Analysis and prediction of hydrological series based on generalized precedents*

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The paper presents a new approach to the use of the apparatus of generalized precedents in the problems of analysis and prediction of hydrological series. Generalized precedents are computational tools that yield to use various a priori, directly observed or preferred for some or another reason local regularities in the data on a unified basis. The main stages of the scheme for applying generalized precedents are presented, and a close relationship is shown with the Hough transform scheme. The possibilities of comparison and joint analysis of meteorological data and actual data on the volume of river flow are investigated. In this case, the generalized precedents are typical nonlinear relationships between certain hydrological parameters. The goal is to identify the differentiation of the regions of the river basin by their accumulating capabilities. We show how this can be done on the basis of an analysis of time-limited contemporary statistics. Obtained flow characteristics in the regions can be further used for short-term forecasting of river level variations and other hydrological processes and phenomena, including flood and drought situations. These characteristics can also serve as an important factor in the study of ecosystems, geology of the region and other similar purposes.

Keywords: *generalized precedent; local regularity; Hough transform; basic cluster; hydrological series; river runoff; environmental warning*

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1 Introduction

Generalized precedents (GPs) are computational tools that allow using on unified basis different a priori, directly observable or preferable for one reason or another, local regularities in data [5–8,23]. A good example is in the field of IP, where one of the important tasks is the restoration of images deformed by interference of smear type. The a priori information in this case is that the bright points of the original image appear as smear lines. This prepares the basis for efficient reconstruction of the smear parameters and for subsequent restoration of the image as a whole. At the same time, other local regularities can be more complicated. For example, they may represent typical geometric specialties of the training sample considered as spatial object. So, in the simplest case such specialties are subsets of a certain shape that are rather densely filled with objects of the training sample [8,23]. We consider such clusters as independent objects of higher level - *basic clusters*. Basic clusters typical in training data behave as multidimensional texture that could determine additional 'textural' features of classes and yield other opportunities, but they are not observable as in case of 2D texture elements [8]. Moreover, in the problem below, from the field of hydrological analysis, generalized precedents are typical nonlinear relationships between certain numerical characteristics. In the scheme of their use, the geometric shape of regularity is built into complicated context and possibility of such geometrical handling is almost lost.

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Namely, we consider some new opportunities for comparing and jointly analyzing precipitation data and actual data on the volume of river flow. Observations of important rivers runoff have been conducted for a long time and on a regular basis everywhere, and so considerable statistical material has been collected [10,12,13,15]. At the same time, a number of such observations have gaps and faults caused by various reasons [22], data quality may be unreliable in view of change of approaches, models, measuring methods, etc. [14,16–18]. Finally, the object and the climate as a whole are undergoing evolution, which calls into question the legitimacy of using old statistics in the current analysis [19–21]. Thus, the classical problem of processing incomplete, inaccurate and partially contradictory data arises [1,2,9]. An important task here is the reconstruction of complete time series describing the behavior of flow volumes on the basis of building adequate mathematical models of observed hydrological processes [14,18,21,22]. Below, we investigate the approach to the analysis of this type of data, aimed at identifying the differentiation regions of river basin according to their damper or accumulating capacities. We show how this can be done via analysis of limited contemporary statistics.

2 Generalized precedents and multidimensional analogues of Hough transform

Above are examples of local regularities in data. In all such cases it is assumed that the shape of a dependency has simple parametric description. To reveal the presence of regularities of interest in these or those positions and with particular set of parameter values, at the first stage we search for them in classes of the initial training sample. The search results are displayed in the parametric space C, and all further analysis is performed being based on the study of secondary clusters structure that appears in C.

It is easy to see that these steps correspond to the classical scheme of applying conventional Hough transform in dimensions 2 and 3, but in this case the dimension of the original feature space is not constrained. We give here only one example of the use of a priori information on the form and possible parameters of the local regularity, in which we demonstrate the carrying out steps mentioned above. Namely, we consider the optimization of decision rule in the problem of pattern recognition by precedents (PRP), where sets of elementary logical regularities (ELRs) of the second kind (ELR-2) are used [2,11].

