular clustering these fragments is made by 30-year time windows with the unified beginning dates [1, 2, 3]. As a result, each local climate norm represents one kind of behavior: a pattern of annual temperature variation averaged per regular 30-year cycle. For example, such climate norm built for St-Petersburg over the recent 30-year cycle (1981-2010 years) is illustrated in Fig.1 (low part). The ensemble form is built by the irregular fragmentation of the temperature time series from one minimum to the next one; and then by irregular two-step clustering these fragments by a unique sequence of time windows with different durations and beginning dates [14, 15]. Such irregular time windows are illustrated in comparison with the regular ones in Fig.1, central part). Within each irregular time window (so-called *quasi-homogeneous section*) the state of a local climate system can be accepted as a homogeneous one from the nonlinear dynamics viewpoint. In other words, each unique sequence of homogeneous behaviors is determined for each local climate system by the QHS-analysis of the data of real measurements (not simulations). In particular, one of three kinds of elemental behaviors (so-called *R-, L-, C*-behaviors) can correspond to annual temperature variation [9, 14]. As a result, a local climate norm can be represented as an ensemble consisting of the three elemental behaviors (so-called *RLC*-pattern) for each irregular time window (Fig.1 upper part in comparison with Fig.1 low part.

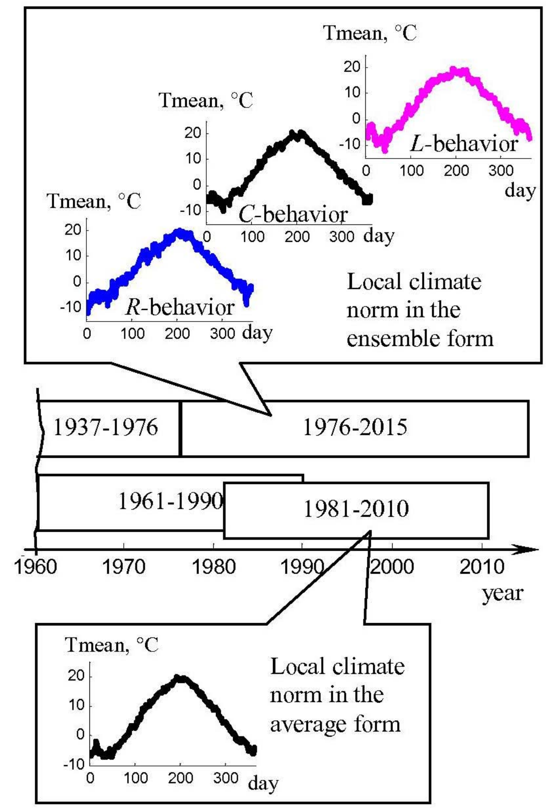


Figure 1. Regular and irregular time windows (central part) used to determine the recent local climate norms in the ensemble form (upper part) and in the average form (low part), an example is calculated for St-Petersburg. Here and after we analyze the data of the meteorological observations of daily average land surface air temperature which are provided by Russian Research Institute of Hydrometeorological Information — World Data Center (www.meteo.ru).

We combine and develop both a variant of the formalized QHS-analysis (AWCC-technology [16]) and the specialized risk assessment (RDC-assessment [9]). The AWCC-technology realizes the comparative time series processing in accordance with both forms of a local climate norm. The RDC-assessment realizes the analytics of technological hazards, where transition from enlarged economic estimations of average temperature hazards to a question on a particular temperature hysteresis is supposed. This transition occurs in relation to each particular technological process, where any deviation from the preset technological hysteresis means a potential emergency [8]. The main cycle (Fig.2a) includes data translation from the initial format of meteorological observations into specialized formats and, after, three procedures of data analysis: building the local climate norms; building statistical models of the technological hazards; estimating the expected hazards and the corresponding economic tendencies (damages and/or benefits). If a local climate norm in the average form is used within this main cycle, then several disadvantages occur. First of all, it is shown only one average statistical model for each annual scenario (Fig.2a) without interannual peculiarities which usually occur between annual cycles [17, 18]. Next, significant errors between the expected and realized hazards are rather typical, as well as the corresponding significant errors between the expected and realized damages. For example, a typical difference between the expected average scenario and the realized scenario is presented in Fig.2a (last procedure), where the estimation is shown in damages per year in relation to an annual income. Here the statistical miss is about 16 %. Finally, it will inevitably lead to errors in prognostic economic tendencies.

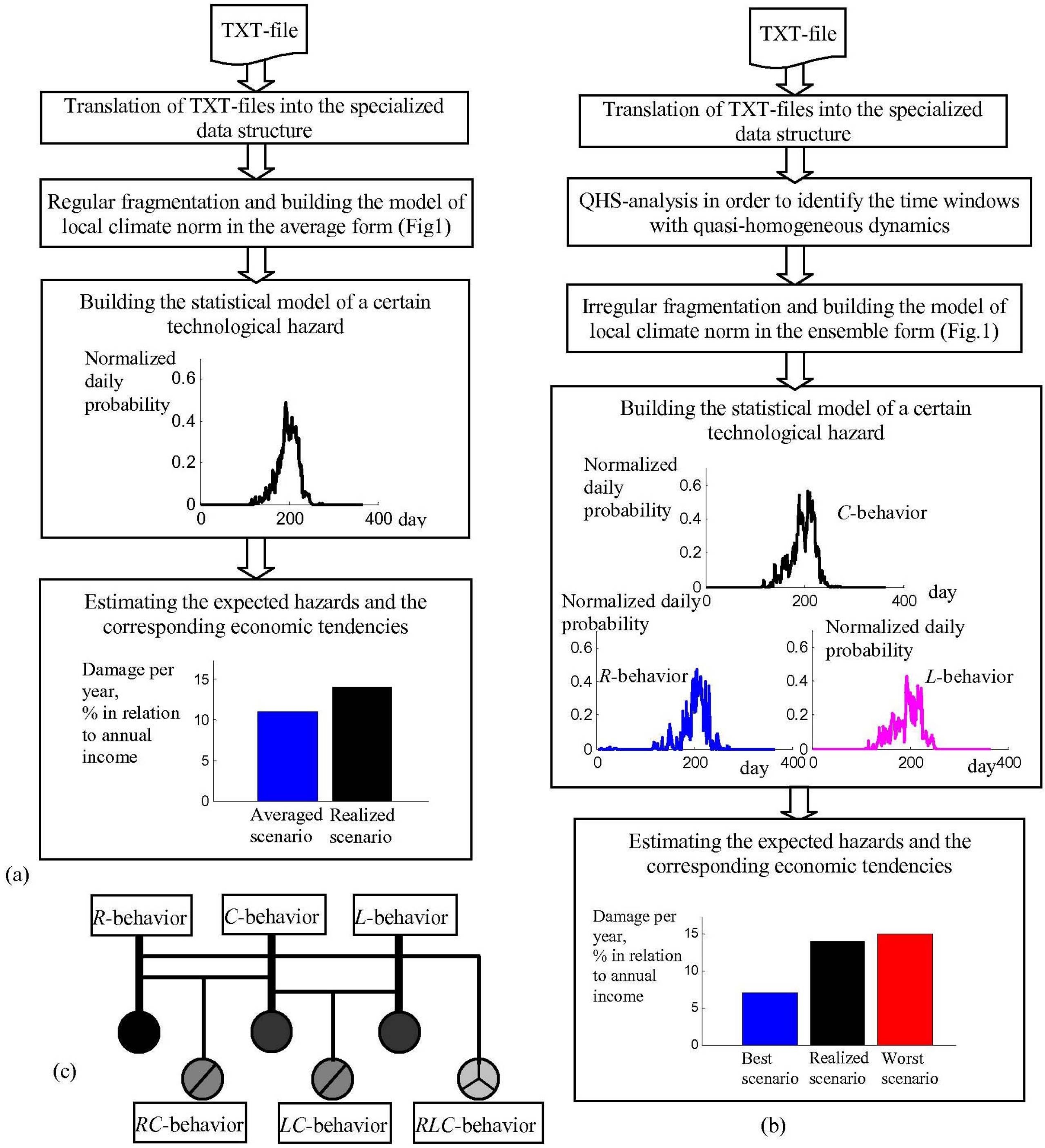


Figure 2. The main cycle of the formalized risk assessment on the basis of the notion of "technological hazard" (a); the main cycle of the proposed technology (b); classification of annual scenarios (c).