In ELR-2 the predicates of linear constraints of general form are used

$$L_i = \&_j R_{j,i}, R_{j,i} = (\mathbf{n}_{j,i}, x_{j,i}) < Thr_{j,i}, n = 1, ..., N. \tag{1}$$

Here $\mathbf{n}_{j,i}$ is the normal vector to the j-th facet of the i-th convex hull, $Thr_{j,i}$ is the boundary threshold. In this case, the decision rule calculates relations of belonging to the class through belonging to the covering hulls. If two different ELR-2s have the same boundary normal vector, they are called *coherent* in the corresponding direction [11]. The product $(\mathbf{n}_{j,i}, x_{j,i})$ is calculated only once for coherent ELR-2s.

We present calculation scheme of Hough-type transform illustrated by the following example, where set of ERL-2 facets is used as set of GPs. Goal is to find and combine most typical orientations of border hyper-planes represented as points in parametric space:

a) we construct a set $\mathbf{L} = \{L\}$ by finding all ELR-2s that form some covering of a class;

b) it is chosen a limited number of parameters characterizing border hyper-plane. Further we consider parametric space $\mathbf{C}$ which provides representation of guide angles α_i of the normal vectors $\mathbf{n}_i$ to i-th border hyper-plane with respect to some selected axis;

c) one-to-one mapping $\varphi : \mathbf{L} \to \mathbf{C}$ of the set $\mathbf{L}$ into selected parametric space $\mathbf{C}$ is constructed, and there some secondary clustering is performed;

d) while clustering we search for the set $\mathbf{C}^T$ of expressed compact clusters $\mathbf{c}^t, t \in T$ in the space $\mathbf{C}$. Each cluster $\mathbf{c}^t, t \in T$, represents some typical direction of normal vectors to border planes of different ELR-2 revealed at the first step.

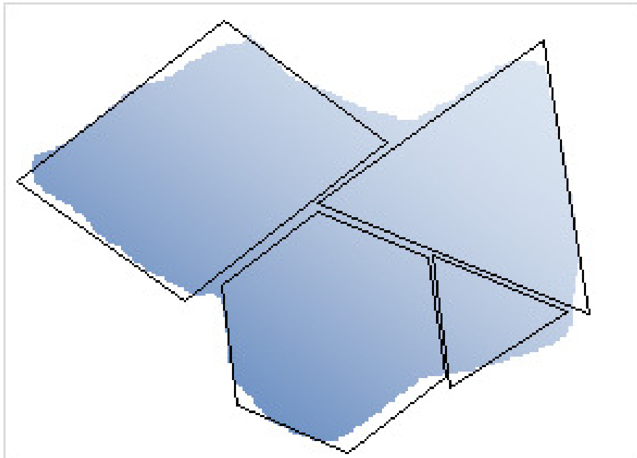

Figure 1 Modeled 4-component ELR-2 covering {L} of class K_λ

Fig. 1 shows step a) that results in (modeled) 4-component ELR-2 covering $\{L\}$ of a class K_λ, where all normal vectors to facets don't coincide.

Parametric space for angles is one-dimensional line occupied by three compact clusters $\mathbf{c}^t, t = 1, 2, 3$, corresponding to three groups of close orientations of facets (steps b, c, d).

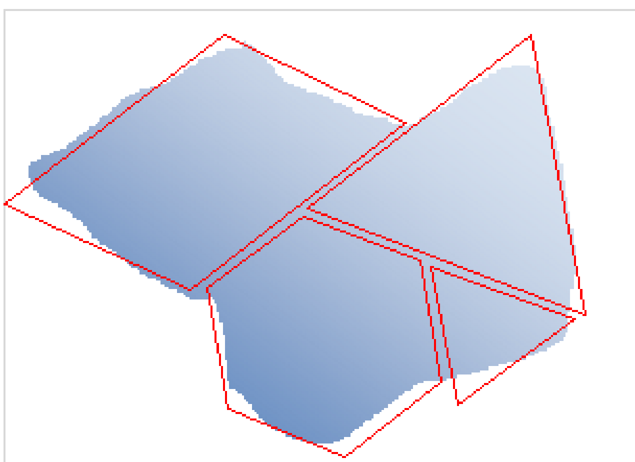

Figure 2 Covering {L} improved with unified representatives. Calculating membership in the class K_λ requires now 3 convolutions instead of 16 ones

Having the set $\mathbf{C}^3$ we can deform representations of ELR-2s collected in the set $\mathbf{L} = \{L\}$ with aim to arrange more pairs of coherent regularities among them. The most direct way is to choose a single representative $c^t \in \mathbf{c}^t$ for each cluster $\mathbf{c}^t \in \mathbf{C}^3, t = 1, 2, 3$, and then replace all normal vectors represented in $\mathbf{c}^t$ with this representative. Fig. 2 shows new covering improved with unified representatives of main clusters.

We continue this example to show possibility of double applying the same scheme of multidimensional Hough-type transform to another set of GPs. Really, each boarder hyper-plane corresponding to i-th facet is linear manifold of co-dimension 1. It means that the ideal $\mathbf{I}_i$ in the ring $\mathbf{R}(x_1, x_2, ..., x_N)$ of polynomials on variables $x_n, n = 1, 2, ..., N$, that defines the manifold containing the facet, is principal ideal produced by a single polynomial of the first order $P_i = (x, \mathbf{a}_i) - b_i, \mathbf{I}_i = (P_i)$, where $\mathbf{a}_i$ is any vector orthogonal to i-th facet.

Each polynomial $P_i = (x, \mathbf{a}_i) - b_i$ being multiplied by arbitrary real value still belongs to the ideal $\mathbf{I}_i = (P_i)$ of corresponding hyper-plane. So, we obtain a priori knowledge, that any hyperplane that's parallel with i-th facet is represented in parametric space arranged for vectors a_i by a point of one and the same straight line crossing zero. Using this new set of GPs, the whole scheme can be applied once again to parametric space $\mathbf{C}$ itself, where such lines play role of basic clusters. Thus we show another way to choose the same representatives improving L as in the case of parametric space for angles. The scheme can be useful in various other applications for enhancement quality of linear decisions [3, 4].

Having this example, we'll make analogous steps to find and use realizations of some important natural regularity in hydrological data series.

3 Reconstruction of dynamics of hydrological series

Forecasting and recording actual volume of river runoff is an urgent scientific and economical task. Important role in its solution and preliminary analysis is taken by information on the levels of precipitation accumulated during observations in a given region [17, 18]. At present, in connection with the advent of satellite weather data, the distribution of precipitation levels and temperatures on weather maps can be reconstructed with a sufficiently high degree of detail [13, 14]. Thus, studies on the similar detailing of river runoff are also promising.

In some cases, the network of gauging stations can be rather dense, as it takes place in Kaliningrad region [22]. At the same time, in less-lived areas, recording actual flow rates for local parts of the river basin is often confronted with fundamental constraints, which makes it difficult to compare precipitation levels and recorded runoff values. For example, a direct estimate, based on the calculation of the channel section and the observed flow rate, is almost impracticable for some regions with complex hydrology. Among the main reasons here is the presence of multiple small tributaries to the main watercourse, the movement of significant volumes through aquifers hidden from observation, the influence of vegetation types, soil cover characteristics, etc. Our goal is to build a river basin model with rain feeding, in which the analysis of actual data and subsequent forecast of runoff behavior rely on the use of GPs as implementations of local hydrological regularities that are described by a limited set of parameters. We further show how this approach can reconstruct the flow features in certain regions of the basin, including regions with complex hydrology, on the basis of an analysis of only the observed dynamics of river runoff as a whole, as well as detailed meteorological data for its basin.