III. DESCISION-SUPPORT TECHNIQUE FOR DETAILED RISK ASSESSMENT

Let us use the local climate norm in the ensemble form and let us comment the necessary modifications of the risk assessment (Fig.2b). In this case the procedure of the QHS-analysis is added in order to determine the irregular sequence of time windows with quasi-homogeneous dynamics. Next, processing each time series becomes to be realized in more complex manner in order to provide the building all the kinds of elemental behaviors of *RLC*-pattern (Fig.1, upper part) and the corresponding statistical models (Fig.2b). Totally, the local climate dynamics can be described by six variants of potentially possible annual scenarios (Fig.2c): elemental cases (*R*-behavior, *L*-behavior, *C*-behavior); compound cases of two-constituents (*RC*-behavior, *LC*-behavior) and three-constituents (*RLC*-behavior). These scenarios cover all the potential interannual peculiarities of the observed dynamics [19] that allows to determine the expected limits of the hazards without losses of important information caused by statistical misses [9, 14, 15]. Correspondingly, the general economic estimations can be more accurately calculated. For example, the expected best and worst scenarios cover the realized one (Fig.2b, last procedure).

So, a wide spectrum of novel abilities of the formalized risk assessment becomes accessible to be realized due to the detailed analysis of the variety of expected realizations in accordance with different scenarios of *RLC*-patterns (Fig.2c). Let us illustrate these abilities. Here a technological hazard is denoted by a basic temperature with which it associated, for example: “20-degree hazard” means that the corresponding hazard is associated with events, when daily average temperature is above 20°C. Here it is taken in to account that such temperature limit could lead to different negative changes in productivity and crop yield [20, 21]. Last, variability of estimations is demonstrated in comparing with C-behavior scenario. Then, each scenario is characterized by own specific pattern to show a probability of potential realizations for a certain hazard per day (for example, black profile of C-behavior scenario in the case of 20-degree hazard, Fig.3) and has specific differences with the patterns of other scenarios (for example, blue and red dotted profiles in Fig.3). Differences depend on different reasons. For example, in the case of any local climate system, patterns built for the same hazard will change in more or less extent depending on behavior (Fig.3a) and over time (Fig.3b). Within the same quasi-homogeneous climate region, close-in-space local climate systems can have different patterns of the probabilities for the same hazard over the same time (Fig.3c). Different hazards over the same time for the same local climate system can show evolutional regularity in more or less extent (Fig.3d).

Correspondingly, each of the significant hazards for each technological process (not restricted number of the averaged hazards for a sector of the national economy) can be separately estimated for a particular local climate