4 Phenomenological model of river flow with precipitation feeding

We divide the basin of river into several regions $R_i, i = 1, 2, ..., I$, the meteorological data for which differ markedly from each other, but further detailing is not necessary or impossible inside regions. Let observations of precipitation in the region be carried out on a certain interval $[0, ..., T]$. We assume that precipitation $\mathrm{Prec}_i(t)$ is the only source of moisture replenishment in the regions, the reverse evaporation of moisture into the atmosphere and other similar deductions from this amount have already been calculated, and all the remaining volume goes to the region's runoff with rate $\mathrm{Flow}_i(t)$. The specific form of the regions R_i is also not important, its choice can be regulated by various additional considerations. For example, regions can correspond to the own basins of tributaries, geographic features of the terrain - plains, slopes, lakes, upland marshes, etc.

In the proposed model, we will concentrate on an important parameter, on which the local in time variations of the total flow of the river depend to the greatest extent. Namely, we will be interested in the differences in degrees of the damping (accumulating) effect of the flow characteristics $\mathrm{Flow}_i(t)$ of individual regions on the river runoff as whole $\mathrm{Flow}(t)$. In practice, this means that the preferred criterion for dividing the basin into regions is the expected dependence F_i of the instantaneous flow rate $\mathrm{Flow}_i(t)$ on the current moisture level $\mathrm{Level}_i(t)$ at time t in the region R_i:

$$\mathrm{Flow}_i(t) = F_i(\mathrm{Level}_i(t)) \tag{2}$$

Here we are talking only about preliminary considerations on the division of basin into regions, the actual form of functions F_i is not known in advance. Moreover, it is the main object of further analysis and search.

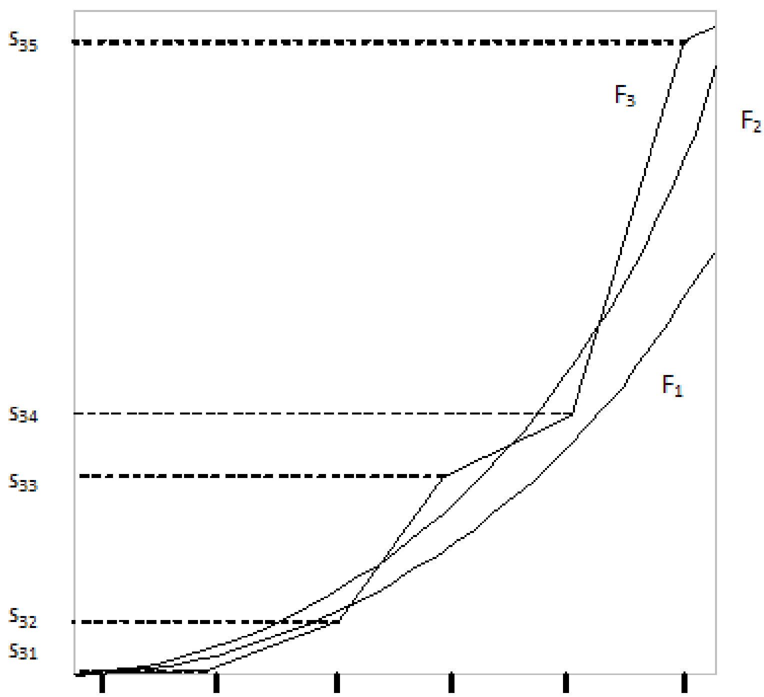

Figure 3 Variants of dependencies F_i

At each moment t, the volume of moisture that enters the region is expressed by the integral value $\mathrm{Input}_i(t) = \int_0^t \mathrm{Prec}_i(\tau)d\tau$. The instantaneous rate of flow of the region R_i is determined by the dependence F_i. As we assume that all the moisture that has fallen down and been accumulated goes into the runoff of the region, the total volume of the region's runoff to the moment t is also expressed by the integral value $\mathrm{Output}_i(t) = \int_0^t F_i(\mathrm{Level}_i(\tau))d\tau$. Since $\mathrm{Level}_i(t) = \mathrm{Level}_i(0) + \mathrm{Input}_i(t) - \mathrm{Output}_i(t)$, we obtain integral equation