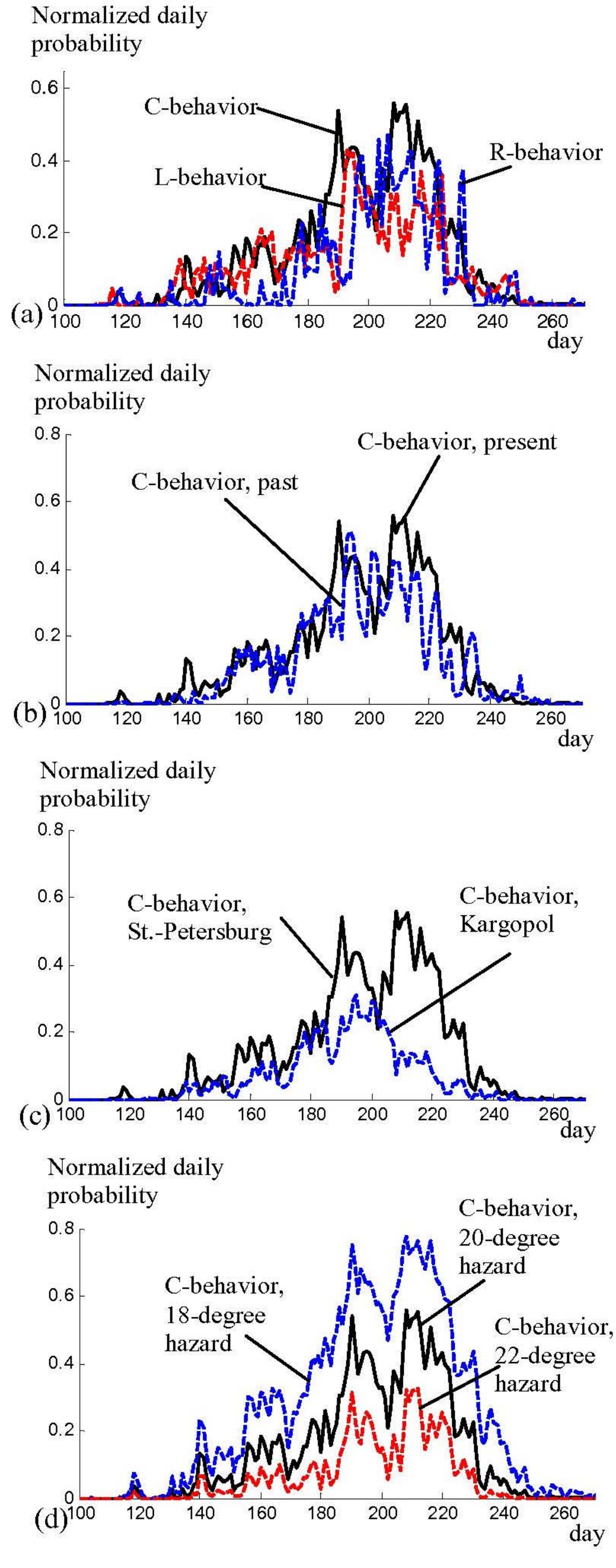
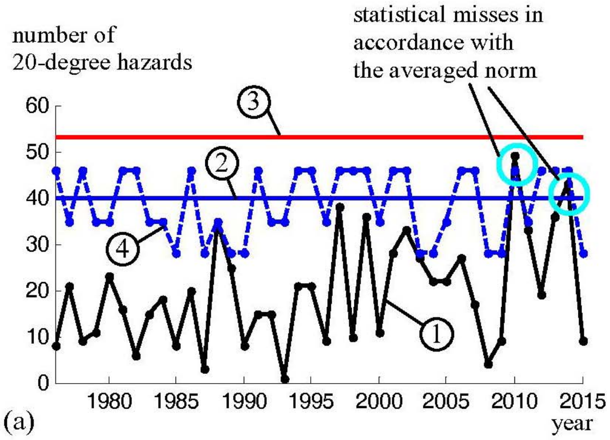
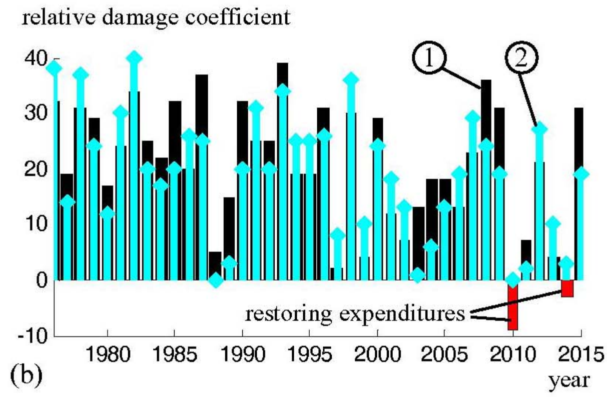


Figure 3. Examples of scenarios concerning the expected daily probability of hazards depending on different kinds of the elemental annual behaviors (a), on evolution over time (b), on different locations of climate systems (c), and on different critical temperature values (d). All examples are compared with C-behavior scenario built for St-Petersburg in the case of 20-degree hazard.



1 - time series of the realized events;
2 – limit determined for the average norm of annual temperature variation;
3 – limit determined for the worst case in accordance with *RLC*-pattern of annual temperature variation;
4 - time series of the norms built in accordance with the realized sequence of *RLC*-behaviors.