$$\mathrm{Output}_i(t) = \int_0^t F_i(\mathrm{Level}_i(0) + \mathrm{Input}_i(\tau) - \mathrm{Output}_i(\tau))d\tau, \tag{3}$$

which can be correctly solved only if the initial condition is known $\mathrm{Level}_i(0)$, that is the water level for region R_i at the initial moment $t = 0$. Solving equation (3), we get the instantaneous rate of flow of the region at each moment $t = 0, 1, ..., T : \mathrm{Flow}_i(t) = F_i(\mathrm{Level}_i(t))$. Below, an approximate solution of equation (3) is described on the basis of a specially organized treatment of meteorological and hydrological statistics. In this way, we also obtain the necessary data on the form of the dependencies $F_i, i = 1, 2, ..., I$.

5 Typical flow characteristics as generalized precedents

The main a priori assumption is that each dependence $F_i, i = 1, 2, ..., I$ is described by an increasing function, namely, the derivative F_i' is strictly positive, $F_i' > o$, in the function's domain, Fig. 3. Substantive background of this condition is that we consider the runoff in entire river system as laminar process with capacity for self-recovery. Namely, we assume that with a consecutive increase in the water level $\mathrm{Level}_i(t)$ in any region, the corresponding flow rate $\mathrm{Flow}_i(t)$ can only increase, and vice versa, the lower the water level, the slower it leaves the region.

Immediately it can be shown that the assumption $F_i' > o$ allows to obtain the final value $\mathrm{Level}_i(T)$ with acceptable accuracy, while the allowable deviation will not affect the robustness of the scheme as a whole. The assertion is easy to prove rigorously in the form of a separate lemma on the behavior of a function satisfying the growth condition $F_i' > o$, but we shall confine ourselves here only to a sketch of the reasoning.

In fact, let's compute the integral (3) approximately on M small successive sub-intervals, $m = 0, 1, ..., M$,

$$\mathrm{Output}_i(t_1) = \int_0^{t_1} F_i(\mathrm{Level}_i(0) + \mathrm{Input}_i(\tau) - \mathrm{Output}_i(\tau))d\tau, \tag{4}$$

by choosing on the first sub-interval $[0, t_1]$ any suitable value L_i, instead of the unknown true value $\mathrm{Level}_i(0)$. For instance, it may be simply $L_i = 0$.

With this choice, the approximate value $\mathrm{Level}_i(t)$ will be less than the actual water level in the region, and during first sub-interval the function F_i will calculate lower flow rate compared to the actual rate $\mathrm{Flow}_i(t)$.This will result in conservation water remaining in this model of region R_i.

In the reverse situation, this rate would be increased, and any overestimation of the amount of moisture in the model of the region will be reduced, too.

Thus, the value $\mathrm{Level}_i(t_1)$ will be computed with smaller error than the error for the value $\mathrm{Level}_i(0) = 0$ used in the first step. In the second step

$$\mathrm{Output}_i(t_2) = \int_{t_1}^{t_2} F_i(\mathrm{Level}_i(t_1) + \mathrm{Input}_i(\tau) - \mathrm{Output}_i(\tau))d\tau, \tag{5}$$

the situation will be repeated, and the error in the evaluation of each subsequent value $\mathrm{Level}_i(t_m)$ in the model will continue to decrease.

Depending on how big the average values of F_i' are in the neighborhood of the most frequently met values of $\mathrm{Level}_i(t)$, we can calculate the integration interval $\theta(\Delta)$,

$$\mathrm{Level}_i(t) = \mathrm{Level}_i(t - \theta(\Delta)) + \int_{t-\theta(\Delta)}^{t} \mathrm{Prec}_i(\tau)d\tau - \mathrm{Output}_i(t), \tag{6}$$

which provides evaluation of the value $\mathrm{Level}_i(t)$ with required accuracy Δ. This statement reflects well-known fact that natural river systems dampen with time to zero even enormous disturbances in precipitation level.

Now, in order to use some dependency F_i as a generalized precedent, we must choose parametric representation for it. Since F_i is an ordinary real function of one variable, there are many possibilities of parameterizations. Variants of the representation F_i can be chosen in the form of a tabulated list; via belonging to a simple parametric family (Fig. 3, F_1, F_2); as description by several real parameters that directly refer to the geometric form of the dependence (Fig. 3, F_3), etc. From the point of view of organizing the Hough-type transform, the latter option is preferable, since in this case close values of parameters indicate similarity in the behavior of corresponding dependencies. In Fig. 3, one of such variants of the parametrization $s_{ij}, j = 1, 2, ..., J$, is given for some function F_3 satisfying the restriction $F'_i > o$, where index $j, j = 1, 2, ..., 5$, points the parameter number. To effectively fill the parametric space, we will use discrete grids on allowed intervals, so each $s_{ij}, j = 1, 2, ..., J, i = 1, 2, ..., I$, can take one of several real values within its interval.

6 Realizations of generalized precedents in parametric space

Further, we act along the usual Hough transform procedure. Each structural matrix **s** determines the dynamics of water levels in regions $R_i, i = 1, 2, ..., I$, in accordance with the shape of flow functions F_i being tested. In case of usual Hough transform, the appearance of various realizations in parametric space is controlled by simple criterion - threshold value of brightness gradient. In our case, the role of spatial operation plays not differentiation, but the solution of equation (3), which determines evolution of the water level $Level_i(t)$ in regions using generalized precedents $\mathbf{s} = [s_{ij}], j = 1, 2, ..., J, i = 1, 2, ..., I$, and the sums (6) of precipitations, actual at time t. In our case, the criterion for selection structural matrices **s** is the following condition

$$\sum_{i}^{I} \mathrm{Flow}_i(t - \eta_i) = \mathrm{Flow}(t), \tag{7}$$

Equality (7) verifies the compliance of the entire model with objective data. Here values η_i describe time delays in evolvement the flows of regions R_i into the main watercourse. We regard η_i as pre-determined, the relative remoteness of regions from the point of measurement of the total river runoff (see Table 1) is taken into account with their help. We consider just discrete values, and have to control truncation errors in equality (7). Remember also that we assume as laminar all flow processes for analyzed statistics, and thus, possibly available data on flood-type situations are not used at the stage of analysis and reconstruction just of regularities F_i themselves.

Thus, the structural matrices **s** satisfying condition (7) appear as points of the empirical secondary distribution on the $I \times J$-dimensional parametric space $\mathbf{C}$. Points corresponding to the most adequate structural matrices for the available statistics gather in the vicinity of the main mode of the secondary distribution in the form of expressed cluster $\mathbf{c^*}$. In this case, the mode vertex $c* \in \mathbf{c^*}$ can be the final result of our analysis if the corresponding structural matrix $\mathbf{s^*}$ better than others fits the statistics used.

Consider for illustration two regions, $I = 2$, for which dependencies $F_i, i = 1, 2$, differ from each other, as seen for F_1, F_2 in Fig. 3. Thus, we set $J = 1$ and use pares of simplest increasing functions, each described by single scalar parameter s_i, as generalized precedents of dependencies $F_i, i = 1, 2$, in this example. Namely, in Fig. 3, functions $F_i(x) = s_i x^2$ are used, each of which is uniquely described by its scalar parameter $s_i > 0, i = 1, 2$. Of course, we could use more parameters to describe the dependencies F_i, as shown in Fig. 3, F_3, which would describe in detail functions' behavior for different values of the argument. Consequently, statistical data would receive a more accurate approximation, but our goal here is only to explain the essence and to demonstrate prospects of the approach.