1 - over-expenditures estimated in accordance with the average norm of annual temperature variation;
2 - over-expenditures estimated in accordance with the ensemble norm of annual temperature variation

Figure 4. Real data about the realized events and examples of different estimations on the expected number of 20-dergee hazards (a); comparative analysis of over-expenditures and restoring expenditures made for the average and ensemble norms (b).

system. These estimations contain detailed information on the most probable periods when a hazard can be annually realized with daily resolution (for example, Fig.3), and contain general information concerning the expected economic damages (Fig.2b, last procedure). At present, as against to [9], it becomes possible to open a way towards detailed economical estimations, at least, per year. For example, let us discuss how to analyze two kinds of damages. The first one occurs due to unjustified expense on preventive actions based on expectation of a certain number of hazards, when the number of the realized hazards is less than the number of the expected hazards (hereafter over-expenditures). The second one occurs due to expense on restoring actions which should be made after negative impacts caused by unexpected hazards (hereafter restoring expenditures). With this purpose, let us estimate the number of the expected 20-degree hazards over 1981-2010 years on the basis of both the norm of annual temperature variation determined in traditional average form (Fig.4a, solid blue line) and the norm of annual temperature variation determined in the ensemble form (Fig.4a, dotted blue piece-wise profile). Let us compare these estimations with the real events (Fig.4a, solid black line) over the considered time window and towards 5 years in past and in future.

What occurs in the case of the traditional estimation? The expected limit is crossed once over the analyzed 1981-2010 years and once over the next 5 years. So, first, there are over-expenditures (Fig.4b, black bars) as well as restoring expenditures (Fig.4b, red bars). Second, such estimations can not be prolonged towards future even during several years. It means that these estimations can be used for already realized events only. In other words, it seems to be rather retrospective estimations with restricted confidence. Next, what occurs in the case of the developed estimation? First, there are only over-expenditures (Fig.4b, cyan bars) in contrast to the previous case. Moreover, nothing restoring expenditures occur not only over the analyzed 1981-2010 years, but also over 5 year towards future. Correspondingly, second, such estimations can be used in order to forecast damages during next several years at least. Third, total over-expenditures made by the traditional way are more in tens percents than total over-expenditures made by the developed way. At the same time, retrospective view towards several years in past is the same for both cases. The estimations in Fig.4 were made in relative units based on the notion of a relative damage coefficient [9]. The essence of such estimations can be explained by the following assumptions: the more days of hazards are, the more expenditure is; simply, a cost of each such day is fixed for similar expenditures (one cost for over-expenditures and another cost for restoring expenditures at least).

IV. CONCLUSION

Due to the synthesis of both QHS-analysis and RDC-assessment, the following advantage of the proposed decision-support technique takes place: the possibility of formalized estimations of different scenarios of local temperature hazards and the corresponding tendencies of economic damages oriented to distinct productions in the context of a local climate dynamics. The conceptual model to formalize such expert analytics is provided by QHS-analysis; the system of the unified scales used for climatic, technological and economic notions is provided by conceptions of RDC-assessment. The main disadvantage of the presented technique is connected with the above mentioned restrictions: we consider only local climate systems and only temperature-related hazards which impact directly on technological processes (not on a social sphere).

Nevertheless, the achieved results seem to be more confident in comparison with the results made by the traditional estimations not only for retrospective analysis, but also for forecasts towards several years at least. First of all, it becomes possible because we take into account that each local climate system can choose one of three annual behaviors instead of one average annual behavior in accordance with the conventional climate model. These three behaviors are characterized by the same periodicity (one year) but different average annual temperatures and different patterns of annual temperature variation. Such patterns become more and more obvious last 50-60 years. Correspondingly, we analyze a novel logic of evolutional changes in local climate dynamics (in accordance with the regularities of HDS-model dynamics) and have a possibility to estimate such realizations of weather-climate events with daily resolution which remain latent for the traditional statistical analysis.

The future outlook seems to be promising from the following considerations: we believe that it is a point on how to select such changes of each particular production which will be proper for coming inevitable changes of local weather-climate factors and, perhaps, could get a benefit.

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