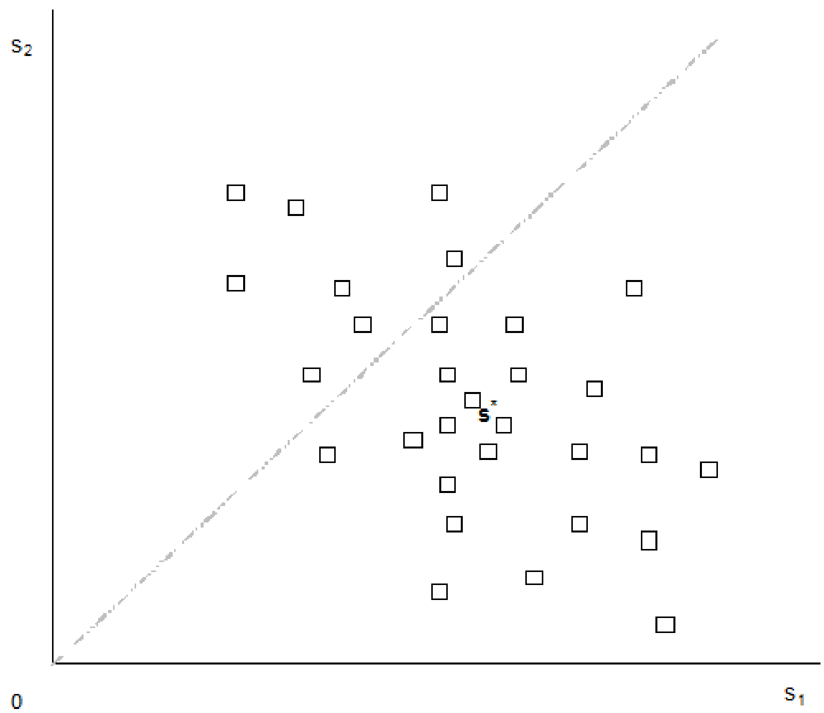

Figure 4 Main cluster **c*** with solution point **s***

Fig. 4 shows the possible shape of cluster **c*** and the point of the solution matrix **s*** in corresponding 2D parametric space for $s_i > 0, i = 1, 2$. Each point represents one reading for river entire runoff during a month. It reflects the currently relevant meteorological statistics processed by consecutive intervals of length $\theta(\Delta)$ and in accordance with the structural hypothesis $\mathbf{s} = [s_i], i = 1, 2$. Deviations from the center mode are caused by measurement errors, truncations, imperfection of the 2D model $\mathbf{s} = [s_{i1}], i = 1, 2$, itself, and so on. We picture the center of the main mode below the diagonal of quadrant. This means that the inequality $s_1 > s_2$ is most consistent with objective statistics, and thus, the region R_1 has greater damper capacity than the region R_2. In fact, as can be seen from the graph of functions F_1 , F_1 (Fig. 3), the rate of flow in region R_1 changes more slowly by variations in the moisture level than in the region R_2.

• Having solution **s*** and condition (7), we acquire base to calculate absolute values $\mathrm{Flow}_i(t - \eta_i)$ in accordance with structural hypothesis $\mathbf{s} = [s_{ij}], j = 1, 2, ..., J, i = 1, 2, ..., I$. As we pointed out earlier, for some regions direct instantaneous measurement of values $\mathrm{Flow}_i(t - \eta_i)$ may be complicated or impracticable.

• Now it's possible to make environmental warnings: if we have big short-time rainfall sum $S_1 = \int_{t_1}^{t_2} \mathrm{Prec}_1(\tau)d\tau$ or $S_2 = \int_{t_1}^{t_2} \mathrm{Prec}_2(\tau)d\tau$, then for the second region R_2 flood-type situation is more probable.

• And vice versa, when the sum S_1 or S_2 is close to zero, fast soil drying is probable for the same region R_2 and not for region R_1 because water leaves the last slower.

• Etc.

We could continue the row of opportunities opened, but it should be said about the "pitfalls"in the presented model. So, if we have in our example $\eta_1 = \eta_2, \mathrm{Prec}_1(t) = \mathrm{Prec}_2(t)$ for all moments t under consideration, then the secondary distribution on the parametric space $\mathbf{C}$ for $s_i > 0, i = 1, 2$, will be symmetric with respect to the diagonal.

In particular, even if the best approximation of the statistical data is achieved with some choice $s_1 \neq s_2$, nevertheless, two equally important main clusters symmetrically disposed relative to the diagonal will be present in the empirical distribution on $\mathbf{C}$.

The last means that the difference in the damping (accumulating) properties of regions $R_i, i = 1, 2$, is actually found, but it is impossible to tell which of them corresponds to the larger of the parameters $s_i, i = 1, 2$. Similar situations are not excluded for greater values of I and J, too. But, such situations arise only in quite exceptional cases and do not have significant effect on the operability of the scheme as whole.

7 Conclusion

In this paper, the possibilities of application of the approach based on Generalized Precedents to the problem of using a priori knowledge about some hydrological regularities are investigated. The first part presents a typical scheme for using generalized precedents on the example of logical regularities of the second kind. In this case, the result is the optimization of calculating predicates of belonging to a class in the problem of recognition by precedents. The ways are indicated for using the same scheme to optimize various other linear solutions in data analysis problems. Parallels are traced with the conventional Hough transform in dimensions 2 and 3. It is shown that the scheme is a generalization of this transform, applicable in higher dimensions. An illustration is also given, showing double applying this generalized Hough transform to the space of coefficients of polynomials describing linear boundaries.

By the same scheme, a space of generalized precedents for nonlinear regularities for some hydrological indices determining the dynamics of river flow and accumulating characteristics of various regions in the river basin is constructed. Each generalized precedent here is a structural hypothesis about the specific form of nonlinear dependencies in parameters of regions.

A phenomenological model of a river basin with rain feeding is proposed, and it is shown how in this model the accumulating characteristics of regions can be calculated on the basis of only limited contemporary statistics. It was taken into account that the current satellite data on precipitation and temperatures can give a rather detailed picture of their distribution on the ground. The hydrological series under consideration represents just only the actual total flow of the river. It is shown how on this basis the own volumes of the runoff of regions can be restored, including regions with complex hydrology where direct measurements of flow are difficult or impossible.

Important condition of such reconstruction is that the statistics should contain enough variability of precipitation level series in time to provide noticeable differences in results of convolution these levels with structural hypotheses investigated.

Obtained characteristics in the regions can be used further for short-term forecasting of river level variations and other hydrological processes and phenomena, including floods and other non-standard situations. These characteristics can also serve as important additional information in the study of ecosystems, geology of the region, etc.

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Анализ и прогнозирование гидрологического ряда на основе обобщённых прецедентов*

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В работе представлен новый подход к использованию аппарата обобщённых прецедентов в задачах анализа и прогнозирования гидрологических рядов. Обобщённые прецеденты представляют собой вычислительный инструментарий, позволяющий на унифицированной основе задействовать априорные, непосредственно наблюдаемые или предпочтительные по тем или иным причинам локальные закономерности в данных. Представлены основные этапы схемы применения обобщённых прецедентов, показана тесная связь со схемой преобразования Хафа. Исследуются возможности сопоставления и совместного анализа метеоданных и фактических данных по объёму речного стока. В этом случае обобщённые прецеденты представляют собой типичные нелинейные зависимости между определенными гидрологическими параметрами. Целью является выявление дифференциации регионов бассейна реки по их аккумулирующим возможностям. Мы показываем, как это можно сделать на основе анализе ограниченной по времени современной статистики. Полученные характеристики стока в регионах могут далее использоваться для краткосрочного прогноза вариаций уровня реки и других гидрологических процессов и явлений, в том числе паводков и других неблагоприятных ситуаций. Эти характеристики

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могут также служить важным фактором при исследовании экосистем, геологии региона и других подобных целей.

Ключевые слова: *обобщённый прецедент; локальная закономерность; преобразование Хафа; базовый кластер; гидрологический ряд; речной сток; экологические риски*

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